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**Using an automated Excel® spreadsheet
to compensate a flyback converter
operated in current-mode**

Christophe Basso, Tomas Petrek/David Sabatié

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The screenshot shows the ON Semiconductor website search results for the keyword 'flyback'. The search bar at the top right contains the text 'flyback'. Below the search bar, the results are categorized by document type: Products (40), Data Sheets (69), Supporting Tech Materials (132), and News / Company Info (1). The 'Supporting Tech Materials' category is highlighted with a red box. Below this, a table lists 132 documents, with the first document, 'Flyback current mode loop compensation design tool', highlighted in blue. An arrow points from the text 'Download this file' to this document. The table has columns for Title, Type, Material ID, Revision, Revision Date, and Score.

Title	Type	Material ID	Revision	Revision Date	Score
Flyback current mode loop compensation design tool	Design & Development Tools	FLYBACK_AUTOMATION (2310.0kB)	1		100
8 W DTA Power Supply GreenPoint™ Reference Design	Reference Designs	TND332/D (275.0kB)	0	Feb, 2008	100
50 W STB Power Supply GreenPoint™ Reference Design	Reference Designs	TND334/D (388.0kB)	0	Feb, 2008	100
NCP1308_LM2575: Universal Input, 50 W, 5 Output quasi-resonant flyback converter	Design Notes	DN06029/D (64.0kB)	1	Jun, 2007	100
NCP1216: 24 V, Off-line Flyback Converter for Motor and Solenoid Applications	Design Notes	DN06049/D (64.0kB)	0	Nov, 2008	100
MOF - Multi-Output Flyback Off-Line Power Supply	Tutorial	TND351/D (234.0kB)	0	Oct, 2008	100
FB - DC-DC Converters Feedback and Control	Tutorial	TND352/D (658.0kB)	0	Oct, 2008	100
Very Wide Input Voltage Range, Off-line Flyback Switching Power Supply	Application Notes	AN1327/D (367.0kB)	1		100
Critical Conduction Mode, Flyback Switching Power Supply Using the MC33364	Application Notes	AN1594/D (117.0kB)	0		100
How to deal with Leakage Elements In Flyback Converters	Application Notes	AN1679/D (299.0kB)	3		100
How to Keep a FLYBACK Switch Mode Supply Stable with a Critical-Mode Controller	Application Notes	AN1681/D (185.0kB)	0		100
5.0 V, 2.0 A Flyback Converter	Application Notes	AND8099/D (204.0kB)	2		100
An Innovative Approach to Achieving Single Stage PFC and Step-Down Conversion for Distributive Systems	Application Notes	AND8147/D (69.0kB)	0		100
Universal Input AC-DC Adaptor with PFC Using NCP1603	Application Notes	AND8207/D (3462.0kB)	1		100
19 V, 3 A, Universal Input AC-DC Adaptor Using NCP1271	Application Notes	AND8242/D (752.0kB)	3		100
Application Note for a 5.0 W to 6.5 W Power Over Ethernet (PoE) DC-DC Converter	Application Notes	AND8247/D (151.0kB)	2		100
High Efficiency 8 Output, 60 W Set Top Box Power Supply Design	Application Notes	AND8252/D (99.0kB)	0		100
IsSpice Model for NCP105x	Models	NCP105X_FLYBACK.DWG (117.0kB)	0		100
Linear & Switching Voltage Regulator Handbook	Reference Manuals	HB206/D (1126.0kB)	4	Feb, 2002	100

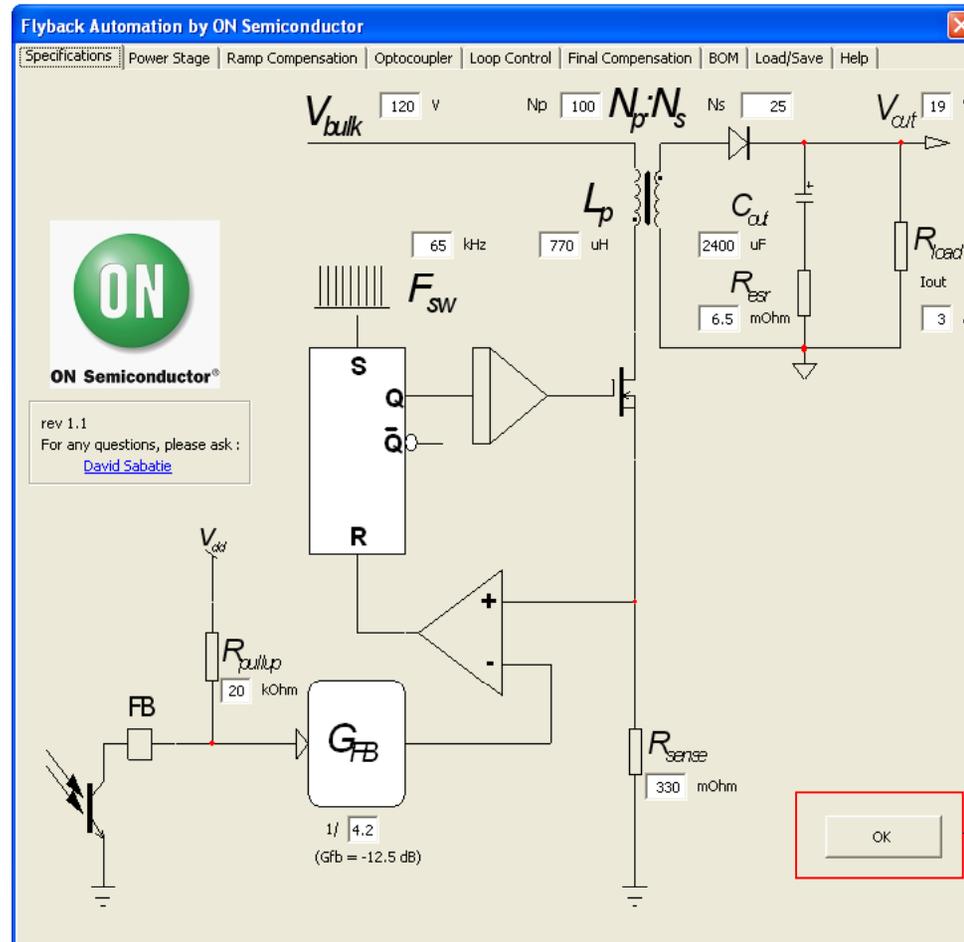
Download this file

<http://www.onsemi.com/pub/Collateral/FLYBACK%20AUTOMATION.XLS>



Launch the file *Flyback_automation.xls*

- ❑ Make sure macro security in Excel® is on medium position
- ❑ Use the “.” as the system decimal separator



Fill-up the fields

Press update



The principle of operation

- ❑ Enter the component values as you calculated them
- ❑ Fill-up the operating fields with the worse case conditions

V_{out} , the dc output voltage in V

I_{out} , the output current in A

V_{bulk} , the rectified bulk voltage in V

R_{pullup} , the opto coupler pullup resistor

G_{FB} , internal FB signal to CS divider

F_{sw} , the switching frequency in kHz

L_p , the transformer primary inductor in μH

N_p , the transformer primary turns

N_s , the transformer secondary turns

R_{sense} , sensing resistor in ohms

C_{out} output capacitor in μF

R_{ESR} output capacitor ESR in ohms

Operating fields

Controller dependent

Your design

From the manufacturer

The principle of operation

□ The adapter example, a 19-V/3-A universal mains converter

V_{out} , the dc output voltage in V = 19 V

I_{out} , the output current in A = 3 A

V_{bulk} , the rectified bulk voltage in V = 120 V

R_{pullup} , the opto coupler pullup resistor = 20 k Ω

G_{FB} , internal FB signal to CS divider = 0.238

F_{sw} , the switching frequency in kHz = 65 kHz

L_p , the transformer primary inductor in μ H = 770 μ H

N_p , the transformer primary turns = 100

N_s , the transformer secondary turns = 25

R_{sense} , sensing resistor in ohms = 330 m Ω

C_{out} , output capacitor in μ F = 2400 μ F

R_{esr} , output capacitor ESR in ohms = 6.5 m Ω



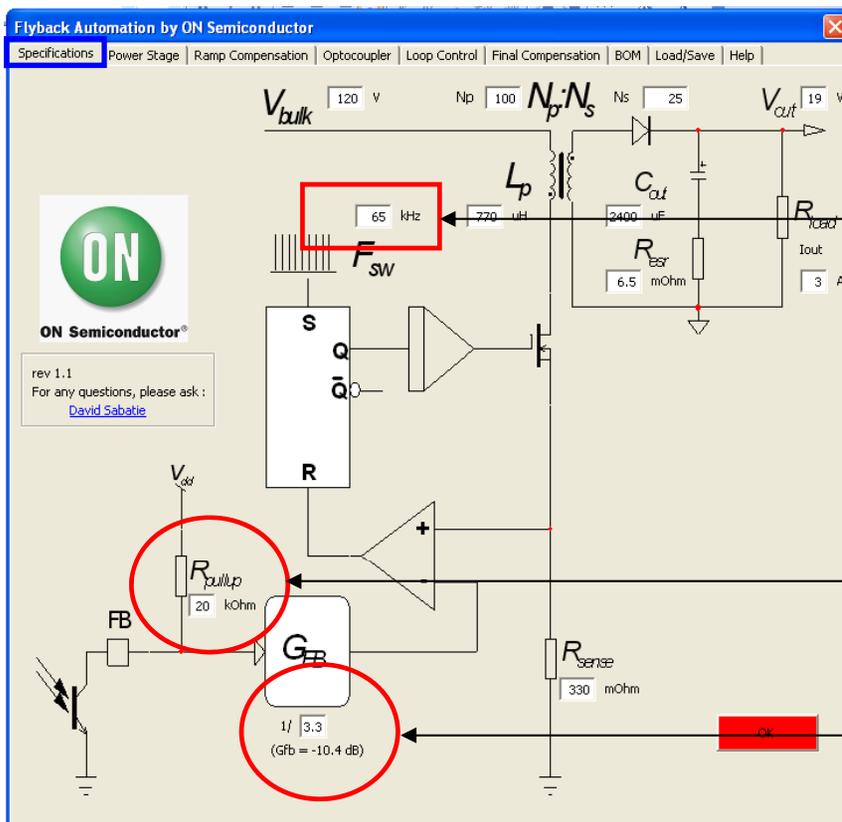
1200 μ F x 2
FM series
Panasonic

Design example with a 19-V/3-A converter

- ❑ Extract the controller data first. Here, a NCP1216P06

FEEDBACK SECTION ($V_{CC} = 11\text{ V}$, Pin 5 Loaded by $1.0\text{ k}\Omega$)

Internal Pullup Resistor	2	R_{up}	20	$\text{k}\Omega$
Pin 2 (FB) to Internal Current Setpoint Division Ratio	-	I_{ratio}	3.3	



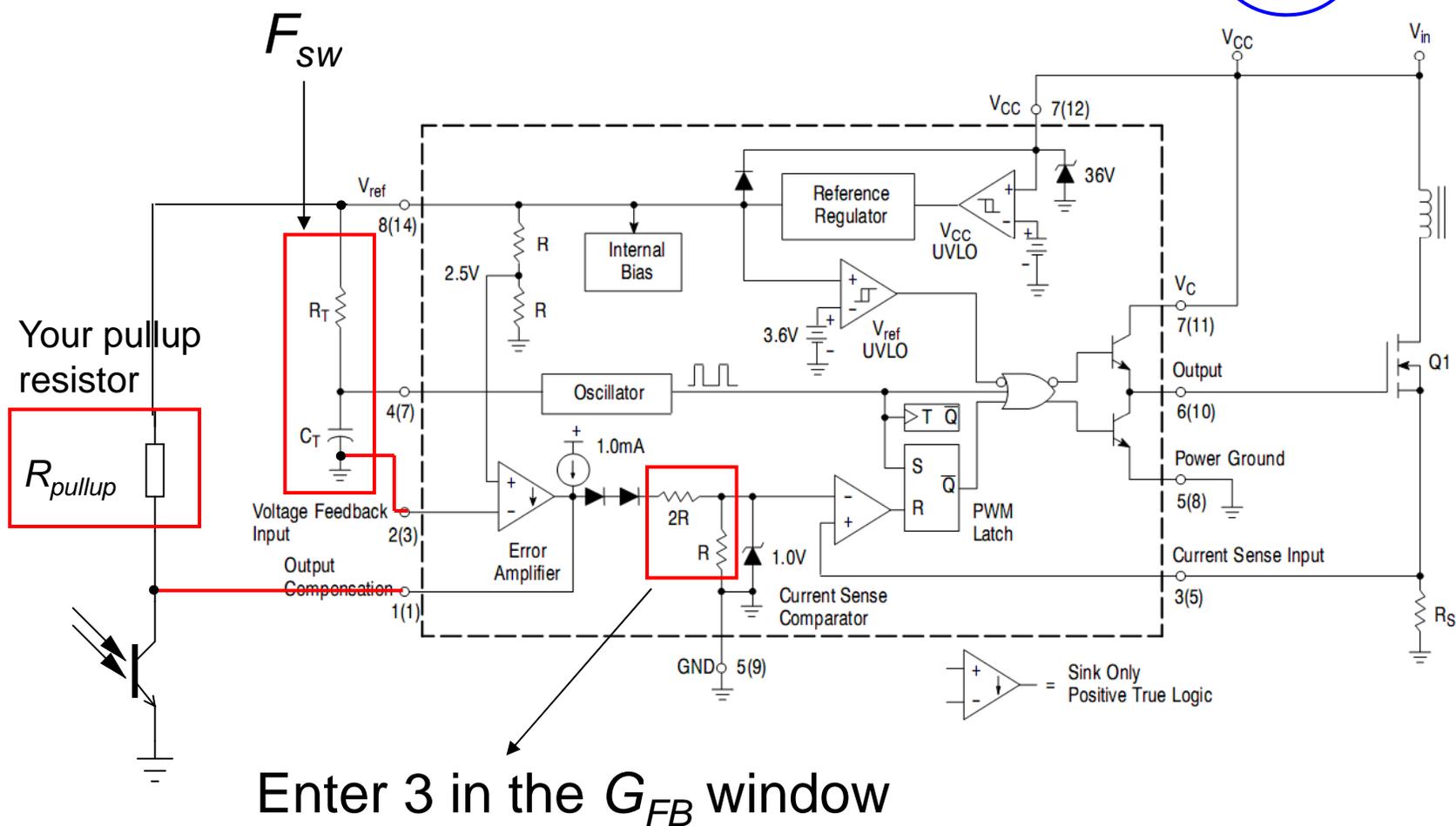
NCP1216P06
 $F_{sw} = 65\text{ kHz}$



Design example with a 19-V/3-A converter

❑ Extract the controller data first. Here, a UC384X

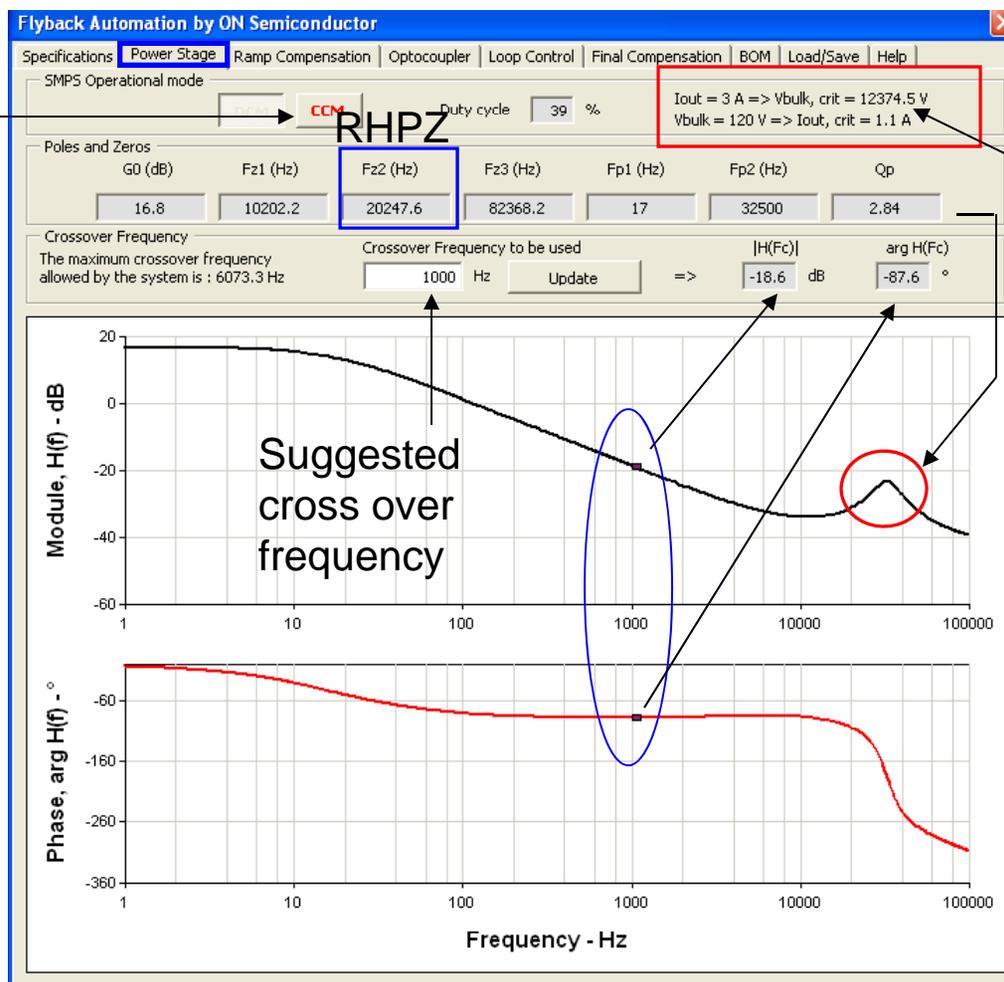
Current Sense Input Voltage Gain (Notes 6 & 7)	A_V	2.85	3.0	3.15	2.85	3.0	3.15	V/V



Design example with a 19-V/3-A converter

- Once data are entered, press the update button

Converter is in CCM



Where mode transition occurs

Always in CCM...

$Q > 1$
peaking!

This is the "plant" Bode plot



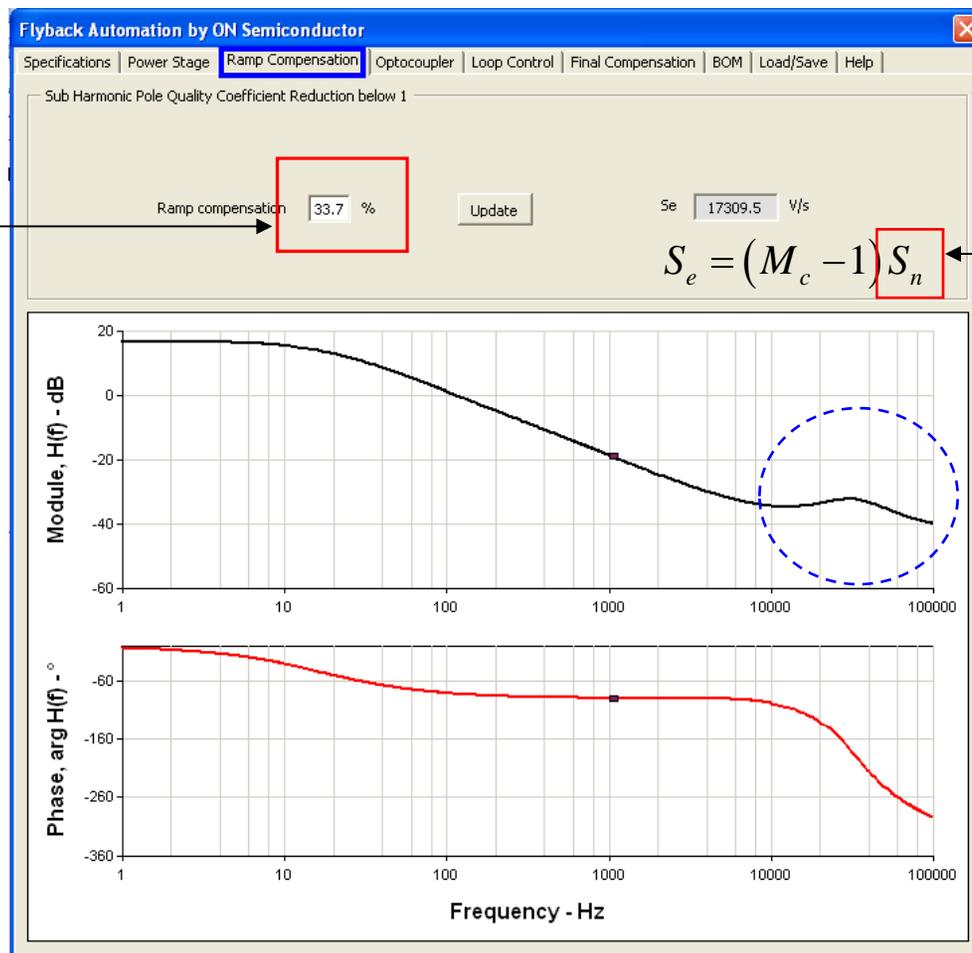
Design example with a 19-V/3-A converter

- In this case, as Q is above 1, ramp compensation is needed

Suggested minimum level. Can be increased to see the effects on the loop gain.

$$Q_p = \frac{1}{\pi(M_c(1-D) - 0.5)}$$

To keep Q_p below 1 $\rightarrow m_c > \frac{1}{\pi} + 0.5$
 $\rightarrow m_c > \frac{1}{1-D}$



On-slope

Ramp comp. damps the Q of the sub harmonic poles..



Design example with a 19-V/3-A converter

- ❑ The optocoupler features an internal parasitic capacitor

This is the controller pull-up resistor

This is the Current Transfer Ratio (CTR) of the selected optocoupler

Flyback Automation by ON Semiconductor

Specifications | Power Stage | Ramp Compensation | **Optocoupler** | Loop Control | Final Compensation | BOM | Load/Save | Help

Rpullup: 20 kohm
CTR: 30 %
Optocoupler's pole frequency: 4500 Hz

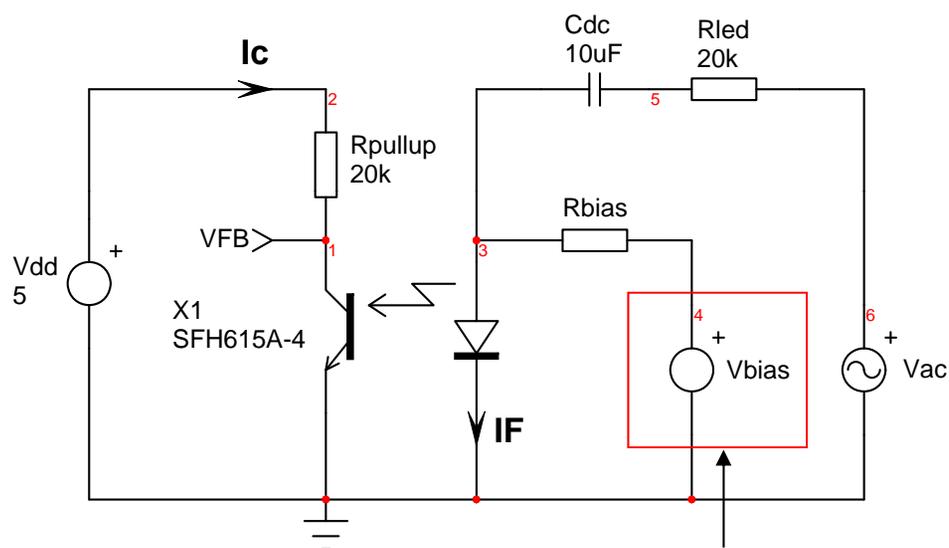
Update Copto: 1768.4 pF

The optocoupler introduces a pole in relationship to the pullup resistor loading its collector. It is the designer duty to characterize this pole and include it in the compensation calculations. To ease the design procedure, the spreadsheet updates the module and argument at the selected f_c with the pole influence. These values are then used to compensate the converter and the final loop gain plot $T(s)$ accounts for the optocoupler presence.

Block diagram: $H(s)$ (Power stage) and $O(s)$ (Optocoupler) combine to form $H(s).O(s)$. The optocoupler block is annotated with f_{opto} and CTR. A small image of an optocoupler component is shown at the bottom right of the block diagram.

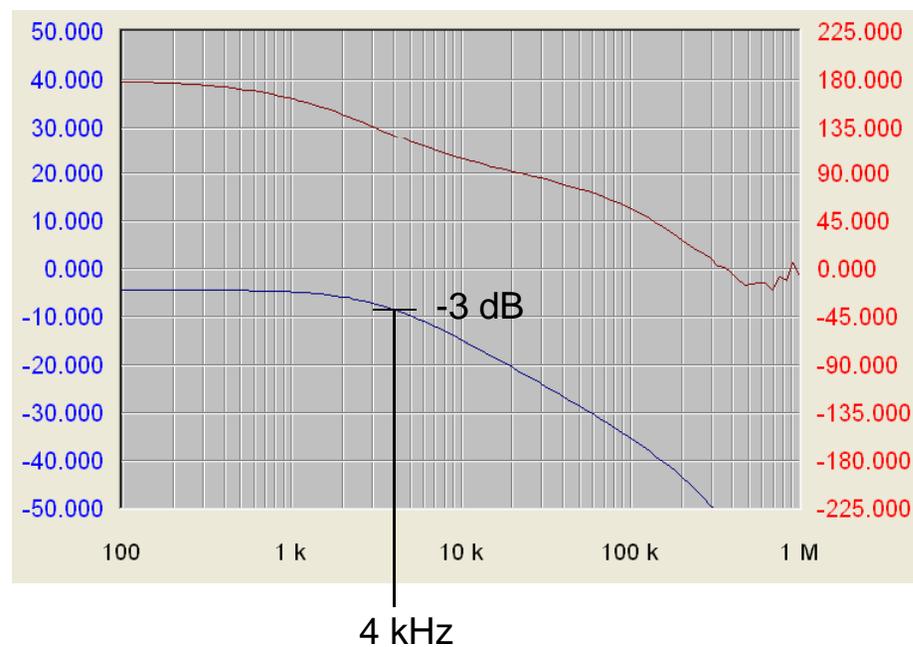
Design example with a 19-V/3-A converter

- ❑ The optocoupler can be characterized on the bench
- ❑ You can extract the CTR and the pole



$$CTR = \frac{I_c}{I_F}$$

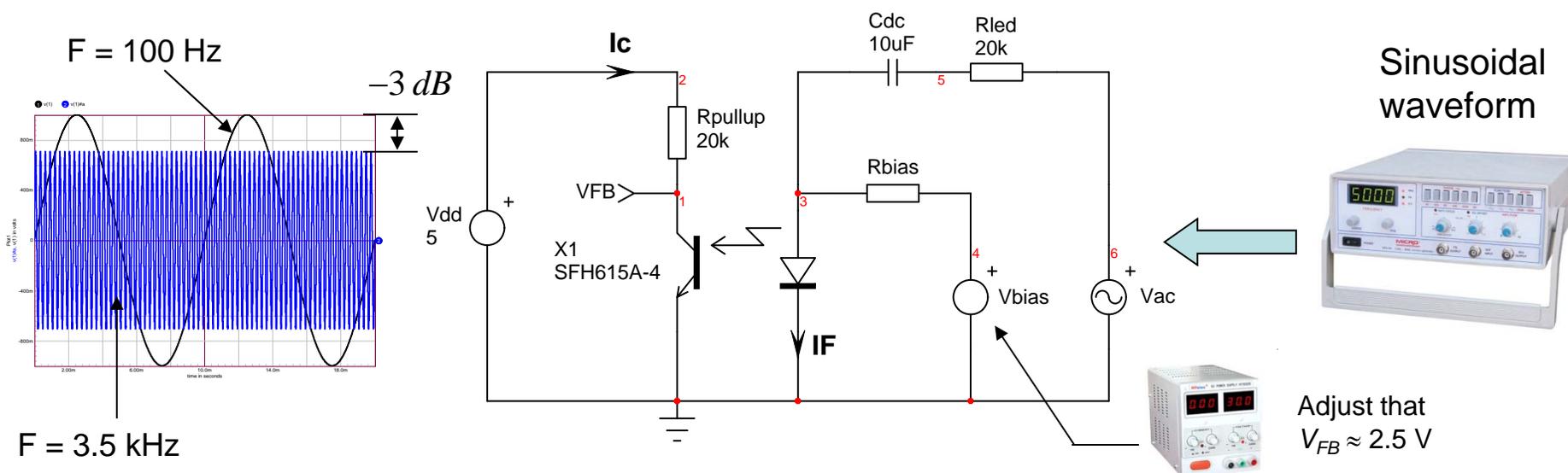
Adjust V_{bias} such that $V_{FB} \approx 2.5 V$



- ❑ Popular optocouplers are: PC817, SFH-615A, PS2913 etc.

Design example with a 19-V/3-A converter

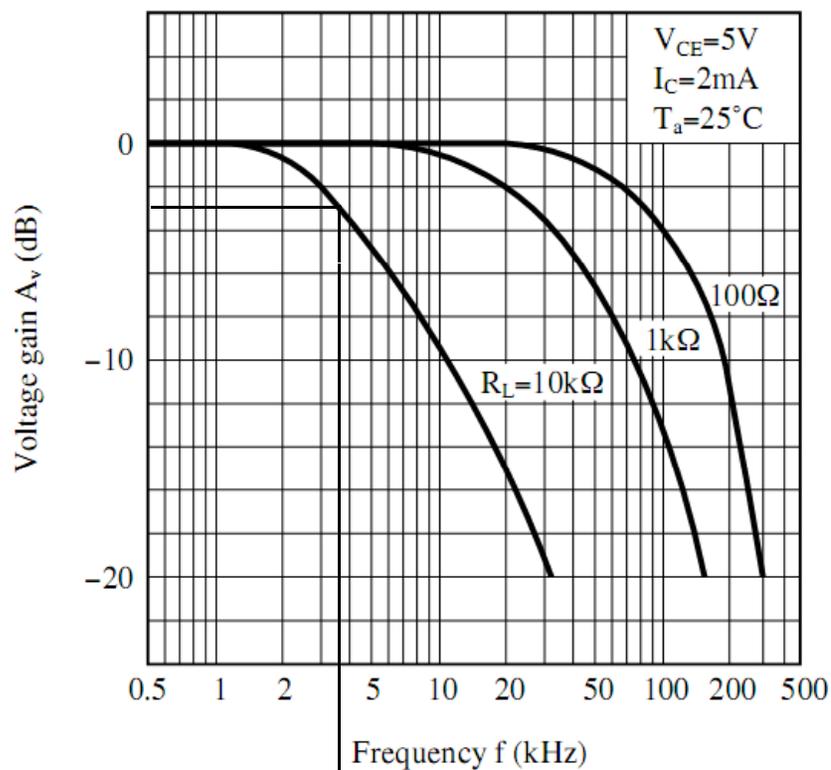
- ❑ The optocoupler can be characterized on the bench
- ❑ The network analyzer can be replaced by a signal generator



- ❑ Observe the output voltage on VFB at low frequency, e.g. 100 Hz
- ❑ Make sure the signal is sinusoidal (no distortion)
- ❑ Increase the frequency until the 100-Hz amplitude is reduced by 0.707
- ❑ At this point, the frequency is your pole location

Design example with a 19-V/3-A converter

- The optocoupler pole can be extracted from the data-sheet



3.8 kHz

Enter the pole position.
The software computes
the equivalent capacitor:

$$C_{opto} = \frac{1}{2\pi R_{pullup} f_{pole}} = \frac{1}{6.28 \times 10k \times 3.8k} \approx 4.2\text{ nF}$$

Design example with a 19-V/3-A converter

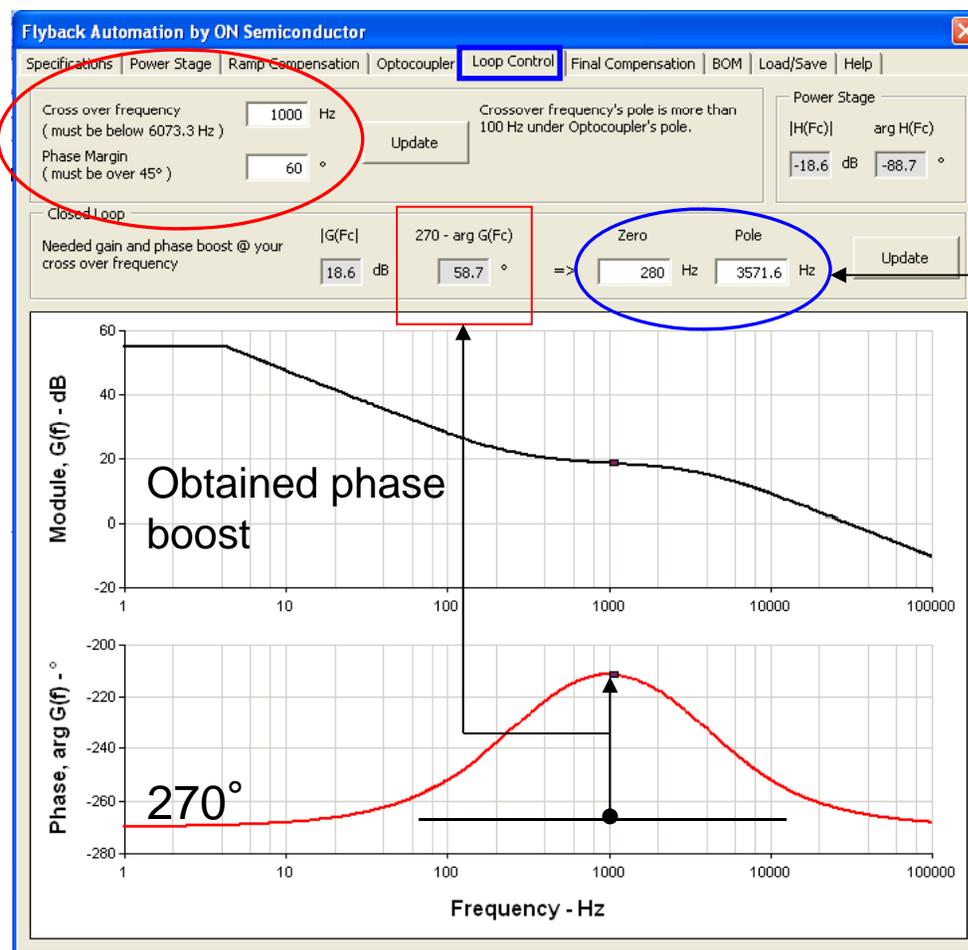
- ❑ For large crossover frequencies, stay away from slow optocouplers: do not intend to reach a 10-kHz crossover frequency with a 5-kHz pole on the optocoupler!
- ❑ The software evaluates the optocoupler pole position and the pole calculated for the compensation network. The calculated pole is obtained by putting a capacitor between the FB pin and GND and comes in parallel with that of the optocoupler.
- ❑ If the optocoupler pole position is lower than the calculated compensation pole, the crossover frequency is automatically reduced by a 10-Hz step. The successive reduction is implemented until an external capacitor above 100 pF is found. This cap. must be wired close to the controller for improved noise immunity.



Design example with a 19-V/3-A converter

- The software now calculates a type-2 compensation

These targets can be altered but depending on the entered values, the crossover can be recomputed based on the optocoupler pole position.

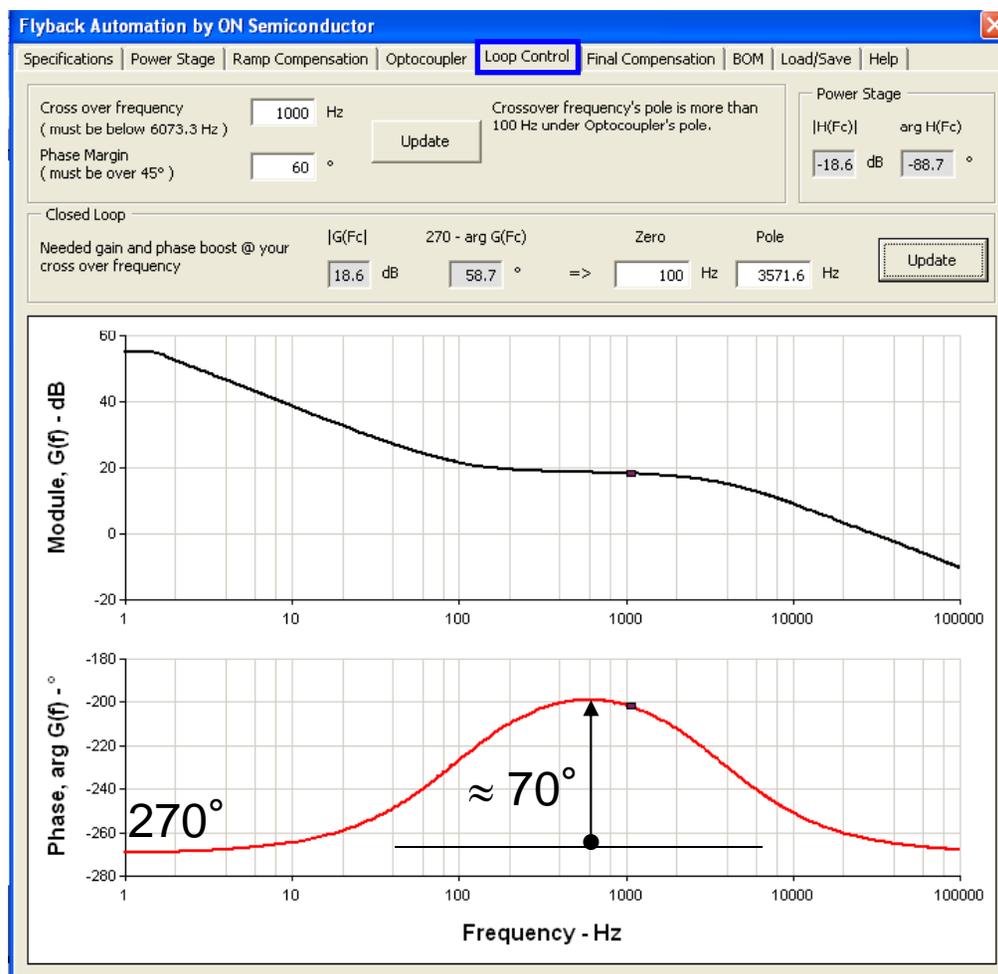


Calculated poles and zeros position based on the entered phase margin target.

If necessary, these positions can be changed to improve the boost.

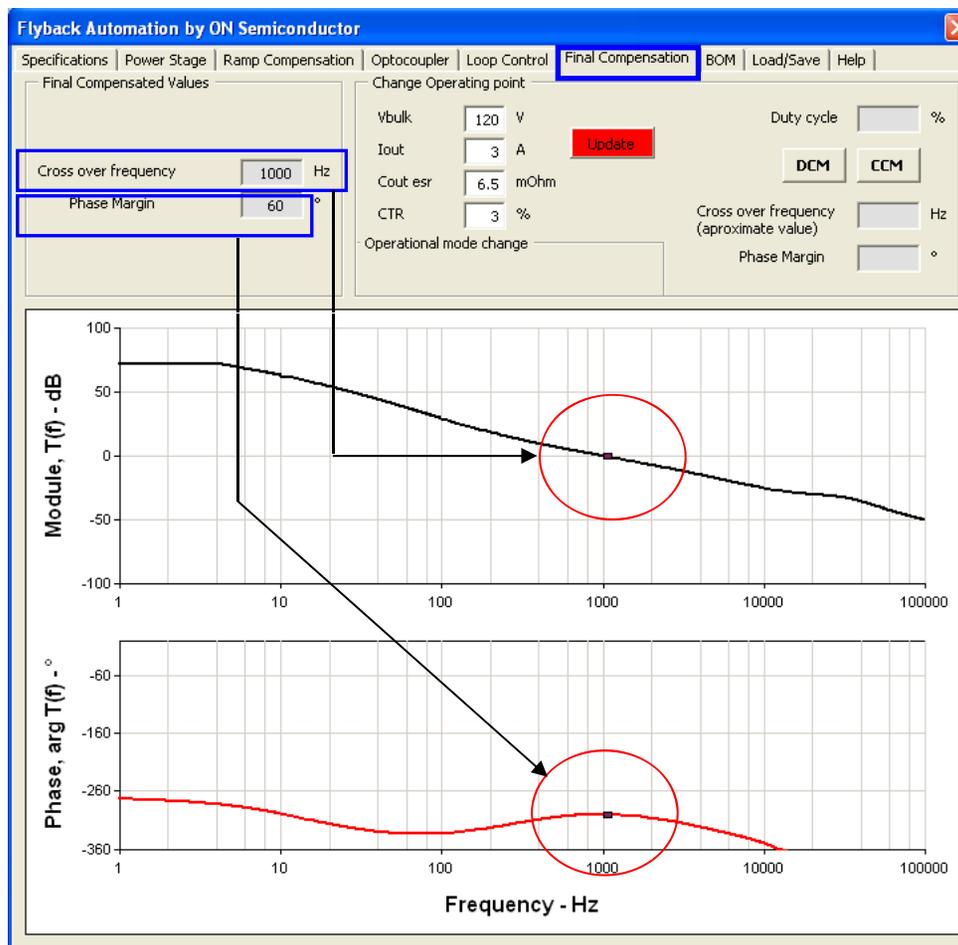
Design example with a 19-V/3-A converter

- The zero has been reduced to 100 Hz, the boost is increased



Design example with a 19-V/3-A converter

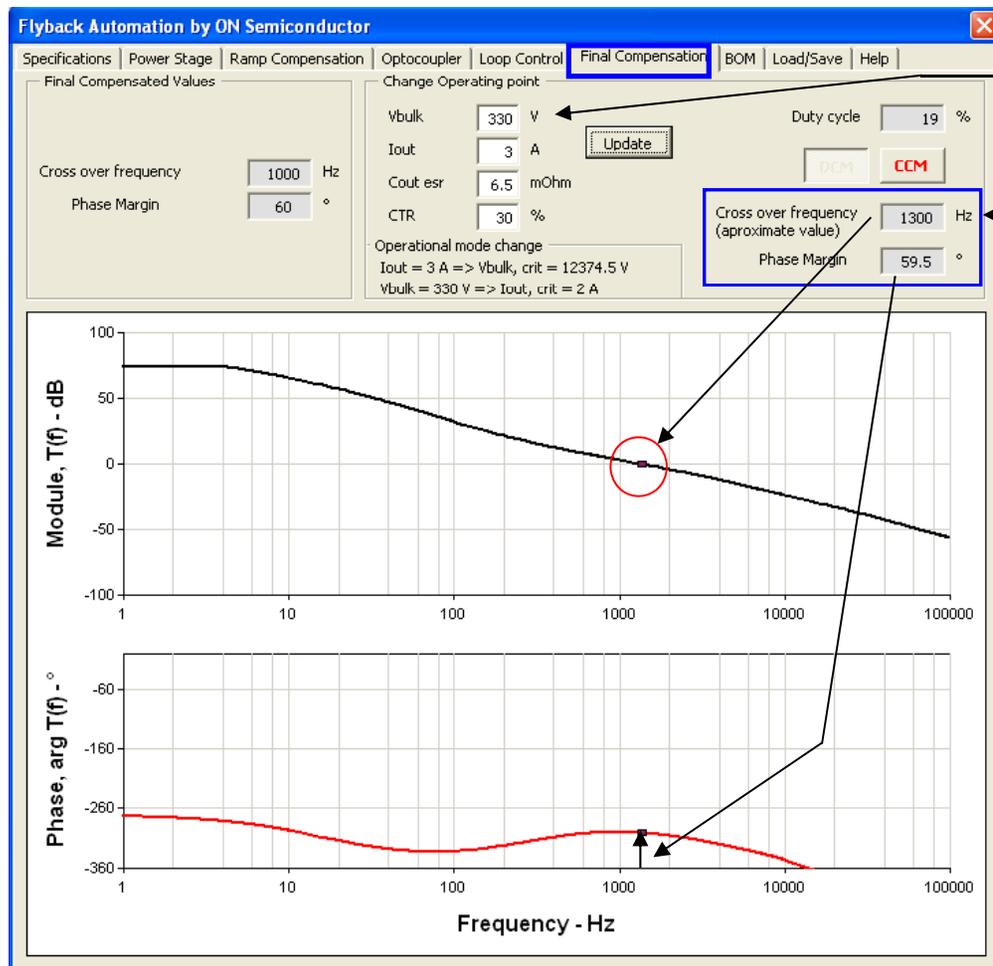
- On the final compensation tab, the loop gain $T(s)$ is plotted



Crossover frequency is respected and the calculated phase margin is 60° as targetted.

Design example with a 19-V/3-A converter

- Now change the operating conditions to check that the phase margin is still ok.



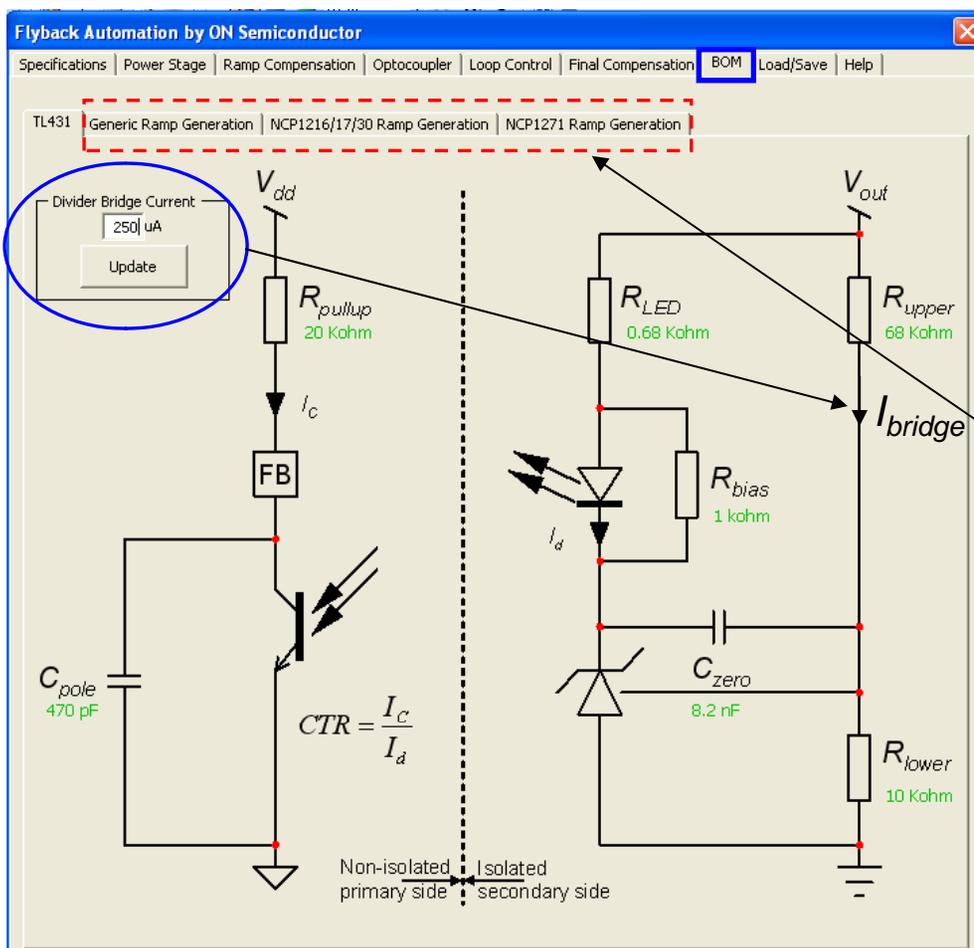
Change input voltage and check the crossover and phase margin changes.

Sweep ESR and optocoupler CTR as they both affect crossover and phase margin.

If the phase margin is too low, change the zero position and make it lower or increase the phase margin target in the loop control tab.

Design example with a 19-V/3-A converter

- On the final compensation tab, the loop gain $T(s)$ is plotted

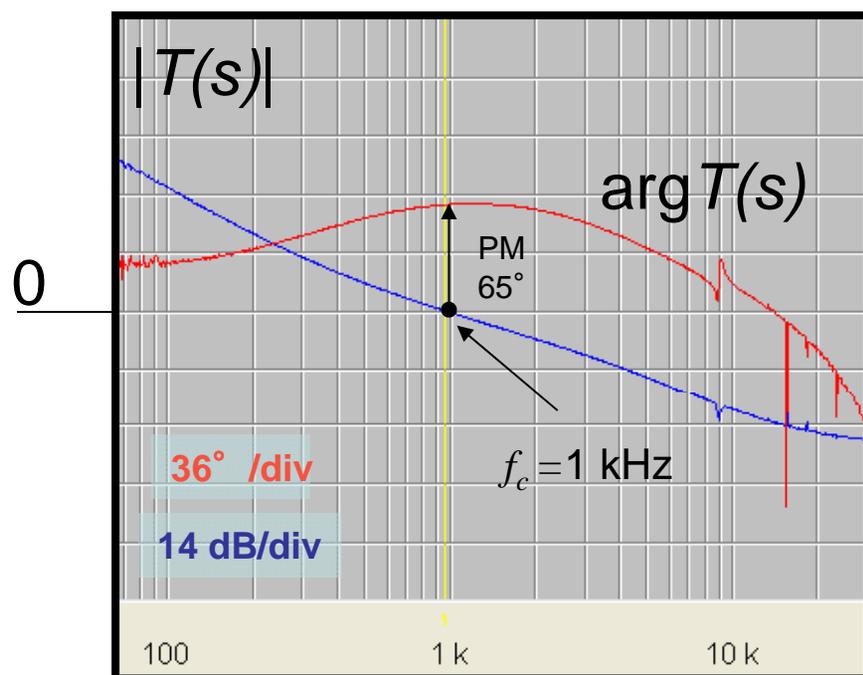


The final type 2 using a TL431 is fed with the computed values. Note the 1-k Ω bias resistor placed here to keep a 1-mA biasing current in the TL431, ensuring the right open-loop gain.

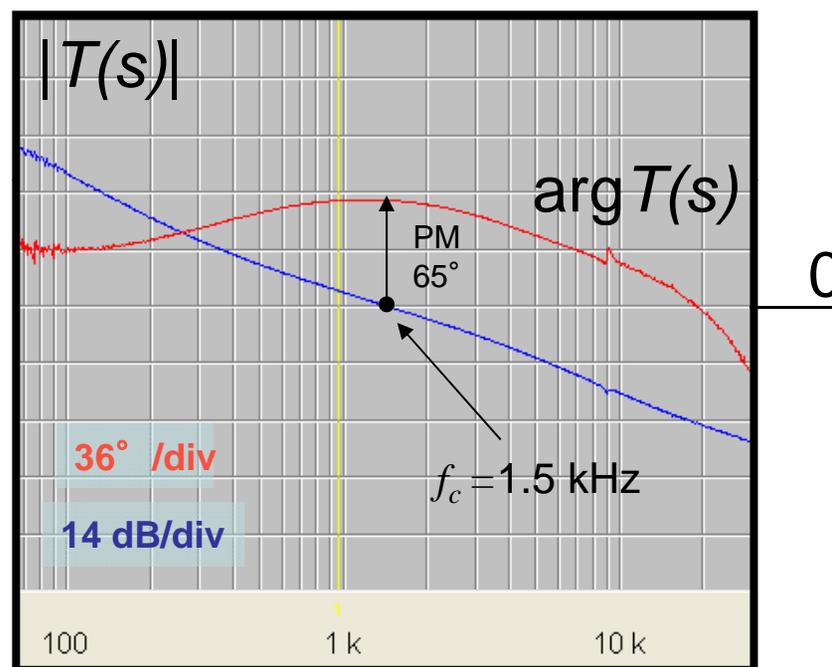
These tabs guide the designer towards the ramp compensation implementation, whether it is included in the controller or not.

Design example with a 19-V/3-A converter

- ❑ We have built the converter with the specs used in this example
- ❑ The loop bandwidth has then been measured at different points



120 V/3 A

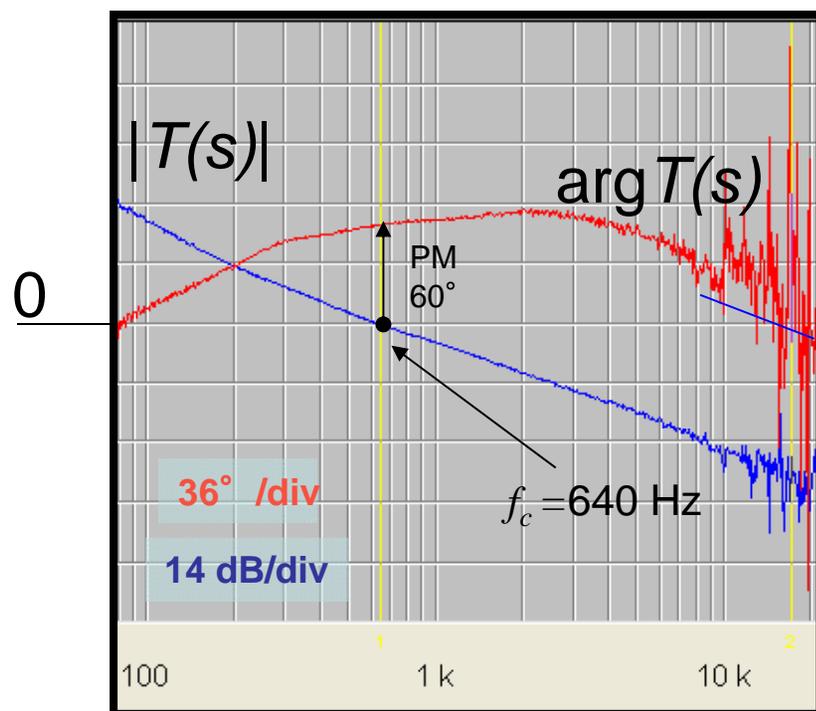


330 V/3 A

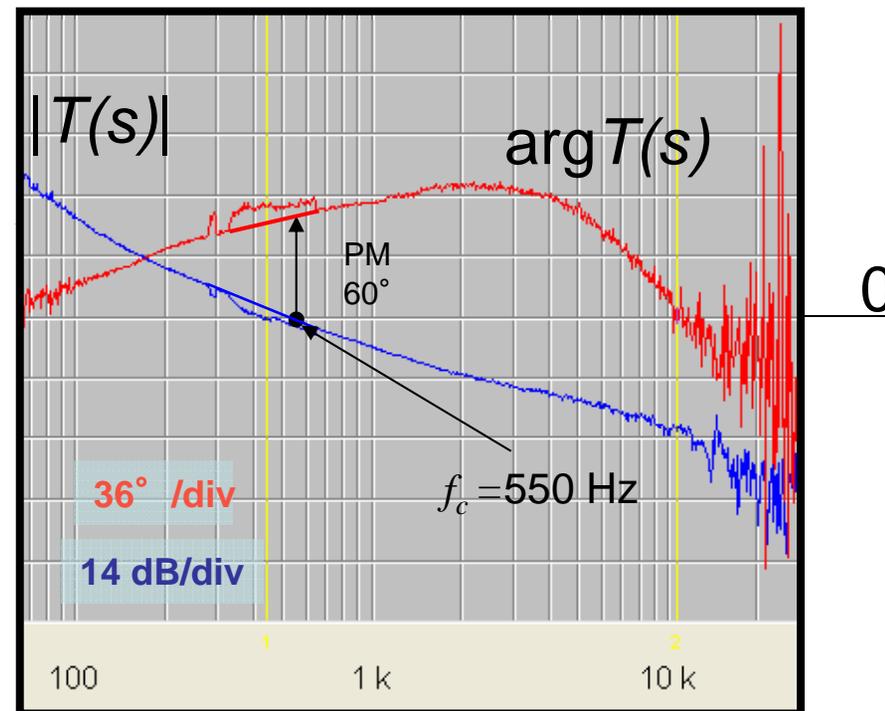
Design target is 1 kHz, 60° phase margin

Design example with a 19-V/3-A converter

- The converter is now operating in the DCM mode



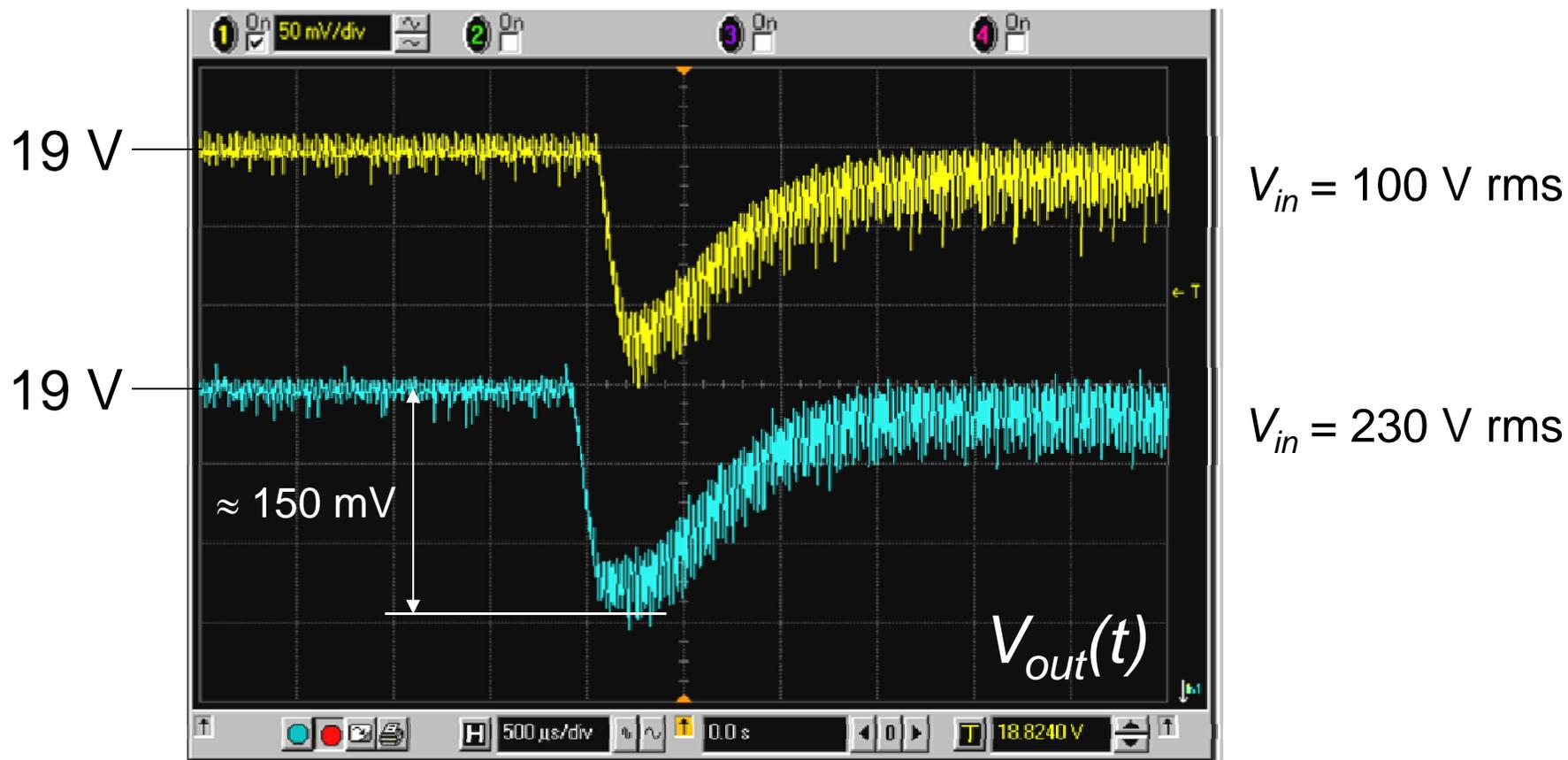
120 V/0.4 A



330 V/0.4 A

Design example with a 19-V/3-A converter

- ❑ Finally, a load step at two different line levels is performed
- ❑ The current is varied from 100 mA to 3 A, $S = 1 \text{ A}/\mu\text{s}$



Conclusion

- ❑ The Excel[®] spreadsheet automates the loop compensation on a flyback converter operated in current mode.
- ❑ The software predicts sub harmonic poles and optimizes slope compensation.
- ❑ The optocoupler pole is taken into consideration and the crossover frequency is automatically adjusted to fit the phase margin requirements.
- ❑ Once the loop is stabilized, the user has the freedom to alter the input/output operating points as well as the parasitic elements contribution and check the resulting phase margin.
- ❑ Bench tests on small-signal and load transient responses agree quite well with the theoretical results given by Excel[®].

