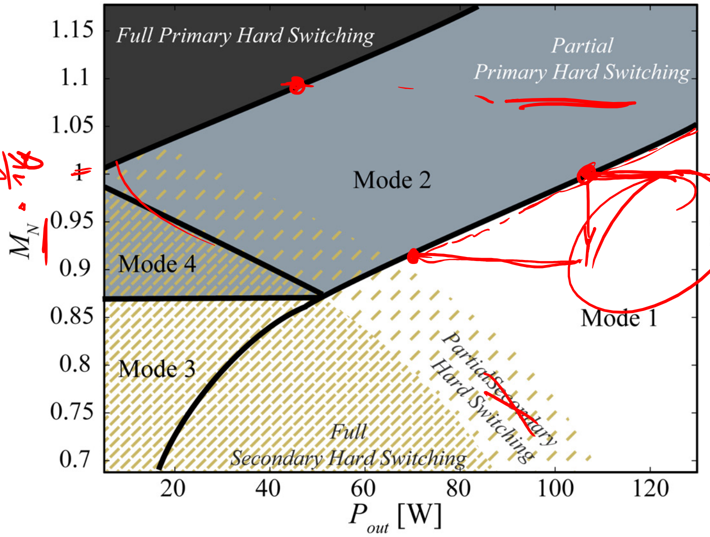
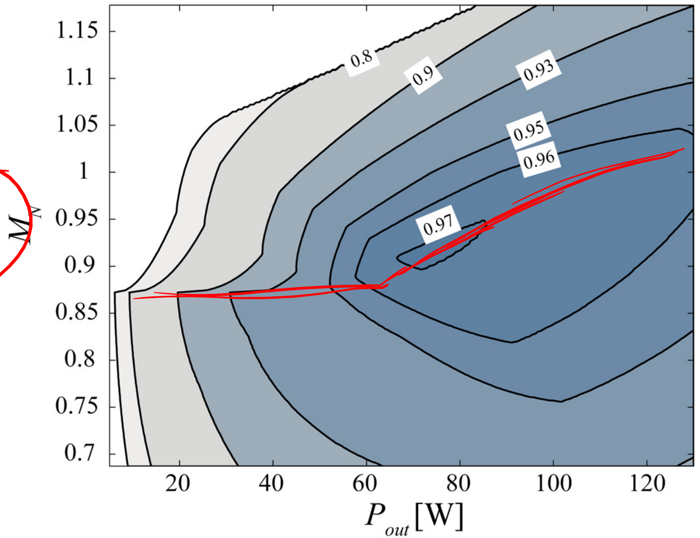
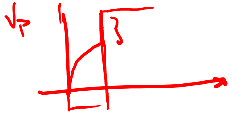
Soft Switching Range with Varying V_{out}







D. Costinett, D. Maksimovic, and R. Zane, “Design and control for high efficiency in high step-down dual active bridge converters operating at high switching frequency,” IEEE Trans. Power Electron., vol. PP, no. 99, p. 1, 2012.

Application Example: Automotive

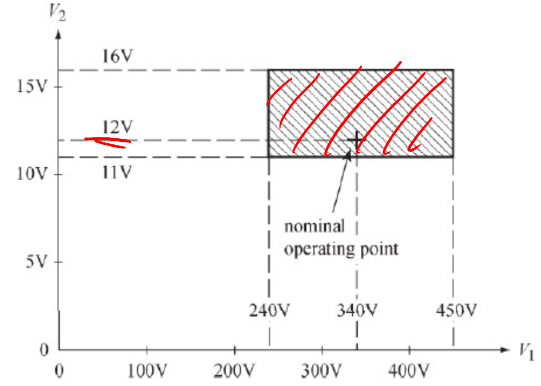


Fig. 1. Converter operating voltage ranges required for automotive application.

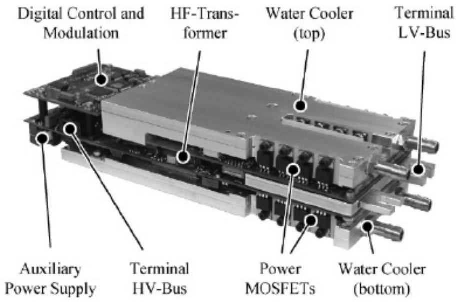
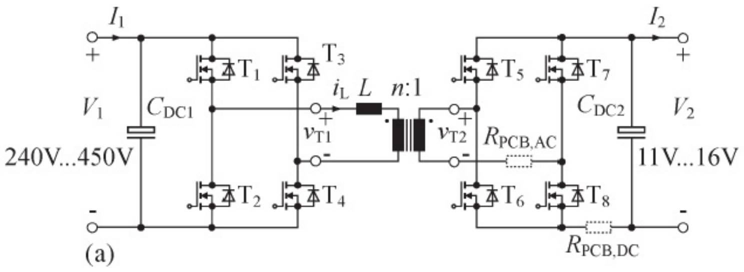


Fig. 3. Automotive DAB converter (273 × 90 × 53 mm).



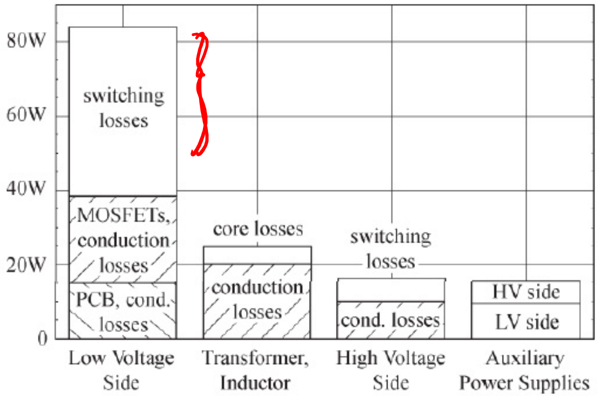


Fig. 13. Calculated distribution of the power losses for operation at V_1 = 340 V, V_2 = 12 V, and P_2 = 2 kW.

*F. Krismer, J.W.Kolar, "Accurate Power Loss Model Derivation of a High-Current Dual Active Bridge Converter for an Automotive Application, IEEE Trans. On Industrial Electronics, March 2010

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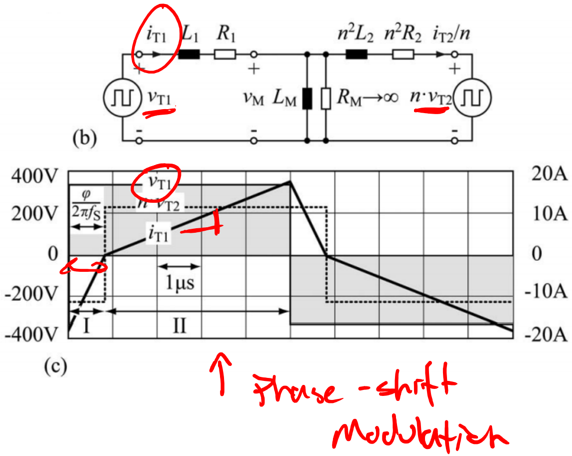
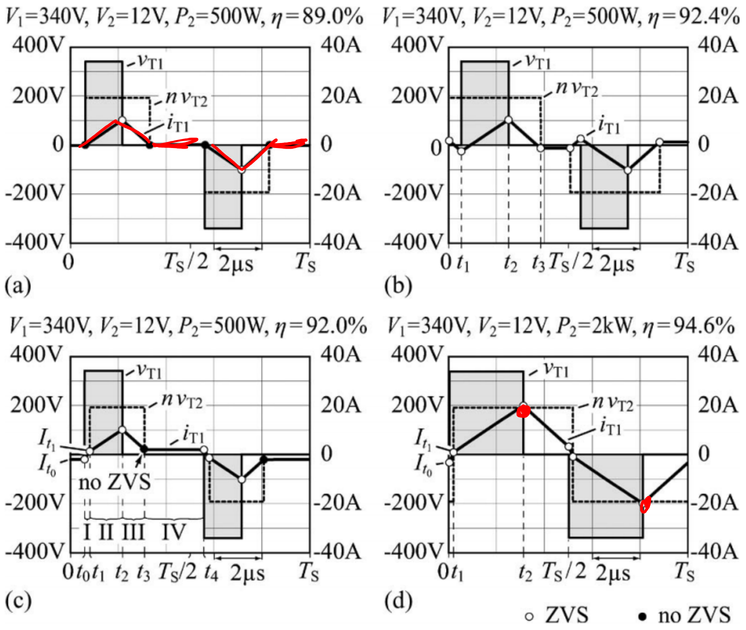
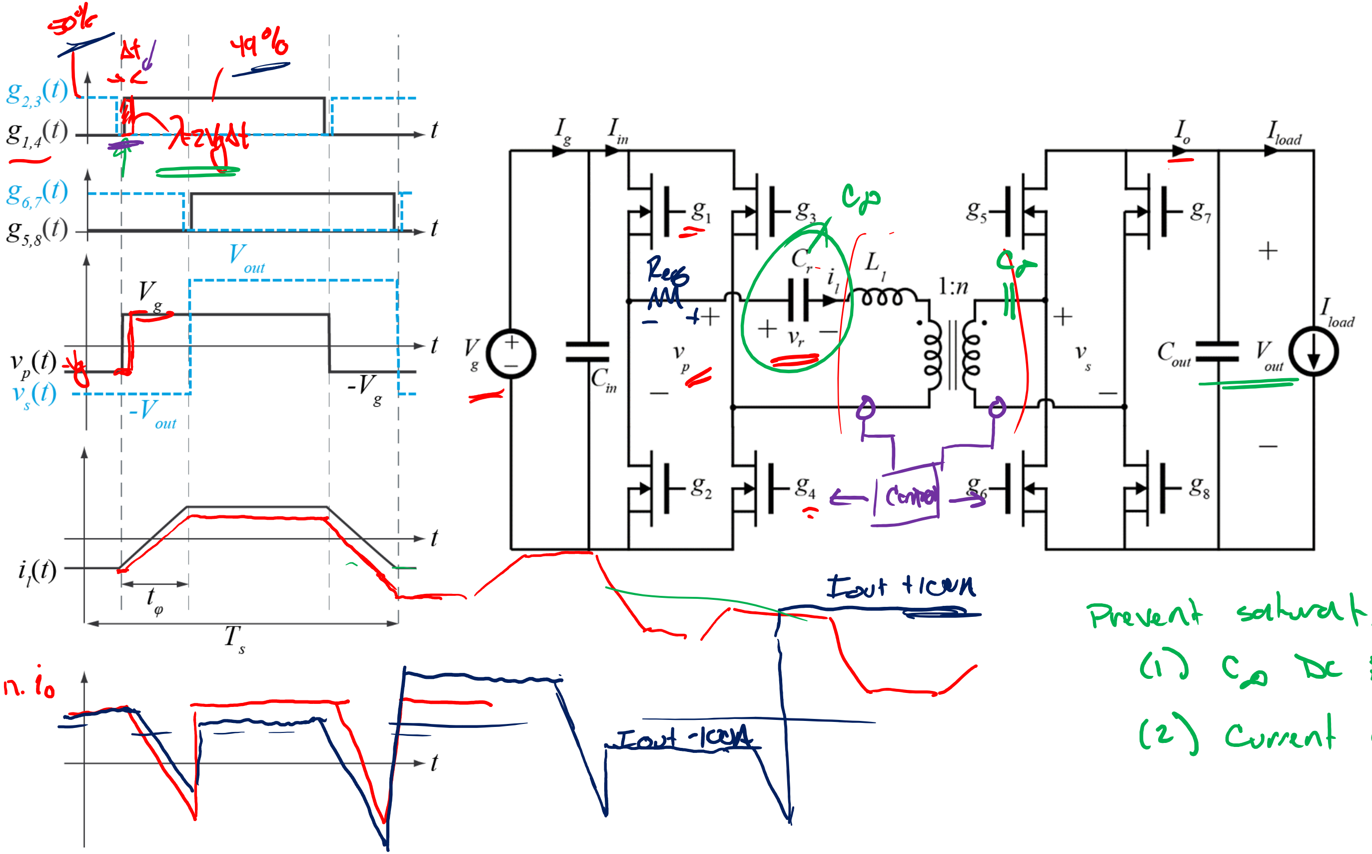
Alternate Modulation Schemes





DAB: Transformer Saturation



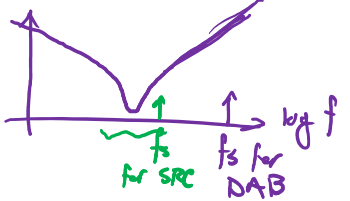
Prevent saturation by

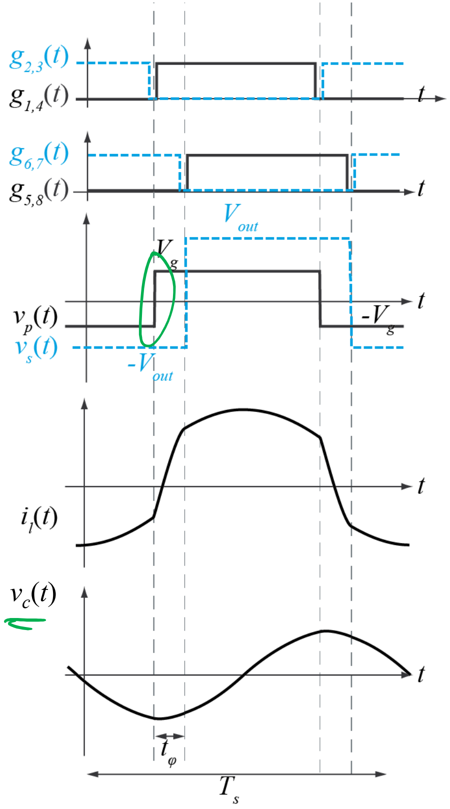
(1) C_p DC blocking cap

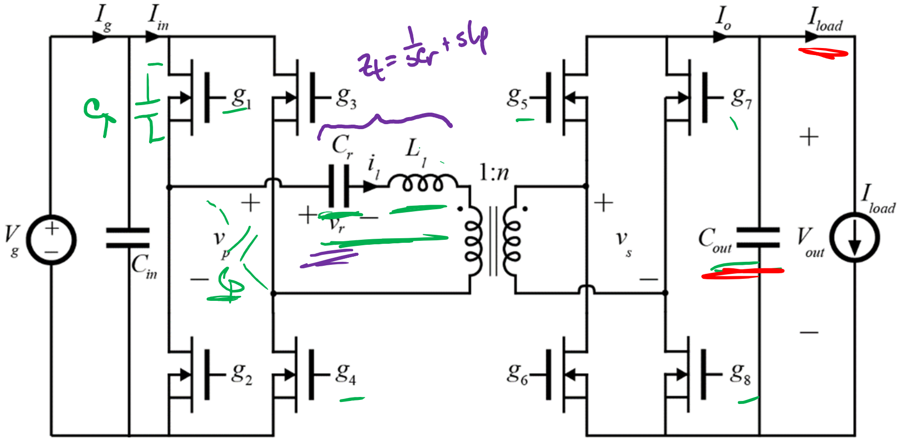
(2) Current control

Series Resonant Converter

DAB: $C_r \rightarrow C_{dc}$

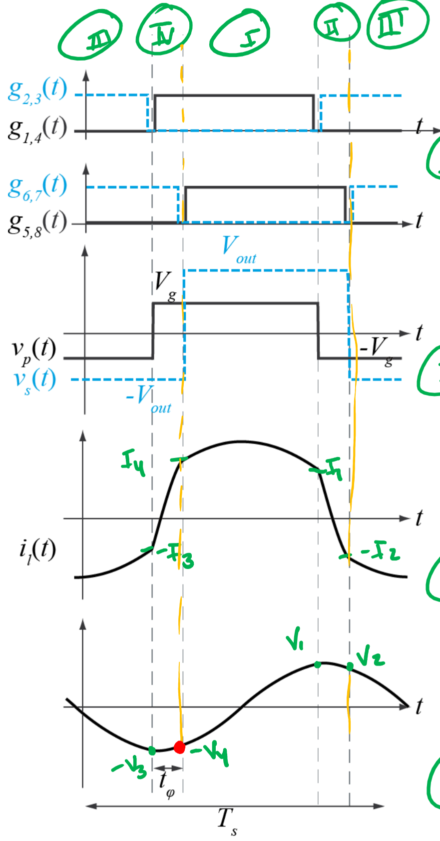


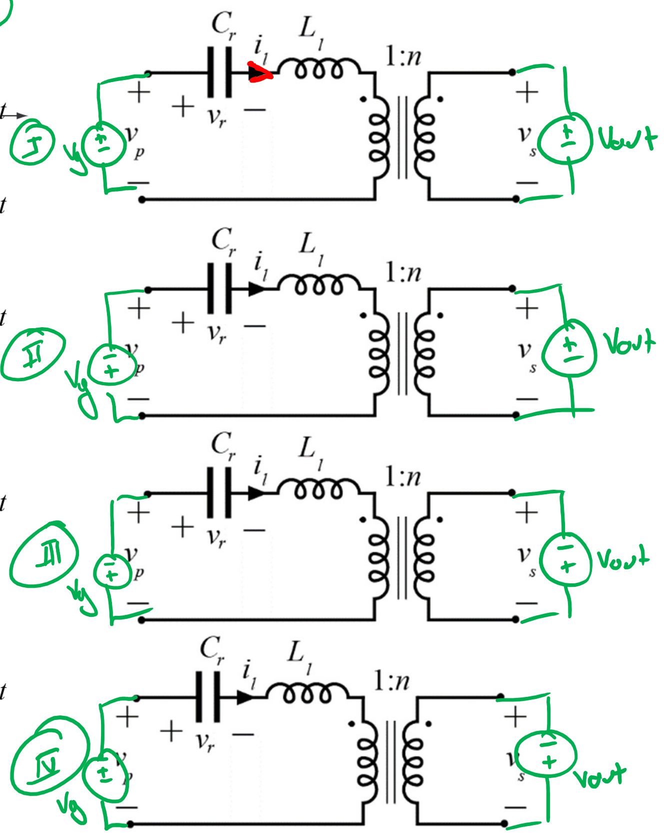




for this model
- Neglect C_p & C_s

Subinterval Equivalent Circuits





$V_{base} = V_g$

Assume: $\boxed{M = n}$

DC solution

$J_{DC} = \emptyset$

$M_{DC} = \dfrac{V_g - \frac{V_{out}}{n}}{V_g} = M_g - M/n = 1 - \frac{M}{n} = \emptyset$

$J_{DC} = \emptyset$

$M_{DC} = -1 - M/n = -2$

$J_{DC} = \emptyset$

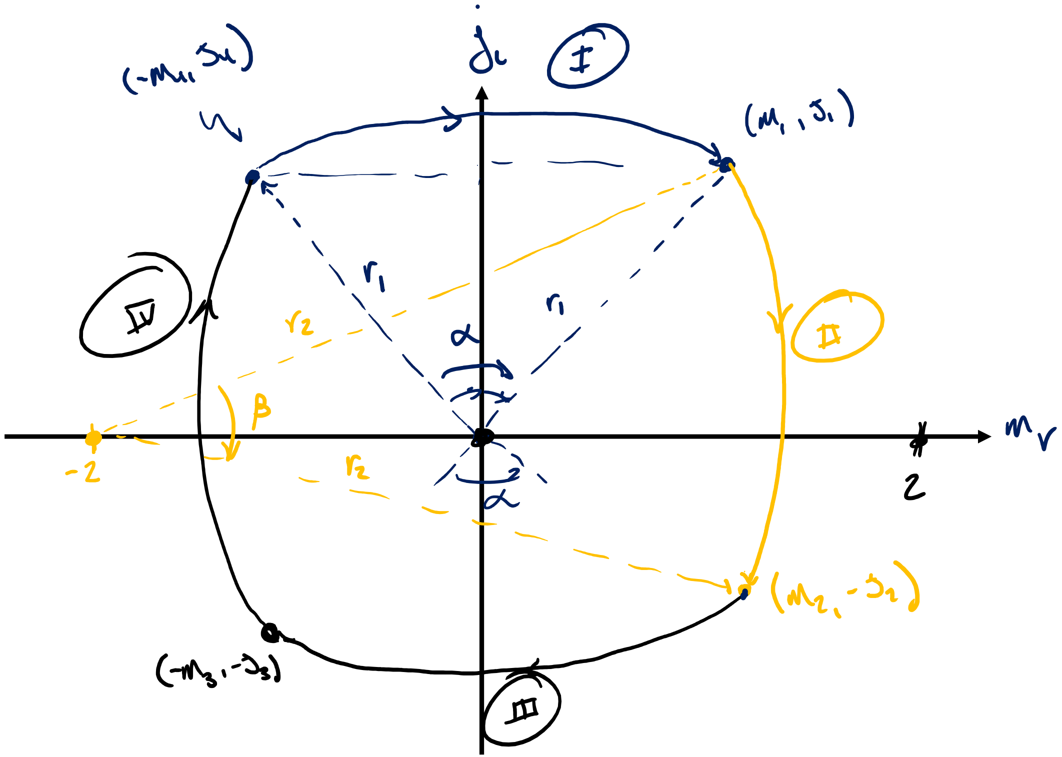
$M_{DC} = -1 + M/n = \emptyset$

$J_{DC} = \emptyset$

$M_{DC} = 1 + M/n = 2$

Complete State Plane – Phase Shift Modulation

(M=n)



State Plane Solution

↓ due to symmetry

Ⅰ $r_1^2 = m_4^2 + j_4^2 = \boxed{m_1^2 + j_1^2 = m_2^2 + j_2^2}$

$$\boxed{\alpha = \tan^{-1}\left(\frac{m_2}{j_2}\right) + \tan^{-1}\left(\frac{m_1}{j_1}\right)}$$

Ⅱ $r_2^2 = \boxed{(m_1+2)^2 + j_1^2 = (m_2+2)^2 + j_2^2}$

$$\boxed{\beta = \tan^{-1}\left(\frac{j_1}{m_1+2}\right) + \tan^{-1}\left(\frac{j_2}{m_2+2}\right)}$$

Period:

$$\frac{T_s}{2} = t_1 + t_2$$

$$\boxed{\frac{\pi}{F} = \alpha + \beta}$$

$$m_1^2 + 4m_1 + 4 + j_1^2 = m_2^2 + 4m_2 + 4 + j_2^2$$

$$(m_1^2 + j_1^2) + 4m_1 = (m_2^2 + j_2^2) + 4m_2$$

$$\left\{\begin{array}{l} 4m_1 = 4m_2 \rightarrow \boxed{m_1 = m_2} \\ (m_1^2 + j_1^2) = (m_2^2 + j_2^2) \rightarrow \boxed{j_1 = j_2} \end{array}\right\} \text{consequence of } m = n$$

Averaging Step

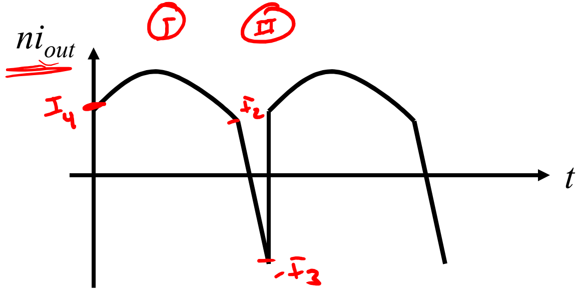
$$n\langle i_o\rangle\Big|_{T_s} = \frac{2}{T_s}\int_0^{T_s/2} i_L(t)\,dt$$

$$= \frac{2}{T_s}\left[q_1 + q_2\right]$$

$$= \frac{2}{T_s}\left[C_r(V_1+V_2) + C_r(V_2-V_1)\right]$$

$$n I_{out} = \frac{2}{T_s}\left[C_r\, 2V_2\right] = \frac{2}{T_s} C_r\, 2V_1$$

$$\boxed{n J_{out} = \frac{F}{\pi}\left[2M_2\right]}$$



Because $m = n_1$ $\quad V_1 = V_2$

Closed-Form Solution

$$J = \frac{F}{\pi} 2 m_1 \qquad \frac{\pi}{F} = \alpha + \beta$$

$$m_1 = \tan\left(\frac{\alpha}{2}\right)\tan\left(\frac{\beta}{2}\right)(2 + m_1)$$

$$m_1 = \frac{2\tan\left(\frac{\alpha}{2}\right)\tan\left(\frac{\beta}{2}\right)}{1 - \tan\left(\frac{\alpha}{2}\right)\tan\left(\frac{\beta}{2}\right)}$$

$$\boxed{J = \frac{F}{\pi}\,\frac{4\tan\left(\frac{\pi}{2F} - \frac{\beta}{2}\right)\tan\left(\frac{\beta}{2}\right)}{1 - \tan\left(\frac{\pi}{2F} - \frac{\beta}{2}\right)\tan\left(\frac{\beta}{2}\right)}}$$

$$\begin{cases} \alpha = 2\tan^{-1}\left(\dfrac{m_1}{J_1}\right) \\ \beta = 2\tan^{-1}\left(\dfrac{J_1}{2 + m_1}\right) \end{cases}$$

$$\begin{cases} m_1 = \tan\left(\dfrac{\alpha}{2}\right) J_1 \\ J_1 = \tan\left(\dfrac{\beta}{2}\right)(2 + m_1) \end{cases}$$

$F \rightarrow$ given by hardware & f_s

$\beta \rightarrow$ normalized phase shift