Single phase Unity Power Factor Rectifier using Scalar Control Technique

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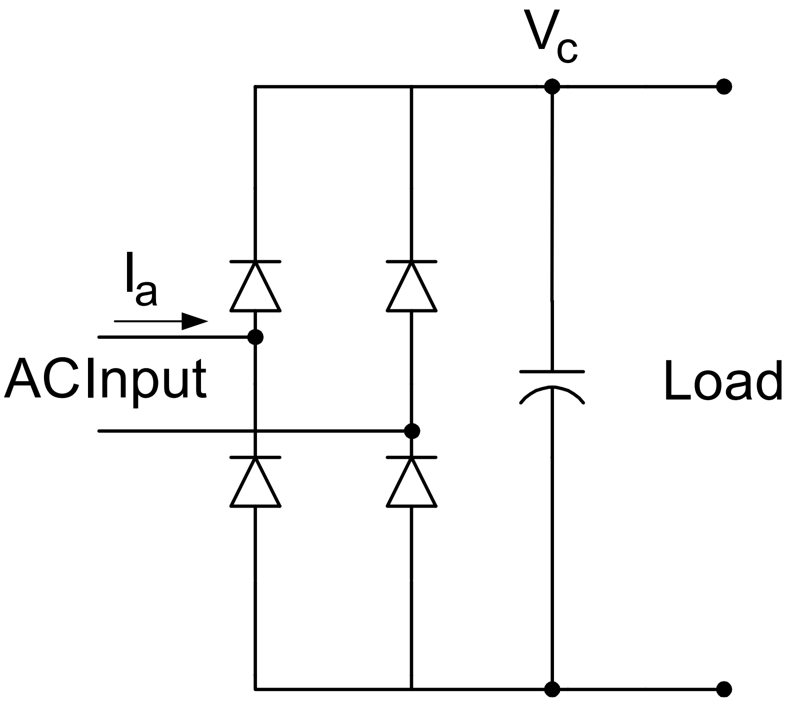
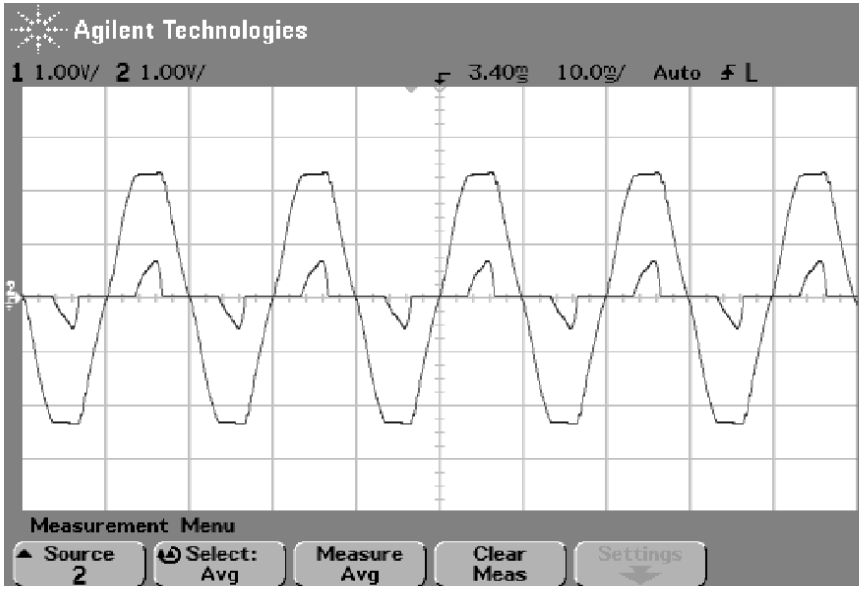
Agenda

- Introduction
- Resistance emulation
- Hardware Implementation
- Steady State stability criterion
- Small signal analysis
- Simulation & experimental results

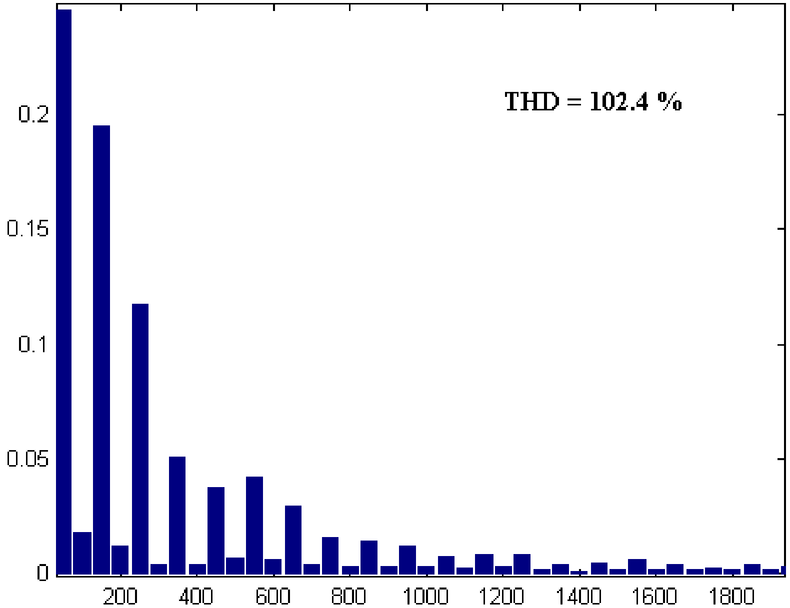
Diode Bridge Rectifier

- Peaky current drawn from the AC source with high harmonic content.
- Higher current stresses on the devices on account of the above problem.





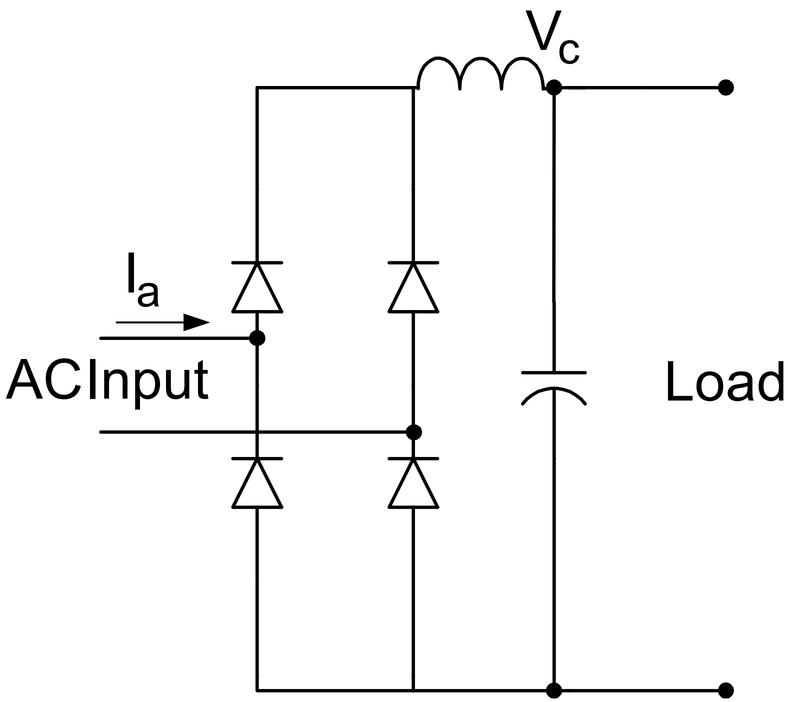
Capacitive filter – Input Voltage & Input Current

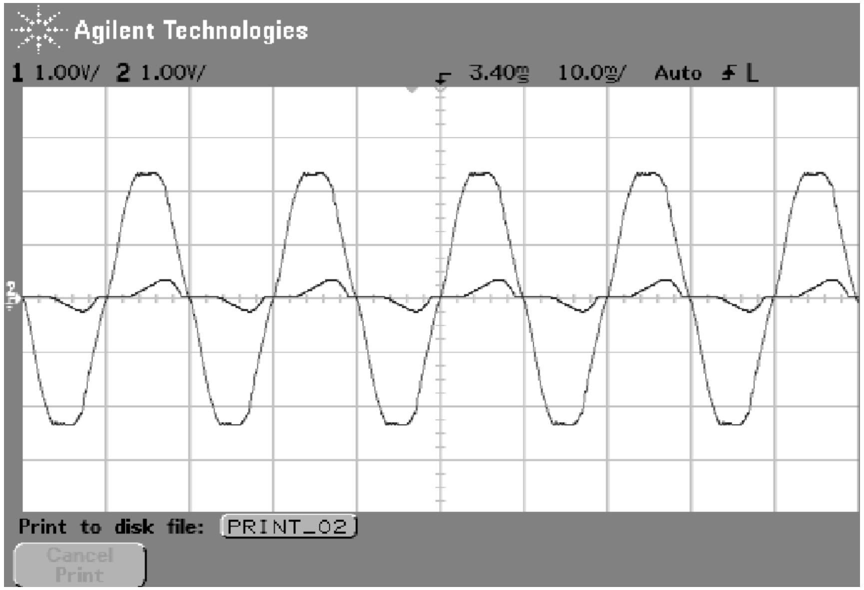


Capacitive filter - FFT of Input Current

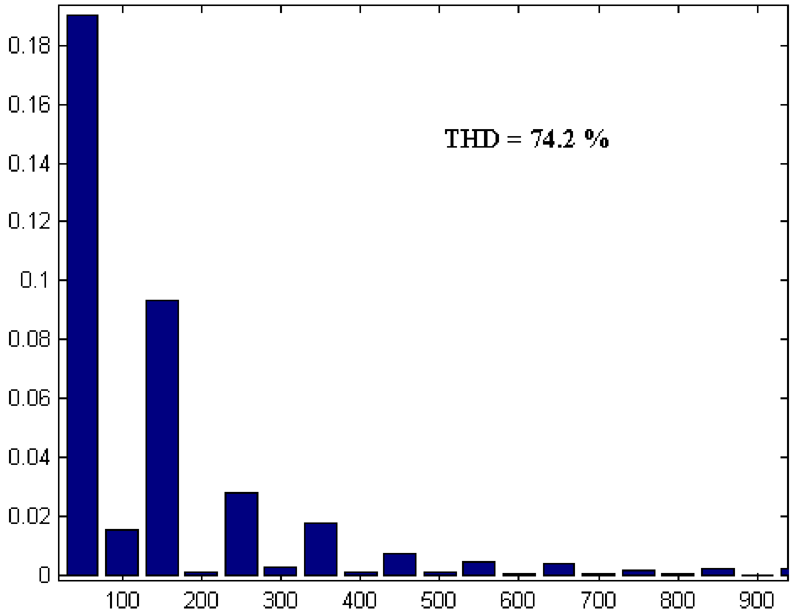
Passive Solution – LC filter

- Harmonic content still observed in the input current.
- DC voltage not regulated which's needed in some applications.
- Need for active solution.





Passive filter solution – Input Voltage & Input Current

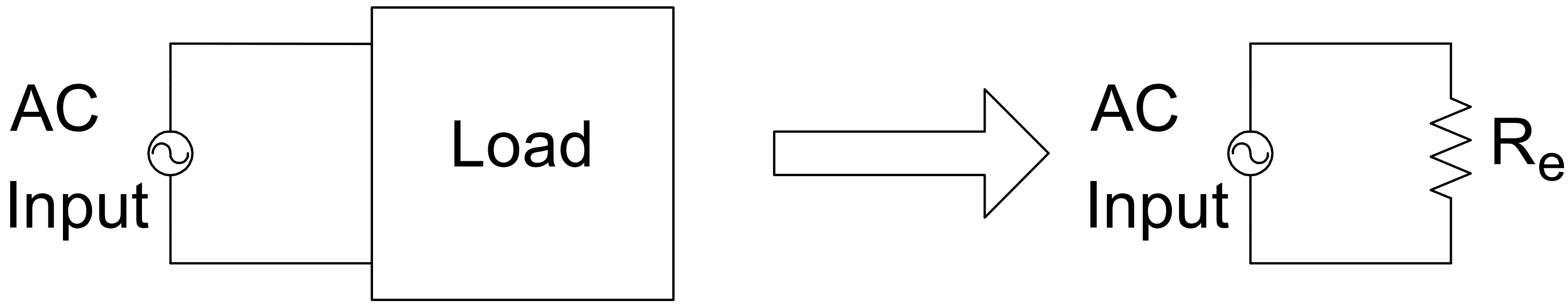


Passive filter solution – FFT of Input Current

Active Solution – Control Objectives

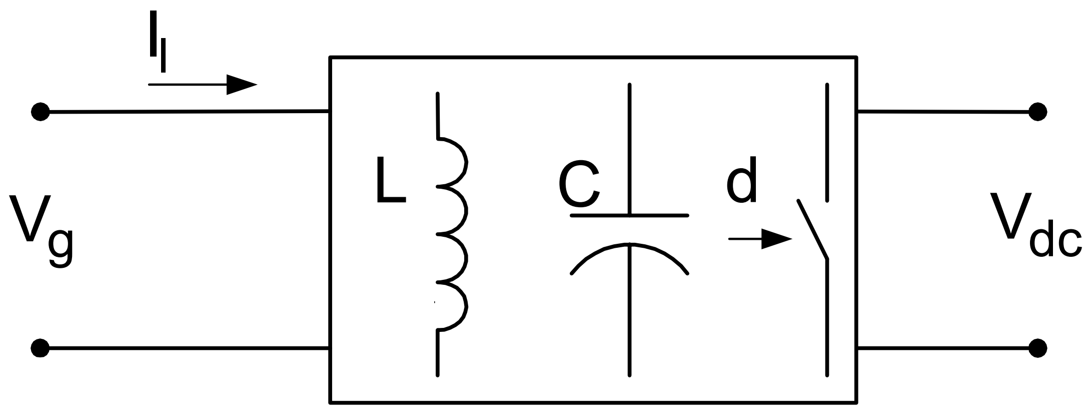
- Sinusoidal input current in phase with input voltage.
- Regulated DC bus voltage.
- Controlled variables – I_{in}, V_{dc}

Resistance Emulation



- R_e controls the amount of real power drawn from the source.
- Extension of the same concept gives rise to Impedence Emulation.

Generalized Resistance Emulator



$$V_g = f(d)V_{dc}$$

$$V_g = I_l R_e$$

Generalized Control Law

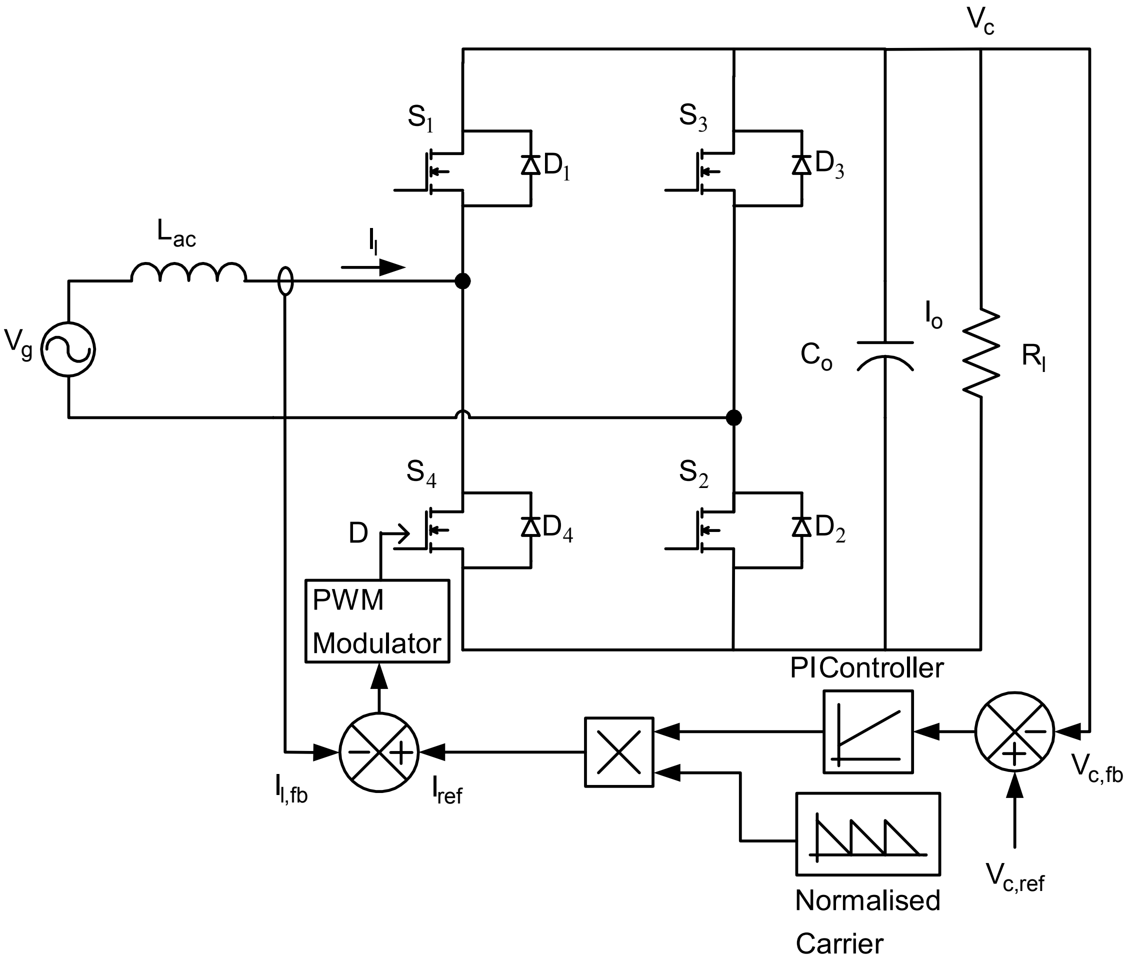
$$f(d)V_{dc} = I_l R_e$$

$$\Rightarrow \quad f(d) = g(I_l)$$

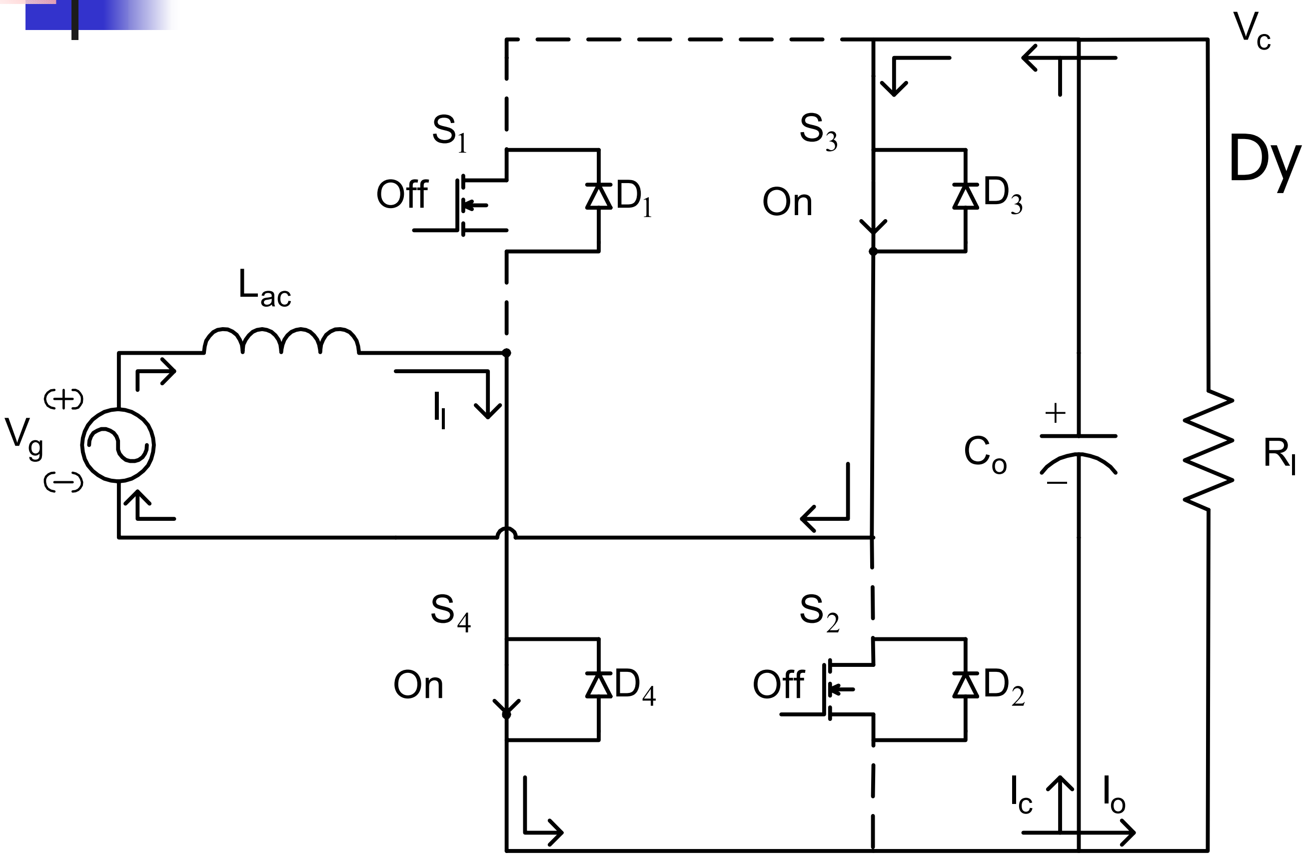
Many Strategies exist based on the above control law

- Average current mode control
- Peak current mode control
- Non-linear carrier control

Hardware Implementation of Scalar Control



Instantaneous model of the converter



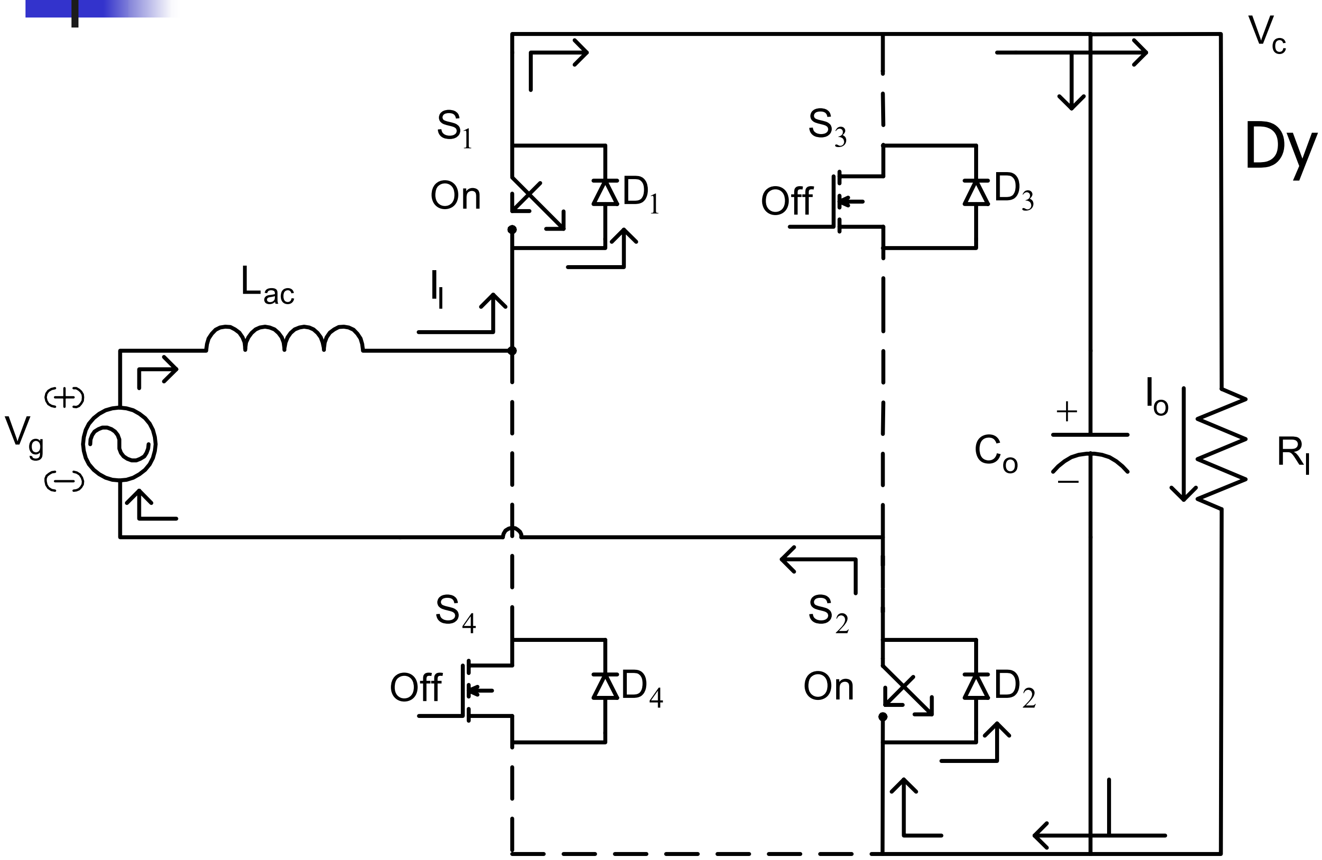
Dynamic Equations

$$v_l = V_g + v_c$$

$$i_c = -i_l - i_o$$

'ON' State Equivalent Circuit

Contd.



Dynamic Equations

$$v_l = V_g - v_c$$

$$i_c = i_l - i_o$$

'OFF' State Equivalent circuit

Application of Resistance Emulation to Scalar Control

- Converter Characteristic :

$$d = \frac{1}{2}[1 - \frac{V_g}{V_{dc}}]$$

- Resistance Emulation Characteristic :

$$V_g = I_l R_e$$

- Control Law :

$$d = \frac{1}{2}[1 - \frac{I_l R_e}{V_{dc}}]$$

Duty ratio command generation

$$d = \frac{1}{2}[1 - \frac{I_l R_e}{V_{dc}}]$$

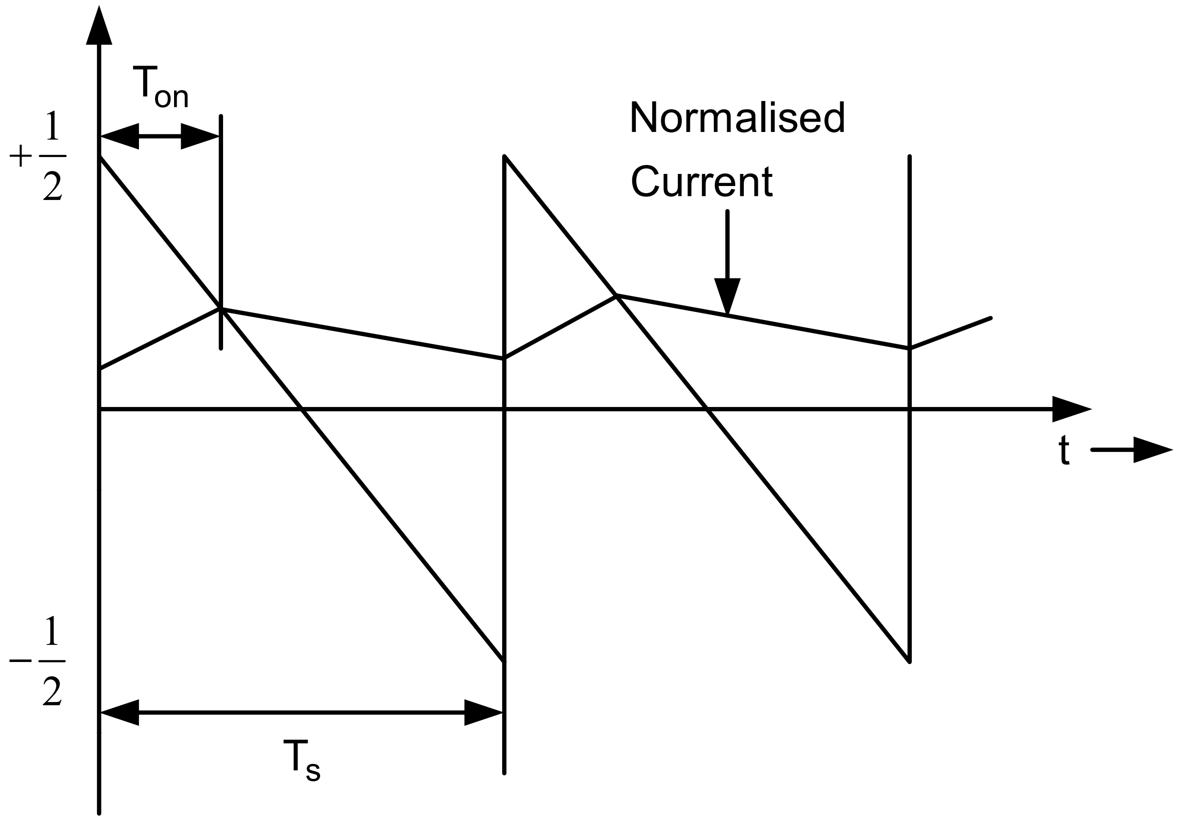
Current reference, $I_{ref} = \frac{V_{dc}}{R_e} = \frac{V_m}{R_s}$

$$\therefore \quad d = \frac{1}{2}[1 - \frac{I_l R_s}{V_m}]$$

where,

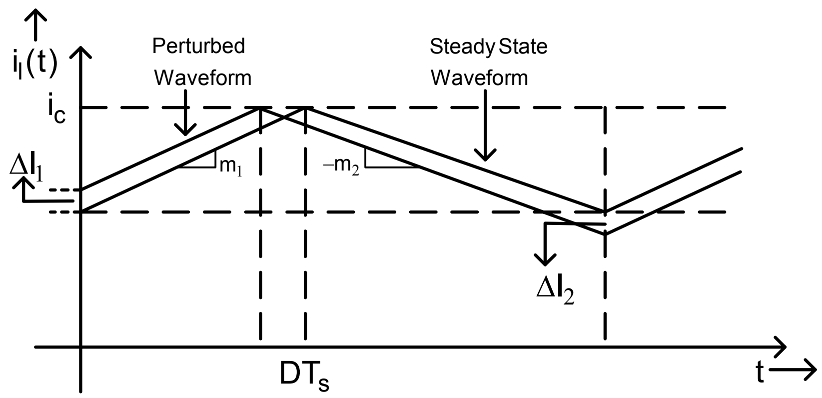
V_m is the output of the voltage controller

Contd.



Duty cycle generation based on normalized carrier

Sub-harmonic instability



- Linear Peak Current mode control :

  Sub-harmonic oscillations set in whenever D>0.5

  Problem is solved by addition of compensating ramp.

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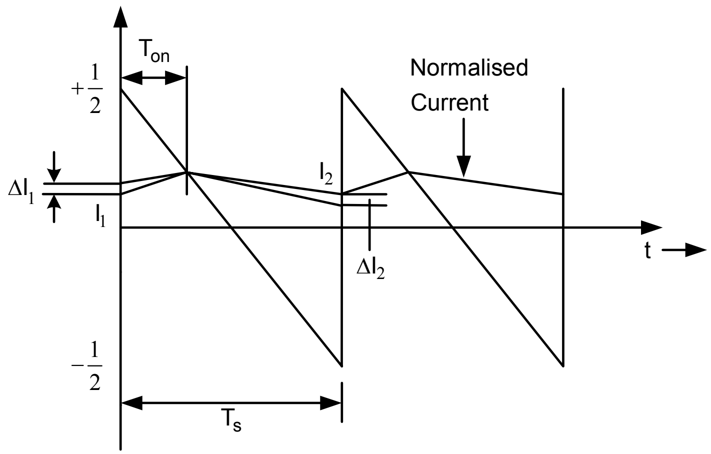
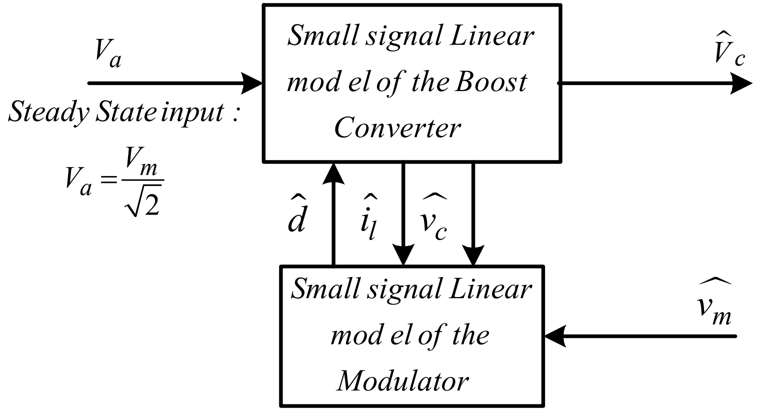


- Perturbation introduced ΔI_1 results in ΔI_2 at the end of the cycle

Stability criterion is $\left|\frac{\Delta I_2}{\Delta I_1}\right| \leq \frac{V_c R_s T_s}{L V_m}$

Small signal model



- The small signal model of the converter is obtained by perturbation analysis
- Operating point is fixed based on power balance

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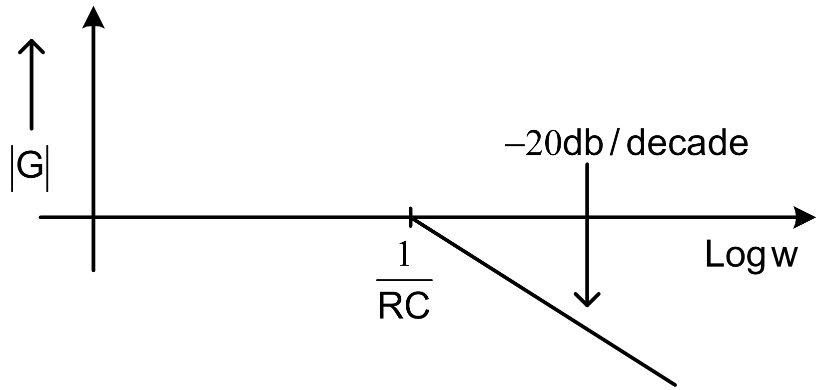
Perturbation & Linearisation of the averaged model

$$\begin{bmatrix} \dfrac{d\hat{i}_l}{dt} \\ \dfrac{d\widehat{v_c}}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \dfrac{2D-1}{L} \\ \dfrac{1-2D}{C} & -\dfrac{1}{RC} \end{bmatrix} \begin{bmatrix} \hat{i}_l \\ \widehat{v_c} \end{bmatrix} + \begin{bmatrix} \dfrac{1}{L} \\ 0 \end{bmatrix} \widehat{v_g} + \frac{1}{2V_m} \begin{bmatrix} \dfrac{2V_c}{L} \\ -\dfrac{2I_l}{C} \end{bmatrix} \left[\widehat{v_m}(1-2D) + \hat{i}_l R_s \right]$$

On solving the above equations we get,

$$\begin{bmatrix} \dfrac{d\hat{i}_l}{dt} \\ \dfrac{d\widehat{v_c}}{dt} \end{bmatrix} = \begin{bmatrix} -\dfrac{V_c R_s}{V_m L} & \dfrac{2D-1}{L} \\ 0 & \dfrac{-1}{RC} \end{bmatrix} \begin{bmatrix} \hat{i}_l \\ \widehat{v_c} \end{bmatrix} + \begin{bmatrix} \dfrac{1}{L} \\ 0 \end{bmatrix} \widehat{v_g} + \begin{bmatrix} \dfrac{V_g}{V_m L} \\ -\dfrac{I_c}{CV_m} \end{bmatrix} \widehat{v_m}$$

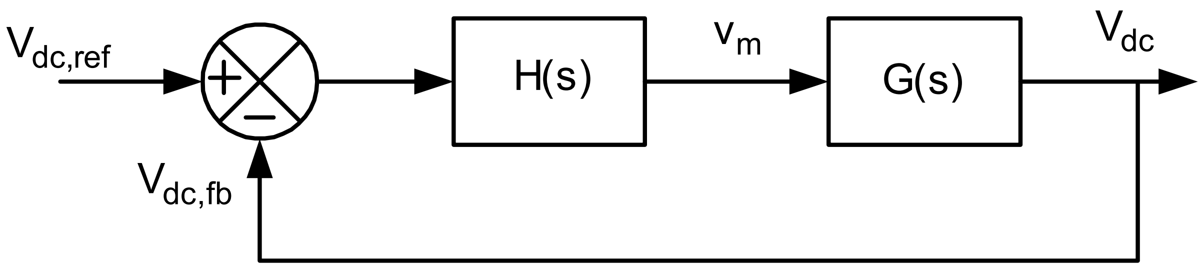
Control Transfer function

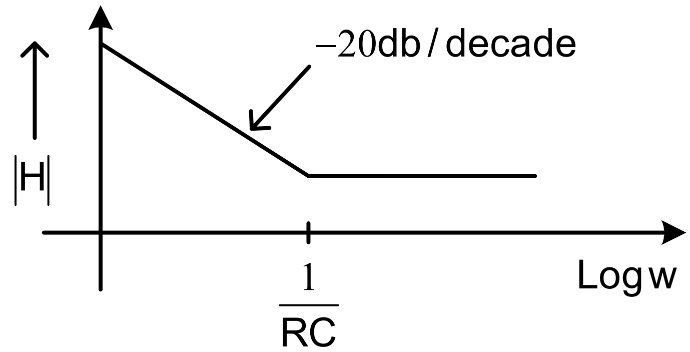


- Output voltage to control variable transfer function

$$\frac{\hat{v}_c}{\hat{v}_m} = \frac{V_c}{V_m}\frac{1}{(1+sRC)}$$

Controller





- PI Controller should be sufficient to serve the purpose of zero steady-state error & desired bandwidth

Features of Scalar Control

- Input Voltage need not be measured.
- Control is based on carrier (constant switching frequency) and is simple to realize which is evident from the control transfer function.
- Protection & Parallel operation are added advantages.
- At the cost of one extra active device, the number of passive devices is reduced.

Contd.

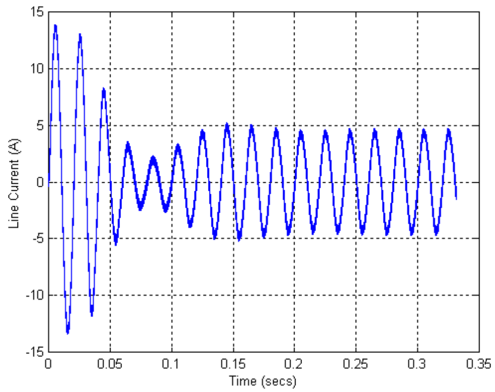
- Steady State Stability problem is observed in scalar control.
- The operation is always in CCM.
- Efficiency is slightly higher in this converter on account of the fact that only 2 devices are in the series path of processed power.

Simulation

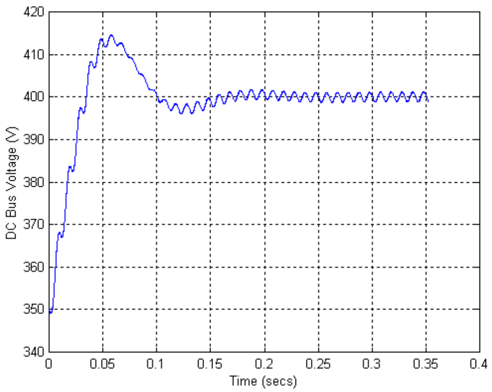
- System Parameters

Input Voltage range	- 100-230V
Output Voltage	- 400 V
Rated Power	- 750 W
Switching frequency	- 19.5 KHz
Line Inductance	- 11 mH
Line frequency	- 50 Hz

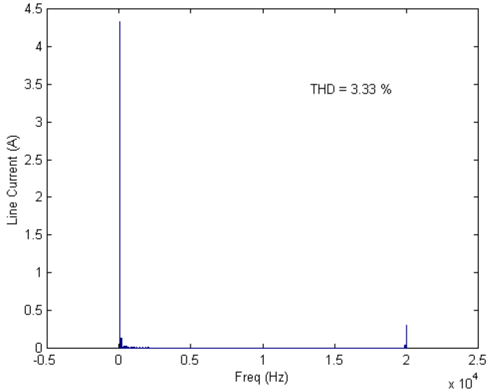
Waveforms



Input current

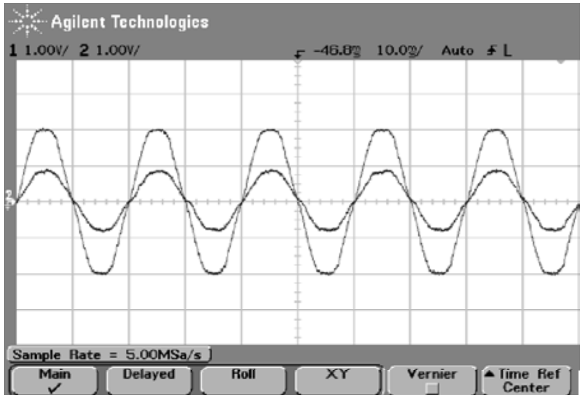


DC Bus Voltage

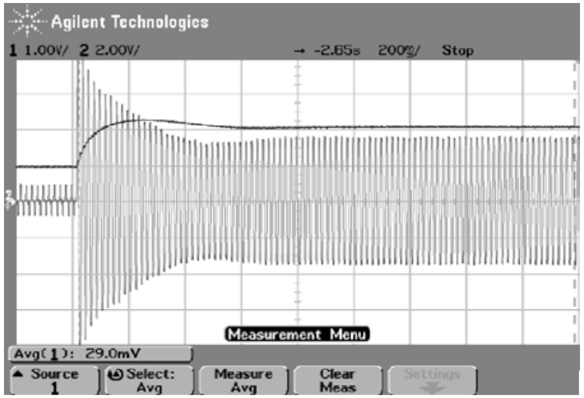


FFT of Input current

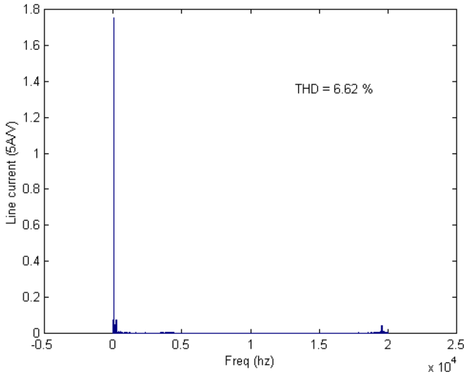
Experimental results



Input Voltage & current

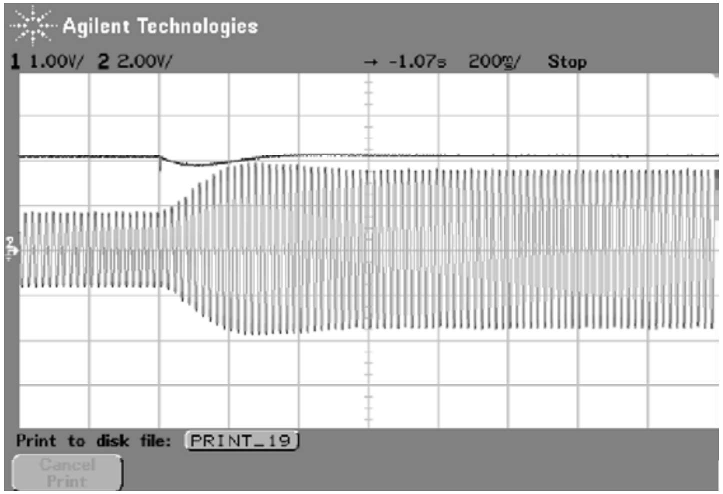


Line current & DC bus voltage

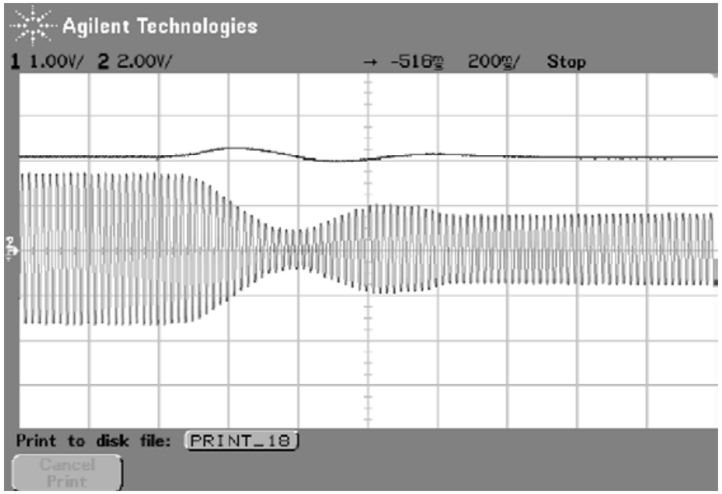


FFT of Input current

Step Response



Step change of load from R=1K to R=300 ohms



Step change of load from R=300 ohms to R= 1K

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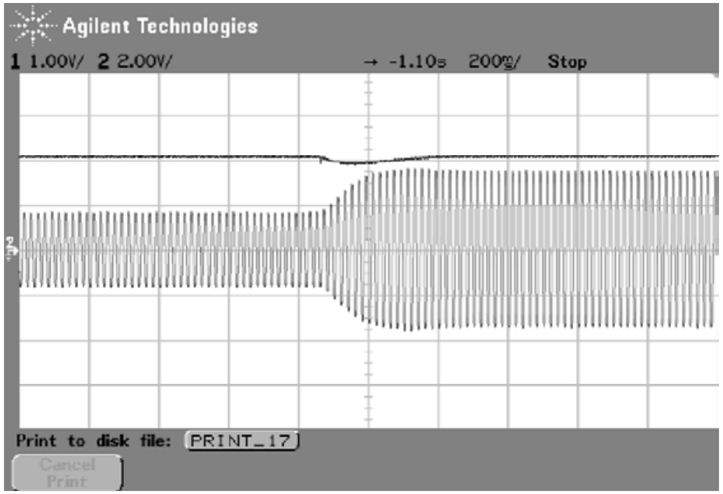

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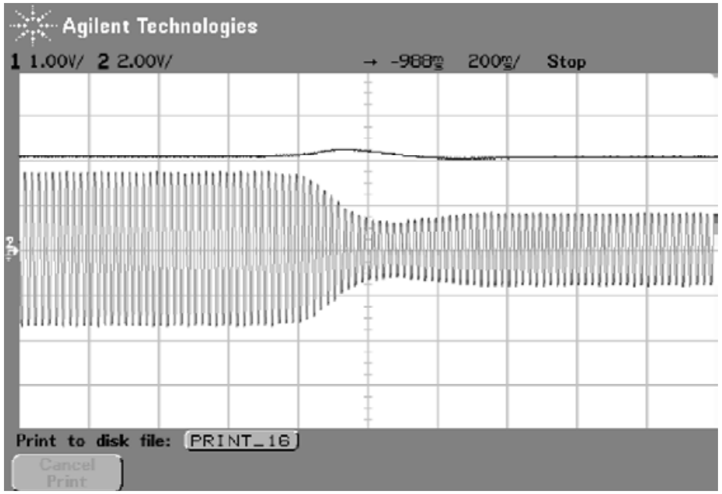
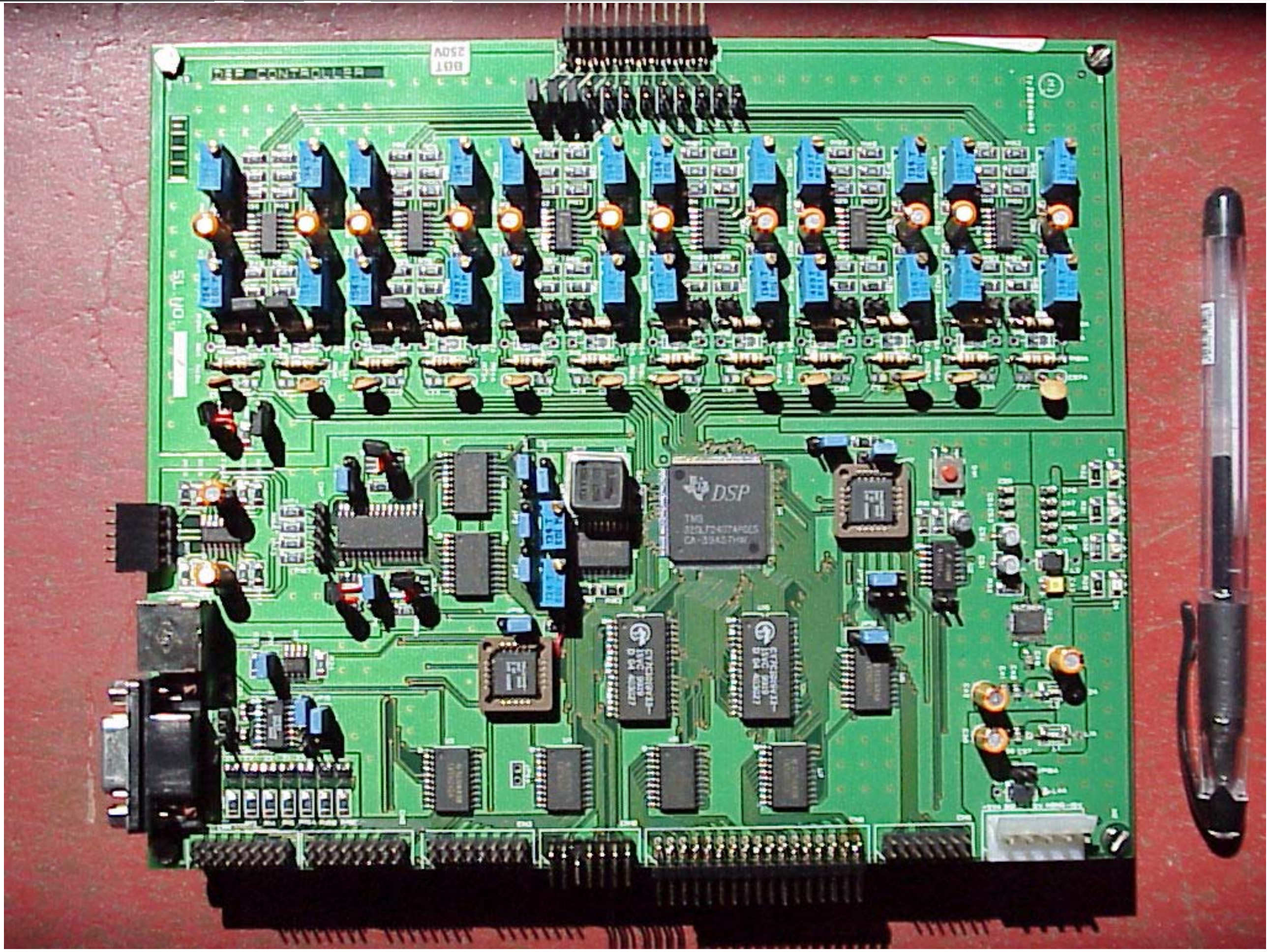


Step change of load from R=300 ohms to R= 1K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Thank You