

# Loop Compensation for the NCP1680

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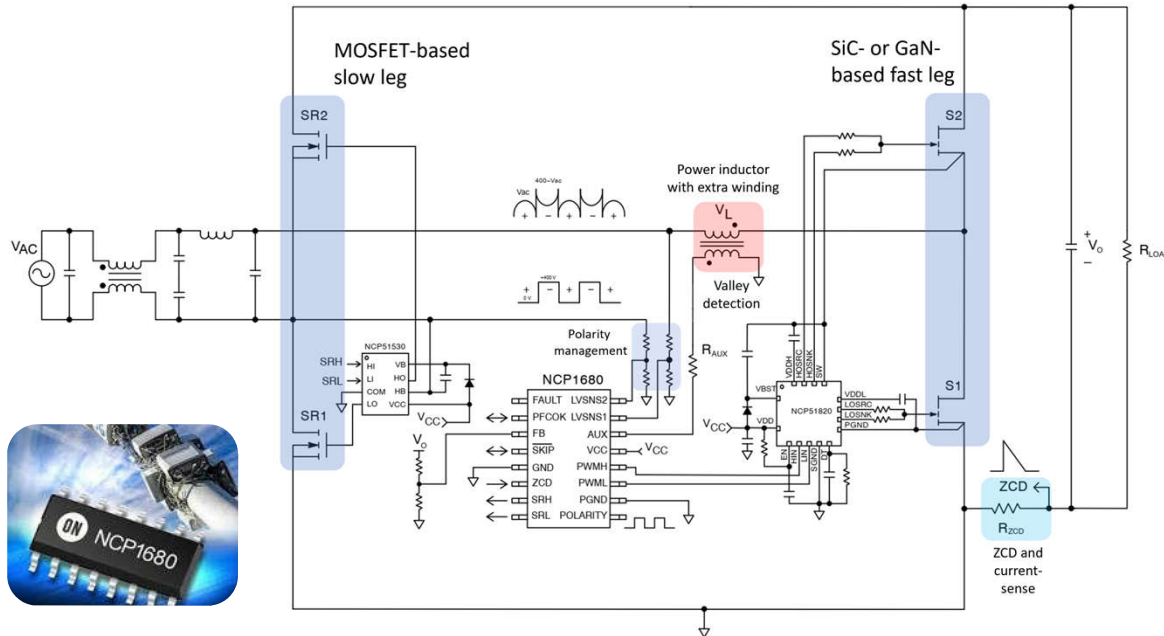
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# NCP1680 Totem-Pole PFC

- The NCP1680 embarks a borderline conduction mode (BCM) engine
- The part is well suited for power levels up to 300 W
- ✓ It is important to check stability considering the internal compensation scheme

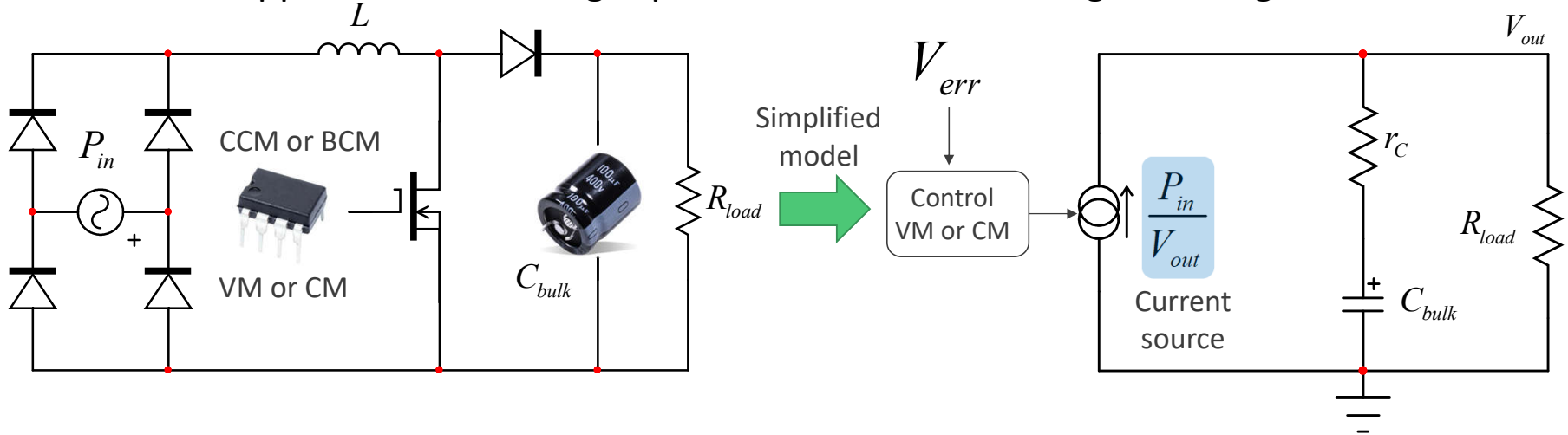


- ✓ You need the loop gain to determine stability margins



# Modeling a Power Factor Correction Stage

- Several ways exist to model switching converters
- ✓ State-space averaging (SSA), PWM switch model, 1<sup>st</sup>-order approximation etc.
- A PFC is a slow system in essence with crossover frequency below 10 Hz
- ✓ 1<sup>st</sup>-order approximation averages power without considering switching mechanism



➤ If the load is a regulated switching converter, the incremental resistance is negative

# Deriving CrM Stage Transfer Function

- The power transmitted by a power stage operated in CrM obeys the formula:

$$P_{in,avg} = \frac{V_{ac}^2}{2L} G_{PWM} V_{err}$$

- ✓ constant on-time voltage-mode control
- ✓  $G_{PWM}$  represents the modulator small-signal gain
- ✓  $L$  is the boost inductor value

100% efficiency



$$P_{in} = P_{out}$$

$$I_{out} = \frac{V_{ac}^2}{2LV_{out}} G_{PWM} V_{err}$$

Nonlinear expression

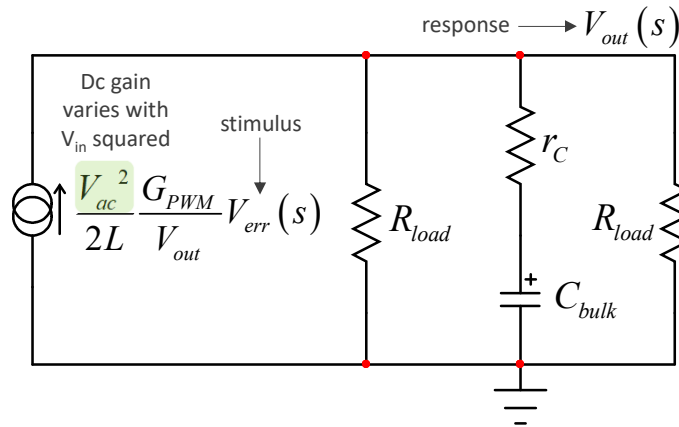
- Run partial differentiation to obtain small-signal coefficients:

$$\hat{i}_{out} = \frac{\partial}{\partial V_{out}} \left( \frac{V_{ac}^2}{2L} \frac{G_{PWM} V_{err}}{V_{out}} \right) \Bigg|_{\hat{v}_{err}=0} \hat{v}_{out} + \frac{\partial}{\partial V_{err}} \left( \frac{V_{ac}^2}{2L} \frac{G_{PWM} V_{err}}{V_{out}} \right) \Bigg|_{\hat{v}_{out}=0} \hat{v}_{err}$$



# Modeling a Power Factor Correction Stage

- From the small-signal equation, build the complete simplified model



ESR contribution high frequency only

$$H(s) = H_0 \frac{1 + \frac{s}{\omega_z}}{1 + \frac{s}{\omega_p}} \approx H_0 \frac{1}{1 + \frac{s}{\omega_p}}$$

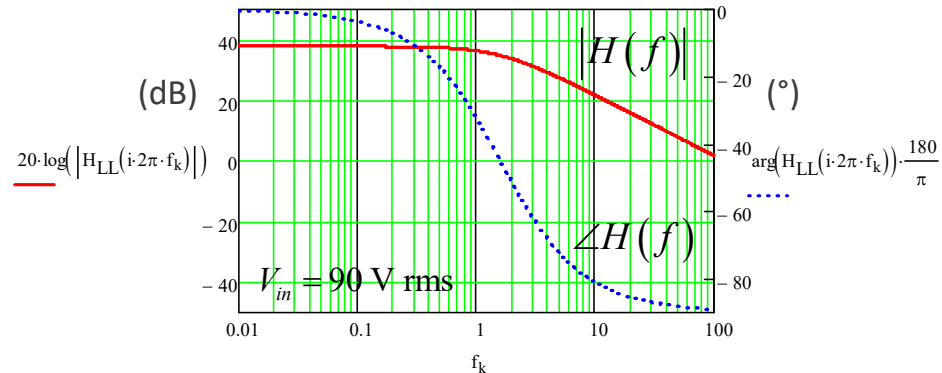
$$H_0 = \frac{V_{ac}^2}{4L} \frac{R_{load} G_{PWM}}{V_{out}} \quad \omega_p \approx \frac{2}{R_{load} C_{bulk}}$$

- Assume the following specifications:

$P_{in} = 144 \text{ W}$   
 $V_{out} = 380 \text{ V}$   
 $L = 250 \mu\text{H}$   
 $C_{bulk} = 200 \mu\text{F}$   
 $R_{load} = 1 \text{ k}\Omega$

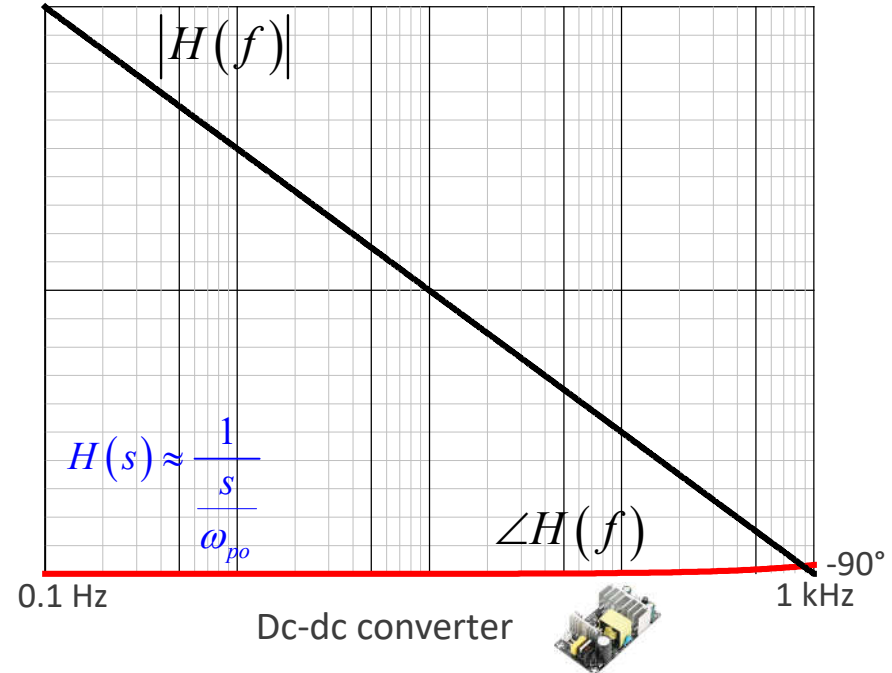
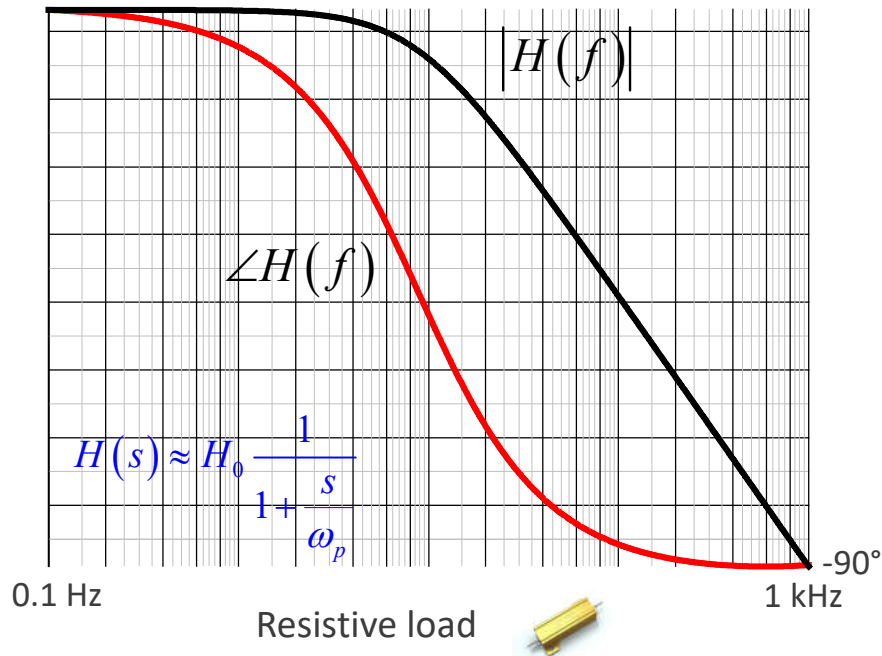
$H_0 = 78 \approx 38 \text{ dB}$   
 $\omega_p \approx 1.6 \text{ Hz}$

Plot  
  
 power stage (LL)



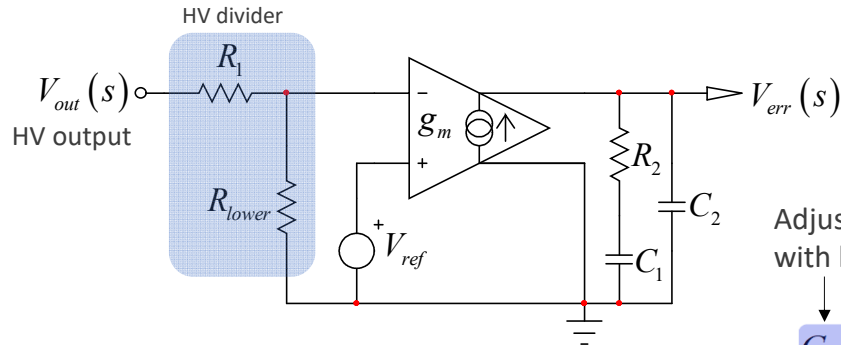
# Different Power Stage Responses

- The control-to-output transfer function of the power stage depends on the load
- ✓ A positive resistance load together with the capacitor sets the low-frequency pole
- ✓ The negative incremental resistance of a dc-dc will bring the pole to the origin



# Internal Compensation

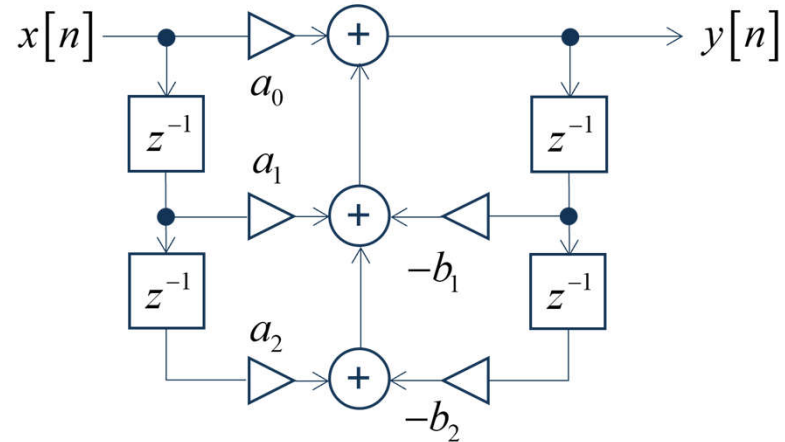
- The NCP1680 embarks an internal type 2 compensator
- A low-pass filter then follows to reduce the ripple contribution
- ✓ Mid-band gain is adjusted based on the input line value



$$G(s) = \frac{V_{err}(s)}{V_{out}(s)} = -G_0 \frac{1 + \frac{\omega_z}{s}}{1 + \frac{s}{\omega_p}}$$

Adjusted with line  
 $G_0 \approx 13.6 \text{ dB}$   
 $\omega_z \approx 1.44 \text{ Hz}$   
 $\omega_p \approx 68 \text{ Hz}$

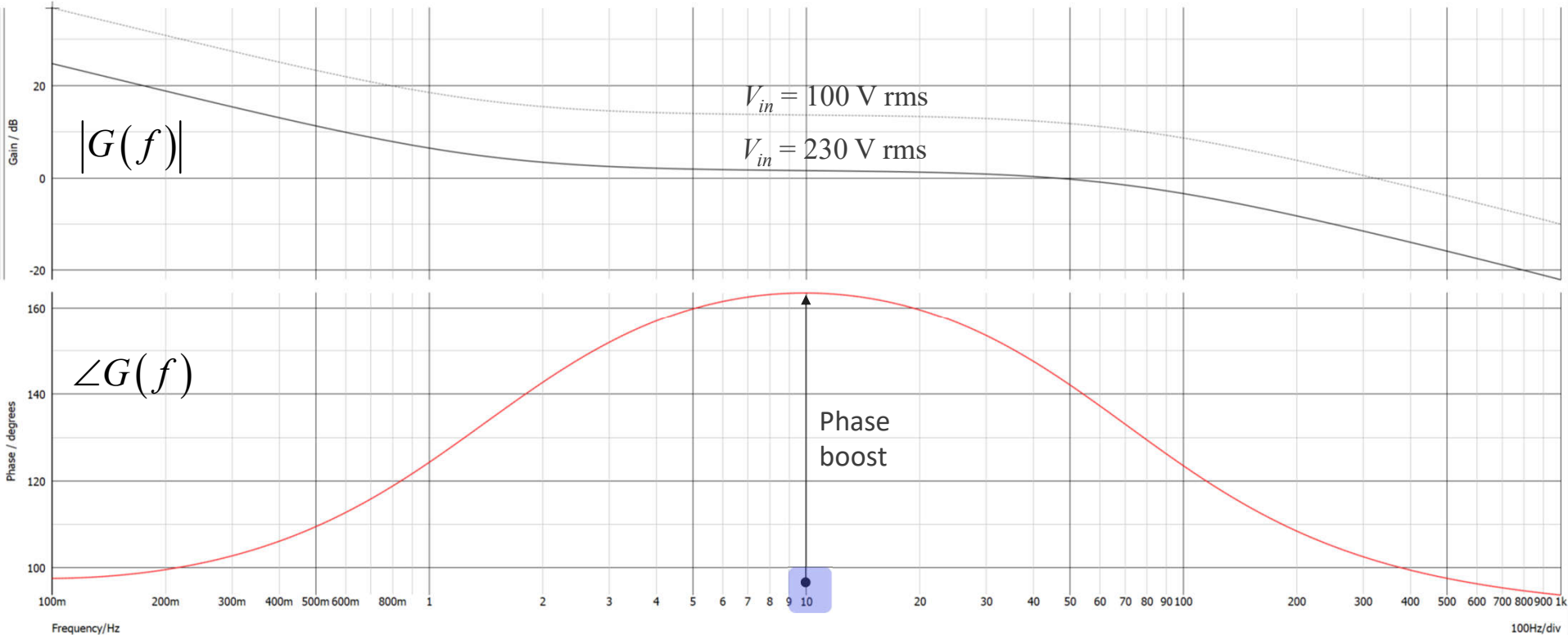
Type 2 compensator – analogue version



Digital implementation

# Typical Type 2 Frequency Response

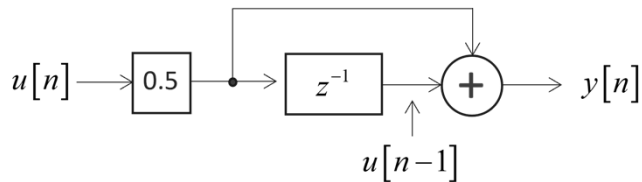
- The mid-band gain changes by 12 dB between low- and high-line operations



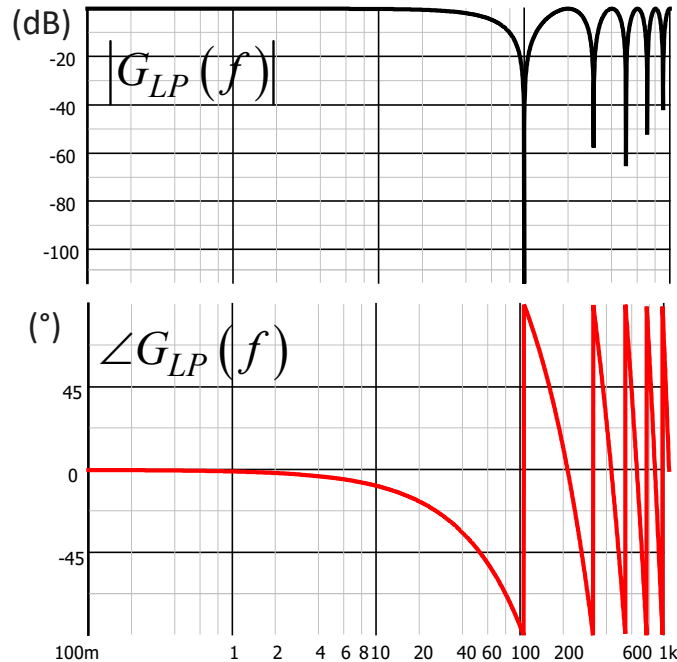
# A Low-Pass Filter Reduces Feedback Ripple

- A low-pass filter is inserted in series with the compensator
- The digital implementation of this filter brings efficient output ripple rejection
- The sampling frequency is adjusted depending on the line frequency

$$y[n] = 0.5(u[n] + u[n-1])$$



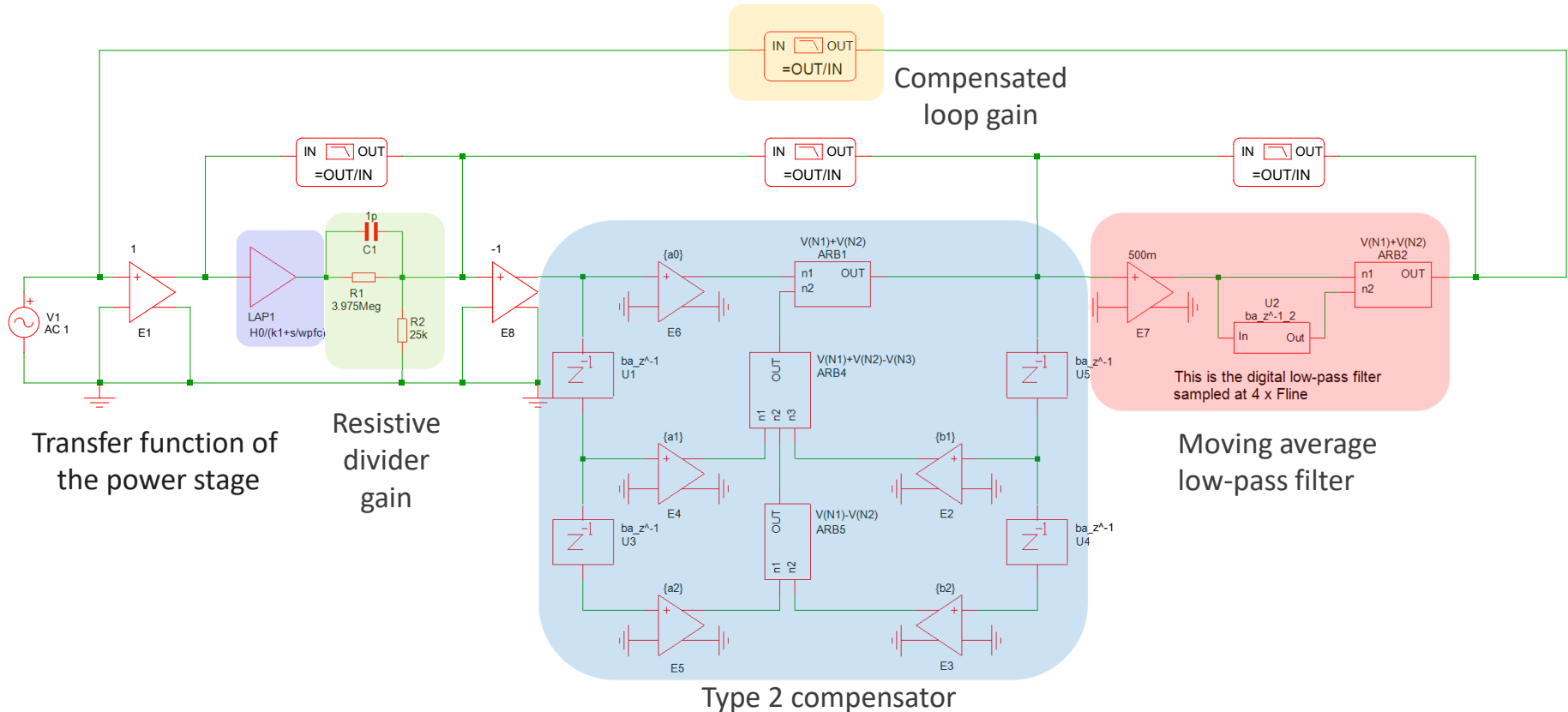
$$G(s) \approx \frac{1 + \frac{s}{\omega Q_N} + \left(\frac{s}{\omega}\right)^2}{1 + \frac{s}{\omega Q_D} + \left(\frac{s}{\omega}\right)^2}$$



- ✓ Sampling frequency is  $4F_{line}$
- ✓ It sets a notch at twice the line frequency

# SIMatrix Compensated Simulation

- The digital filter is simulated with delay lines and fed by a Laplace expression



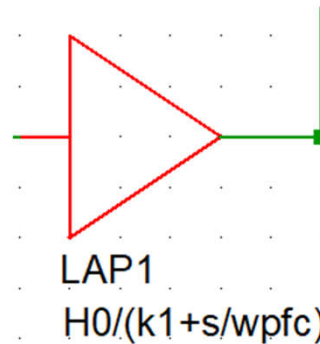
# Gain Changes in Relationship with the Load

- The plant transfer function changes whether a resistance or a neg. resistance loads it

$$H(s) = H_0 \frac{1}{1 + \frac{s}{\omega_{p1}}} \quad \text{Positive resistance}$$

$$H(s) = \frac{1}{s} \frac{1}{\omega_{p2}} \quad \text{Negative resistance}$$

Implementation of power stage TF in SIMetrix



If load ==0, dc-dc load, negative incremental resistance:  $H_0 = 1$  and  $k_1 = 0$   $\omega_{p2} = \frac{V_{ac}^2 G_{PWM}}{2LV_{out}C_{out}}$

If load ==1, dc-dc load, positive resistance:  $H_0 = \frac{V_{ac}^2 R_{load} G_{PWM}}{4L V_{out}}$  and  $k_1 = 1$   $\omega_{p1} = \frac{2}{R_{load} C_{bulk}}$

# Toggle Between Load Types

- SIMetrix allows you change the load nature (resistive or dc-dc) on the fly
- The mid-band gain is also recomputed based on the input line value

```
*
* PFC Parameters
*
.PARAM Load=0
* Load = 0, dc-dc neg. resistance
* Load = 1, positive resistance
*
```

```
.PARAM Vac=100
.PARAM Vout=400
.PARAM Pout=300
.PARAM Fline=50
.PARAM Cout=182u
.PARAM L=126u
.PARAM R={Vout^2/Pout}
*
```

PFC operating parameters

```
* NCP1680 parameters
*
.PARAM a0={G0*Tsw*wp*(Tsw*wz+2)/(2*Tsw*wp+4)}
.PARAM a1={G0*Tsw^2*wp*wz/(Tsw*wp+2)}
.PARAM a2={G0*Tsw*wp*(Tsw*wz-2)/(2*Tsw*wp+4)}
.PARAM b1={-8/(4+2*Tsw*wp)}
.PARAM b2={(4/(Tsw*wp+2))-1}
*
.PARAM wpfc1={2/(Cout*R)} ; positive load
.PARAM wpfc2={Vac^2*mt/(2*L*Vout*Cout)}
.PARAM k1={ IF (load==1,1,0) } Low-pass or integrator PFC TF
.PARAM H0={ IF (load==1,(Vac^2*R*mt/(4*L*Vout)),1) }
.PARAM wpfc= { IF (load==1, wpfc1,wpfc2) }
*
```

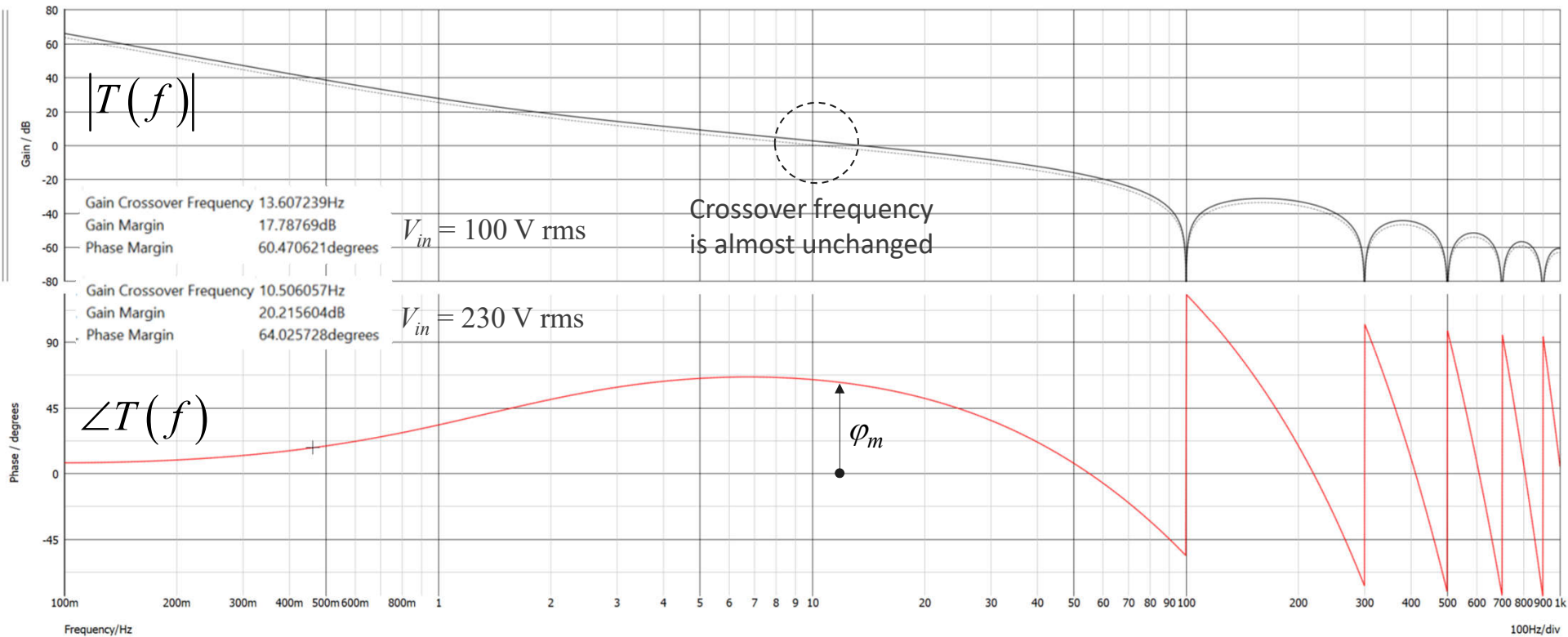
Input-line-dependent  
mid-band gain change

```
.PARAM FCCM=65k
.PARAM Vramp=3.75
.PARAM gm={ IF (Vac < 180,200u,50u) }
.PARAM Vref=2.5
.PARAM mt={1/(FCCM*Vramp)}
.PARAM Fsw=10k ; type 2 filter sampling freq.
.PARAM Tsw={1/Fsw}
.PARAM Ts=Tsw
.PARAM fz=1.435 ; internal zero position
.PARAM fp=68.2 ; internal pole position
.PARAM Rz=24k
.PARAM wz={2*pi*fz}
.PARAM wp={2*pi*fp}
.PARAM G0={gm*Rz} ; internal mid-band gain
.PARAM Tsdel={1/(4*Fline)} ; internal low-pass FIR
```

Low-pass filter calculations

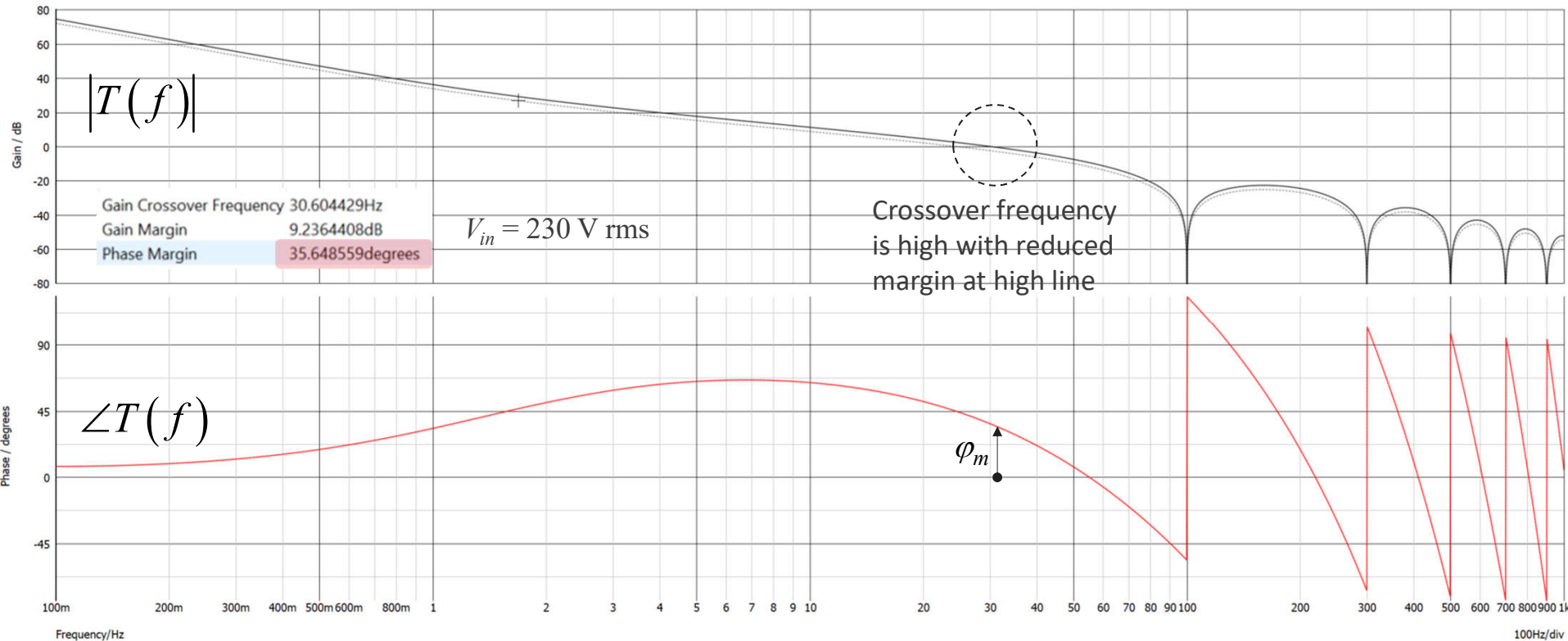
# Typical Results for a 300-W Board

- The 300-W TPPFC features a constant crossover frequency regardless of input line



# Watch the Output Capacitance

- Too low an output capacitance affects stability considering the internal compensation



# Conclusion

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- ❑ The NCP1680 includes a digital compensation scheme of fixed values
- ❑ It is important to study the overall loop gain to ensure a reliable operation
- ❑ The compensator includes an automatic mid-band gain adjustment
- ✓ The crossover frequency becomes independent from input line conditions
- ❑ The SIMetrix template works with the free demonstration version
- ✓ You can immediately visualize the loop gain and check for margins
- ✓ Make sure the output capacitance is large enough to guaranty safe operation