



HiGENs FDA7000

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d_q

DSP



Oct. 05, 2005
Changwon, Korea

1.



19

1830 : (Jacobi)

1880 : (Ferraris, Tesla)

60%

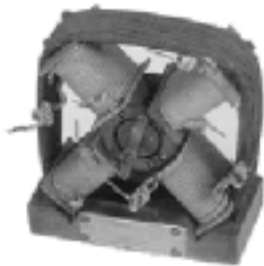
80%

(, , , ,)

(Battery)

,

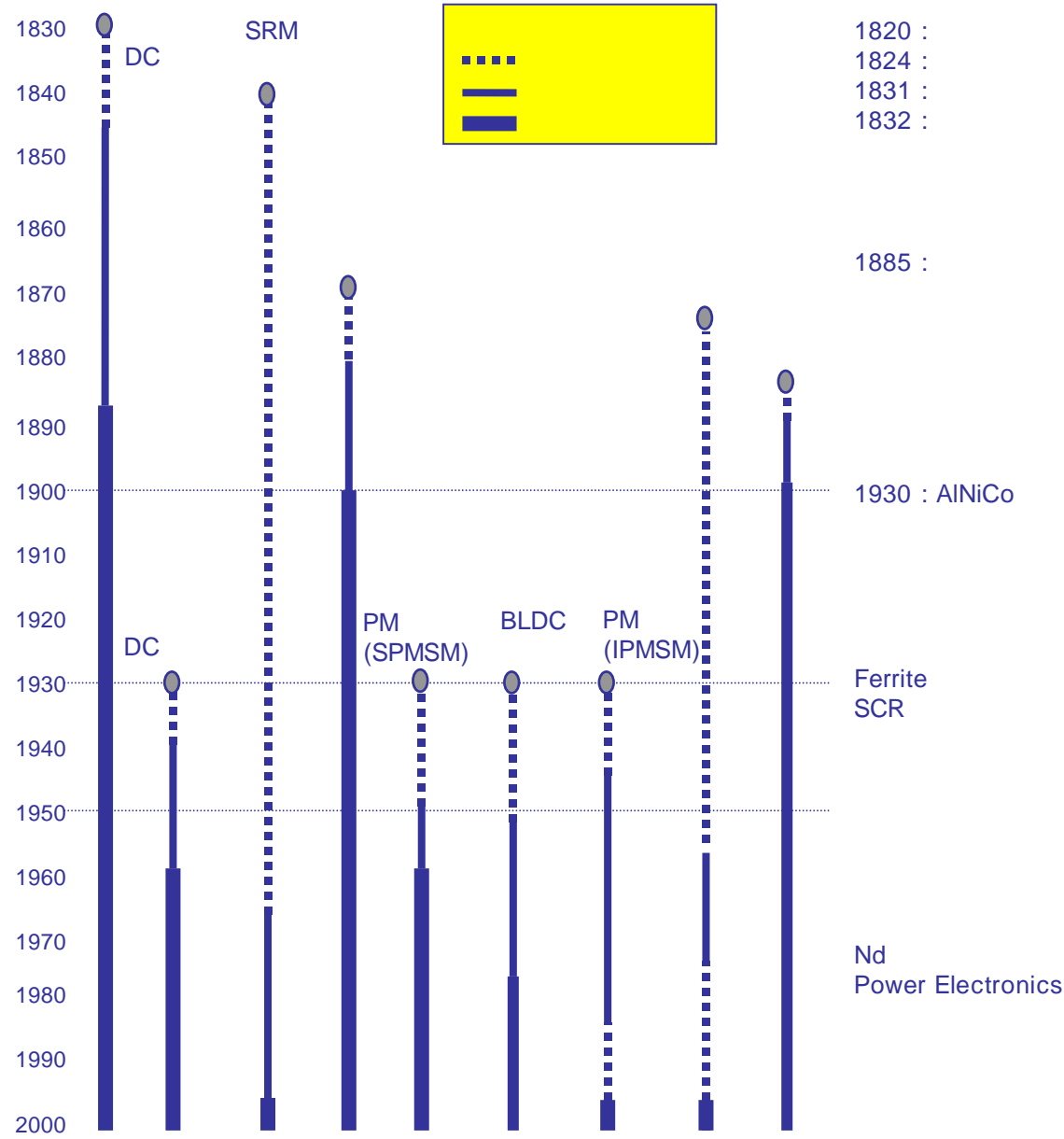
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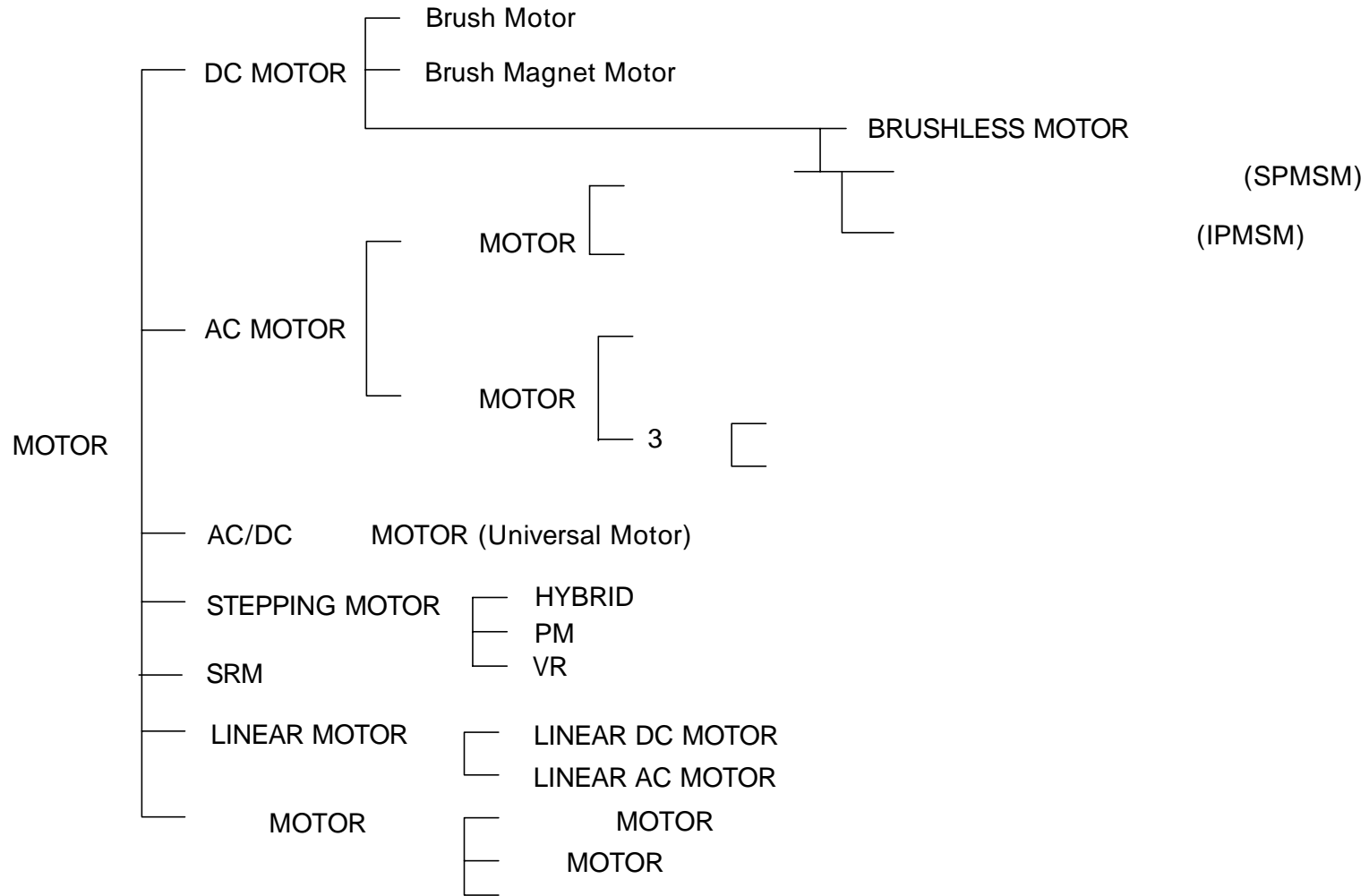
1.1



BRINGING SOLUTIONS TOGETHER



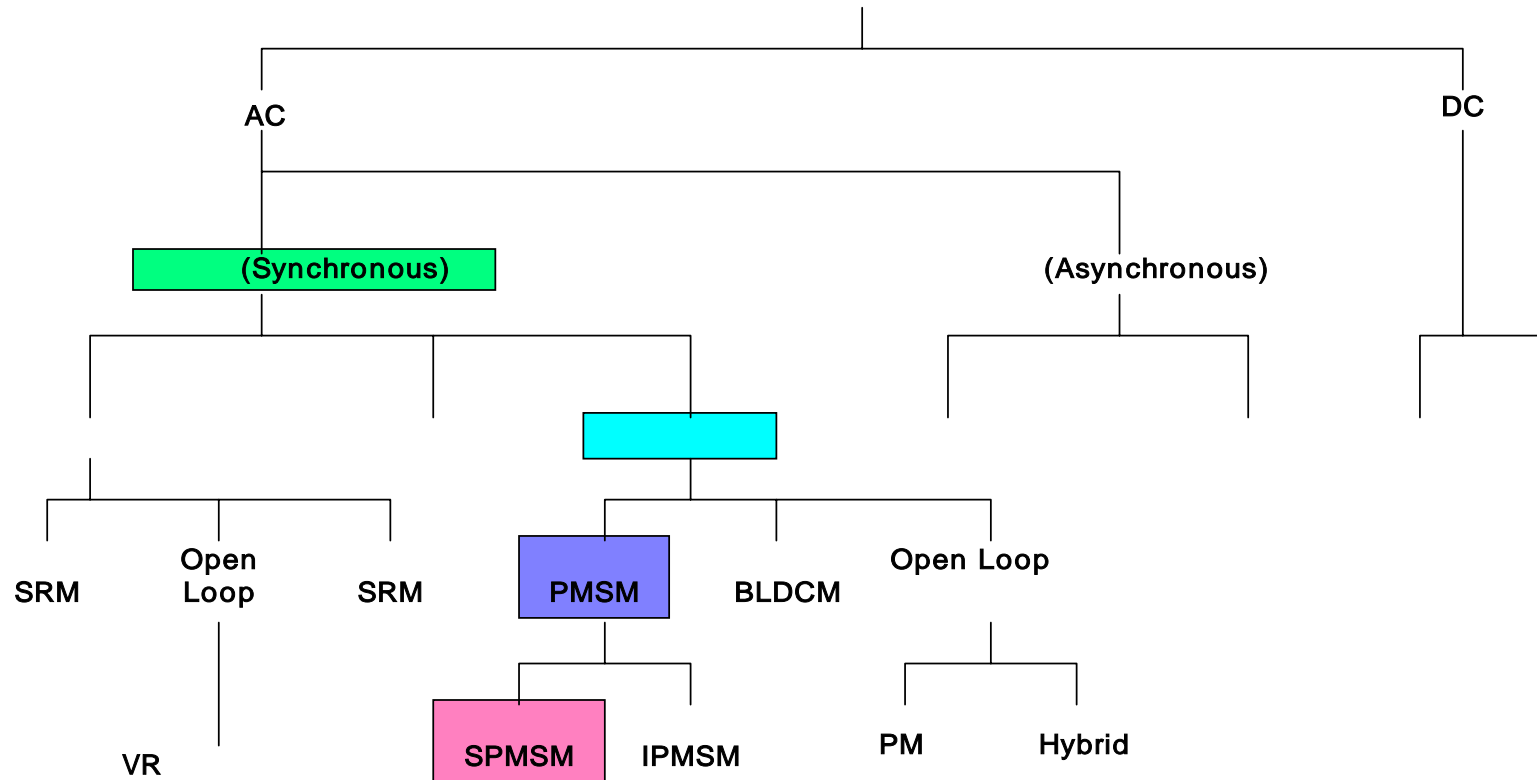
1.2



1.3



- 1)
- 2)
- 3)
- 4)
- 5)



1.4 _ Linear Electric Actuator

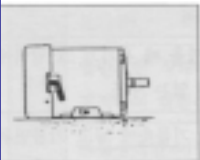
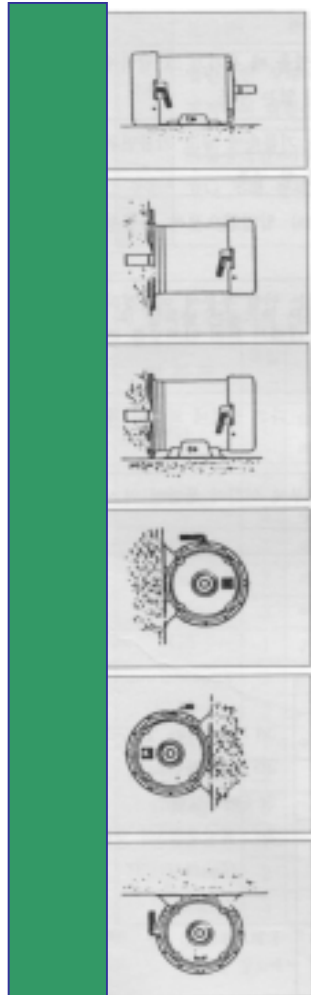
BRINGING SOLUTIONS TOGETHER



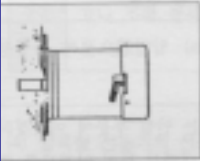
- 1) LSM , 20kgf.m, 4m/s
- 2) X-Y LPM
- 3) ,

		電磁力	
Actuator	LIM		Pulse
Solenoid	LDM		Head
Pump	LPM		X-Y Plotter 2
	LOA		Air Compressor
	LES		Type Writer Key
	LED		Pump
	LSM		
	LHM	+	Turn Table

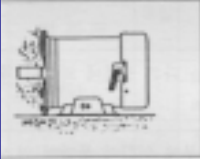
Ref/ : :



B3
Base Plate



B5
Flange



B3/B5(B35)
Base Plate Flange



B6
Base Plate ()



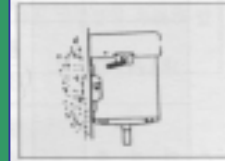
B7
Base Plate ()



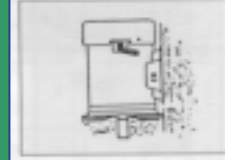
B8
Base Plate



V1
Flange



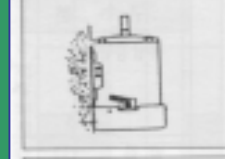
V5
Base Plate ()



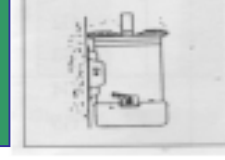
V1/V5(V15)
Base Plate ()



V3
Flange



V6
Base Plate



V3/V6(V36)
Base Plate
Flange

1.5

&

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[]

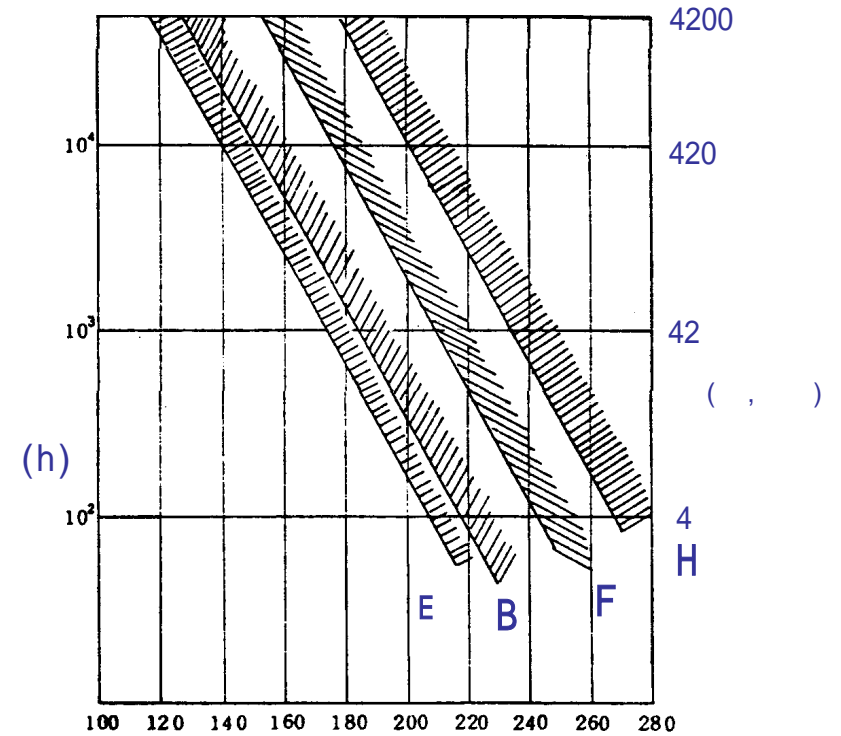
E	75deg	1) 40
B	80deg	2) , , 가
F	105deg	
H	125deg	3) () 55deg

= , ,

[]

熱	+
	가

[]



1.5



(2) / (1)

		15. 内 Drop of Water		60. 内 Spraying water		Splashing Water	Water Jet	Ship's Deck	immersion	submersible
		1	2	0	2	3	4	5	6	7
	0	IP00				X	X	X	X	
50mm内	1	IP10	IP12				X	X	X	
12mm内	2	IP20	IP22	IP23	IP24		X	X	X	
1mm内	4	X			IP44					
	5	X			IP54	IP55	IP56			IP58

- IP : International Protection,

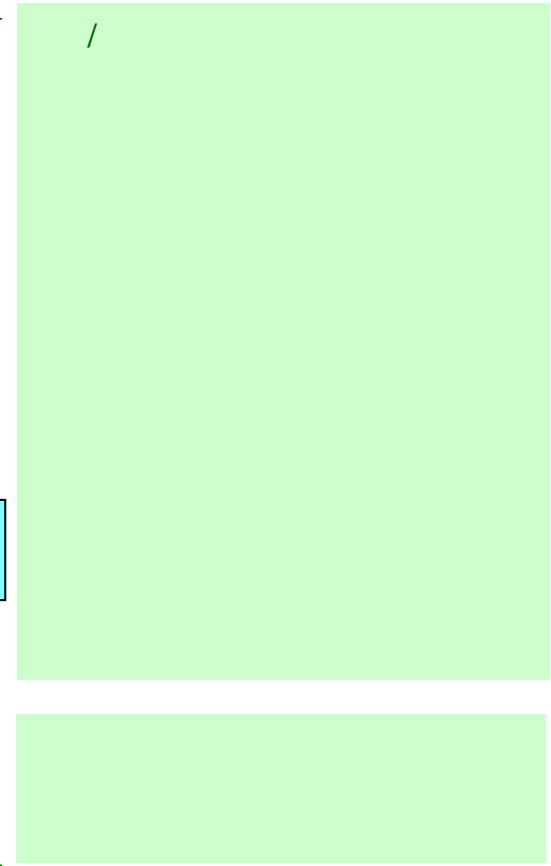
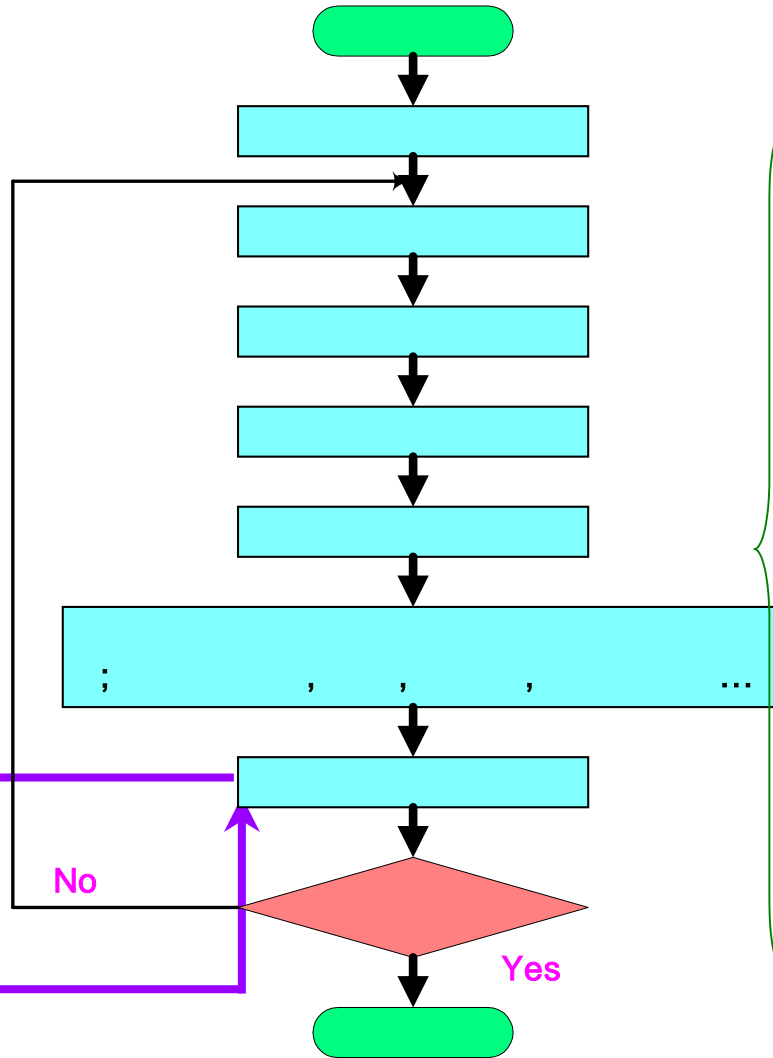
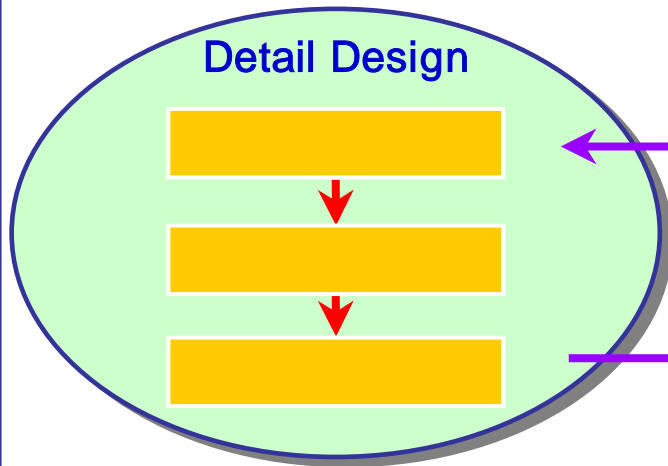
IEC34 -5

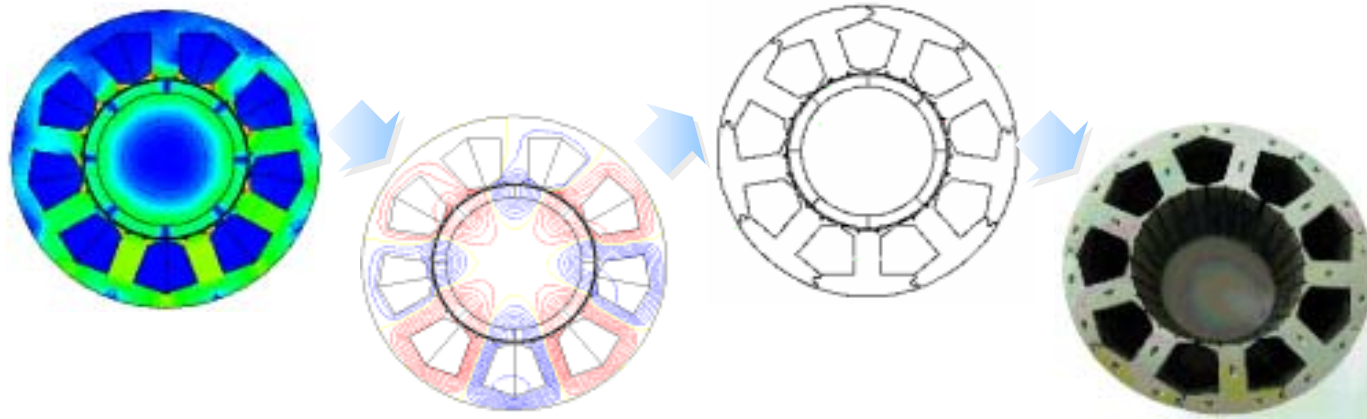
- OTIS.LG

2.

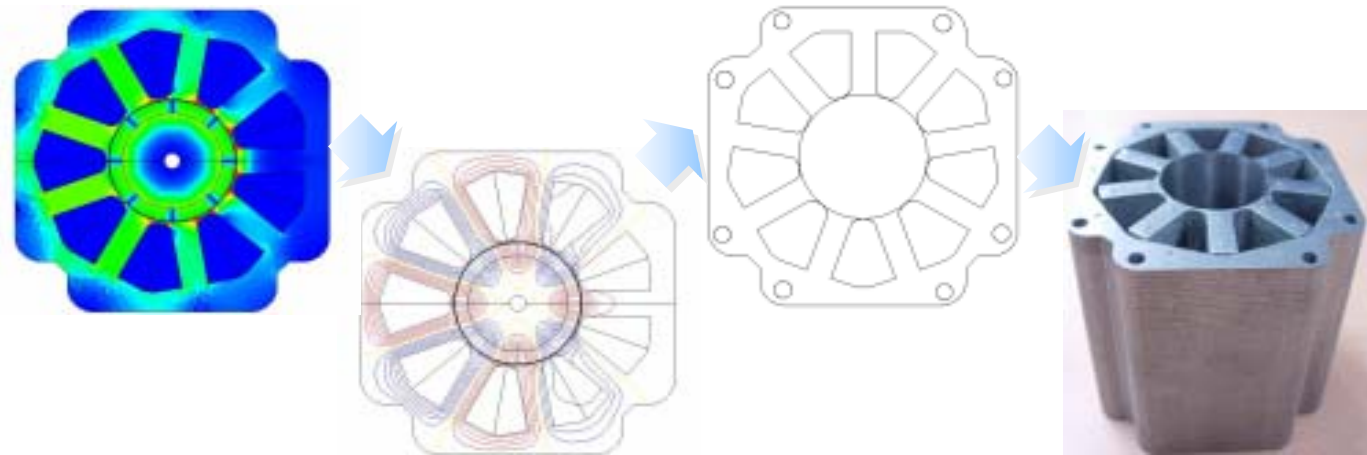


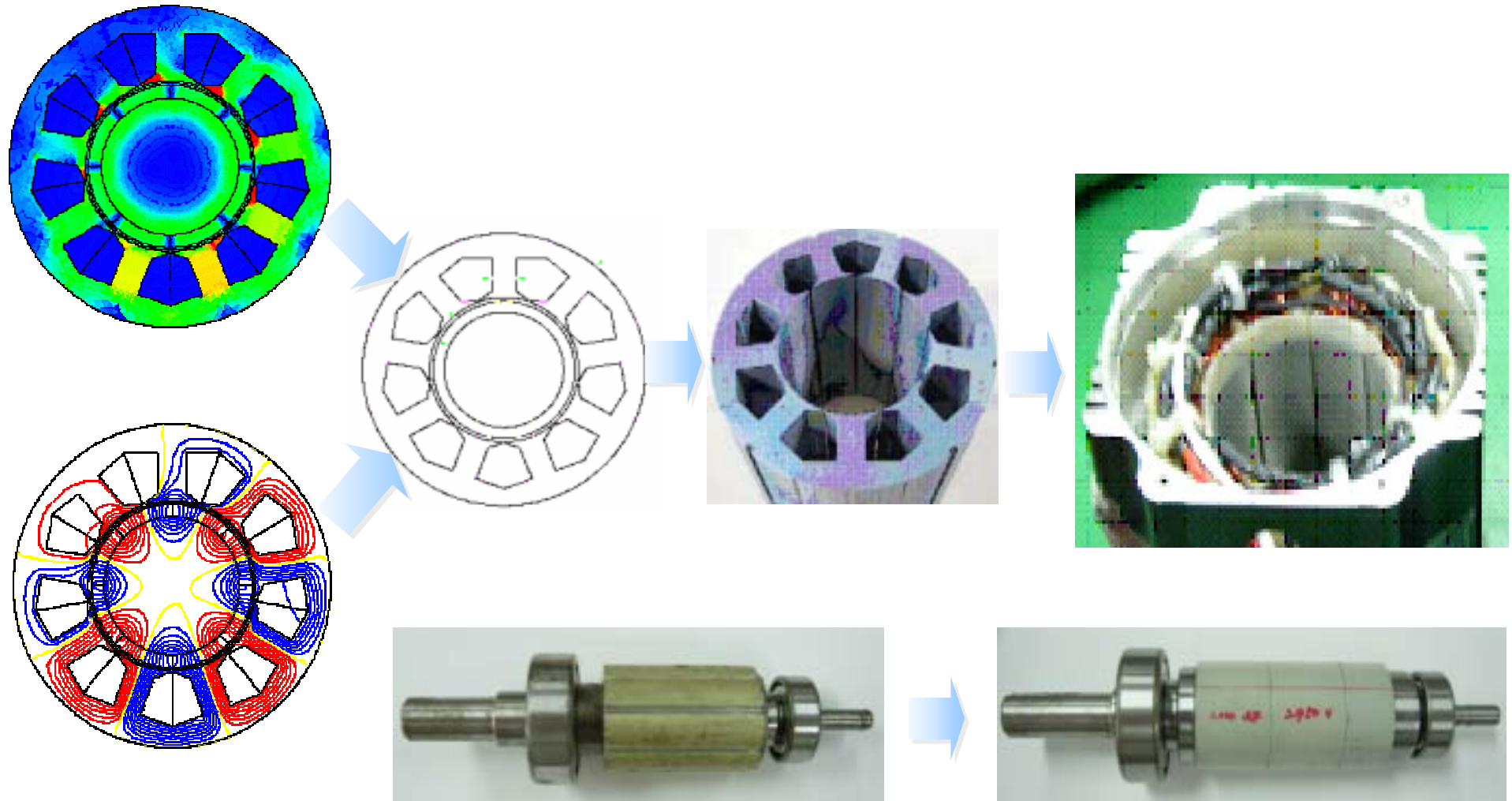
- 1.
- 2.





BMC Mold







?? (Alnico Magnet)

(Cast)
(Sinterd)

- ◆ High remanent flux density
- ◆ Low coercive force
- ◆ Low temperature dependence
- ◆ Low resistance to demagnetization
- ◆ High cost

??? (Ferrite Magnet)

(Ba)
(Sr)

- ◆ Low remanent flux density
- ◆ High coercive force
- ◆ high temperature dependence
- ◆ Lower resistance to demagnetization
- ◆ Very cheap and plentiful
- ◆ Widely used (more than 90%)

?? (Rare -Earth magnet)

(Sm -Co)
(Nd -Fe -B)

- ◆ Highest remanent flux density
- ◆ Highest coercive force
- ◆ Relatively low cost
- ◆ Low maximum operating temperature
- ◆ High remanent flux density
- ◆ High coercive force
- ◆ Extremely high cost

??? (Bonded Magnet)

(Ferrite)
(Alnico)
(Nd -Fe -B)
(Sm -Co)

3.



가

Adjustable Speed Drives (Power Electronics)

Energy Saving : (Pump), (Compressor)
: (Precision Motion Control)
: (Wind -Electric Systems)
(Hybrid -Electric Vehicles)

3.1 Electric Drives

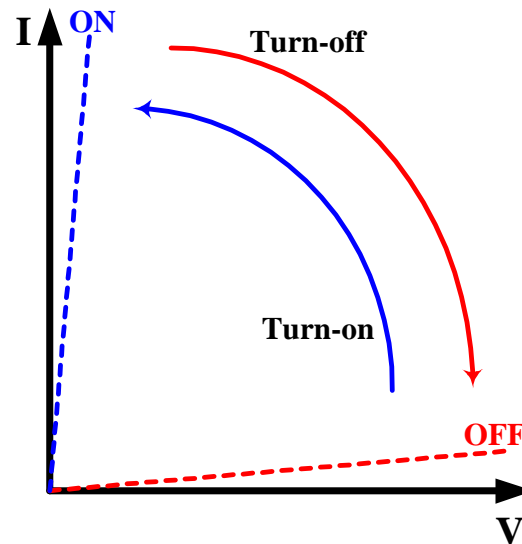
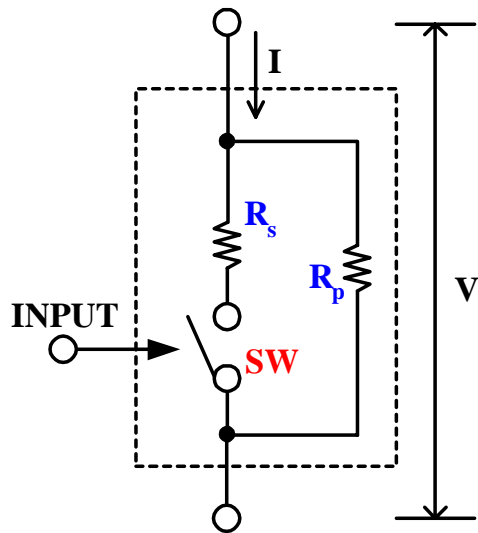
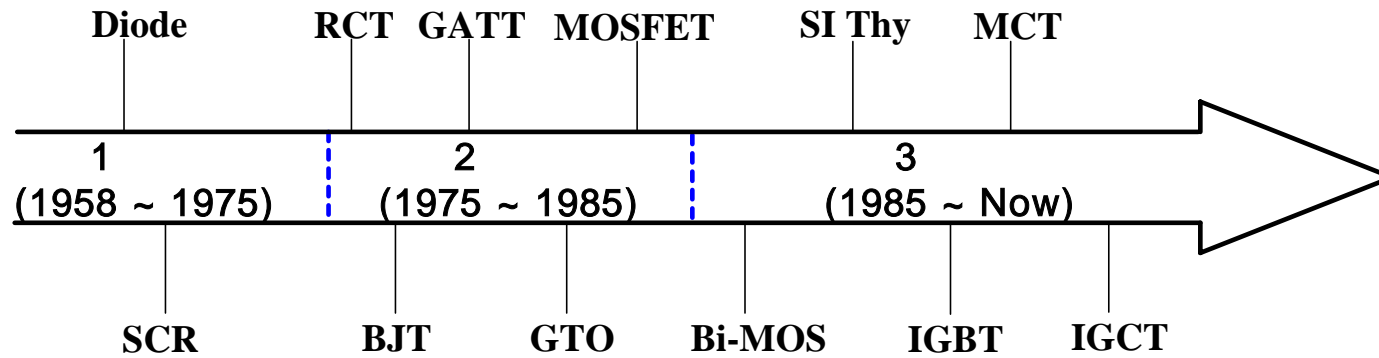
1.3 Motion System Performance Comparison`11

	V/f IM Drive	Vector Controlled IM Drive(servo)	Flux Vector Control	PM Servo
Power Range	0.5 ~ 500 HP	0.5 ~ 500 HP	3 ~ 500 HP	0.4 ~ 8 HP
Speed Control Range	1:20 ~ 1:40	1:200 ~ 1:3000	1:100	1:5000
Speed Control Accuracy	$\pm 2 \sim \pm 3\%$	$\pm 0.5\%$ ($\pm 0.01\%$ with rotor time constant comp.)	$\pm 0.5\%$ ($\pm 0.1\%$ with rotor time constant comp.)	0.03%
Frequency Response	1 ~ 3 Hz	60 ~ 100Hz	20 ~ 50Hz	100 ~ 150Hz
Peak Torque	120 ~ 150%	180 ~ 330%	250%	180 ~ 250%

-
- ac 가 (dc)
- 가 .

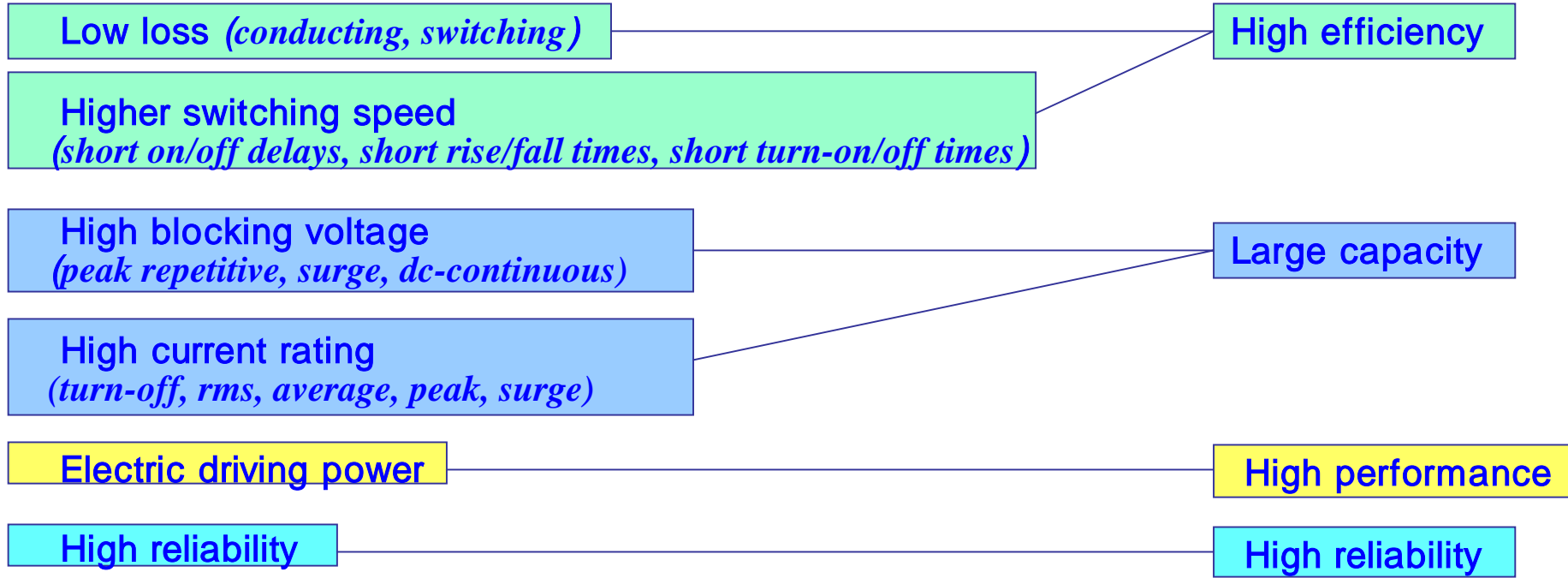
3.2

BRINGING SOLUTIONS TOGETHER



- 가
- Current
- Blocking voltage
- Saturation voltage
- Switching frequency
- Temperature

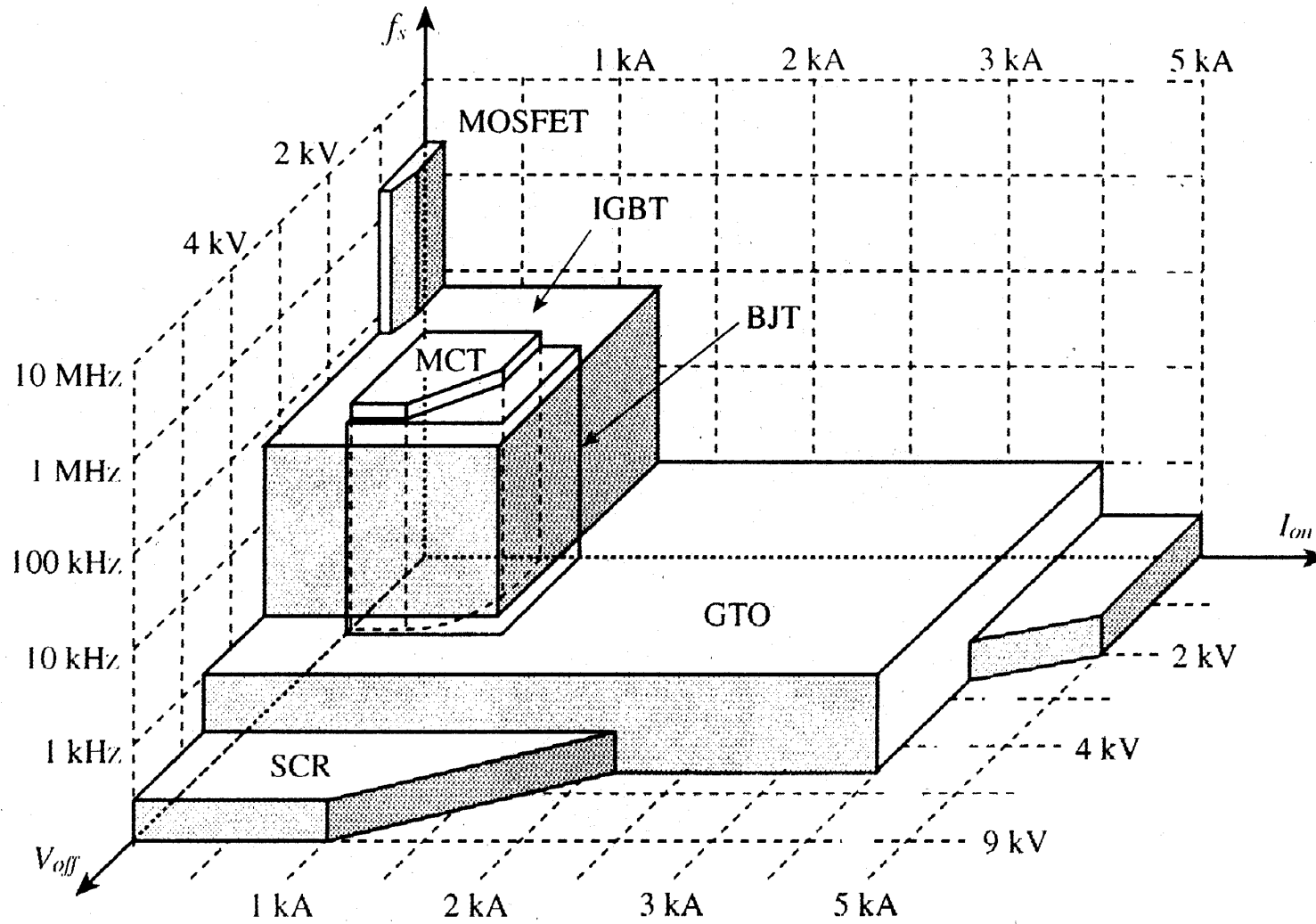
3.3



-
- 가 :
- 가 : SCR
- 가 : GTO, BJT, MOSFET, IGBT, MCT, IGCT

3.4

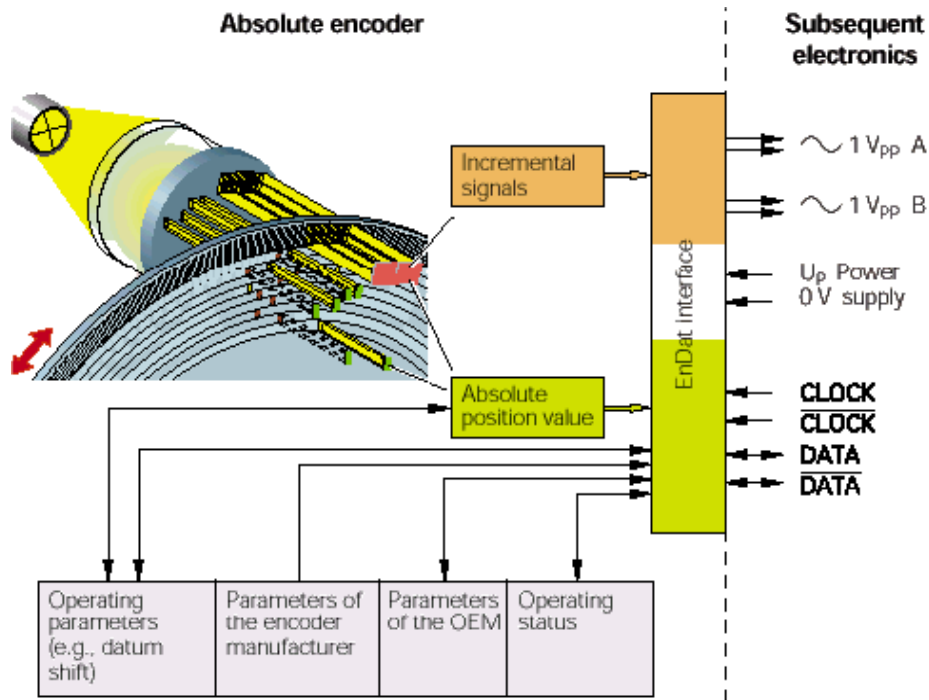
BRINGING SOLUTIONS TOGETHER



4.



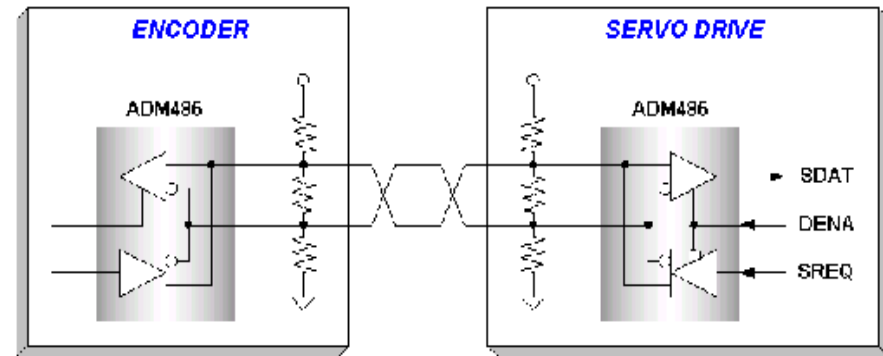
ABS



ADVANTAGES

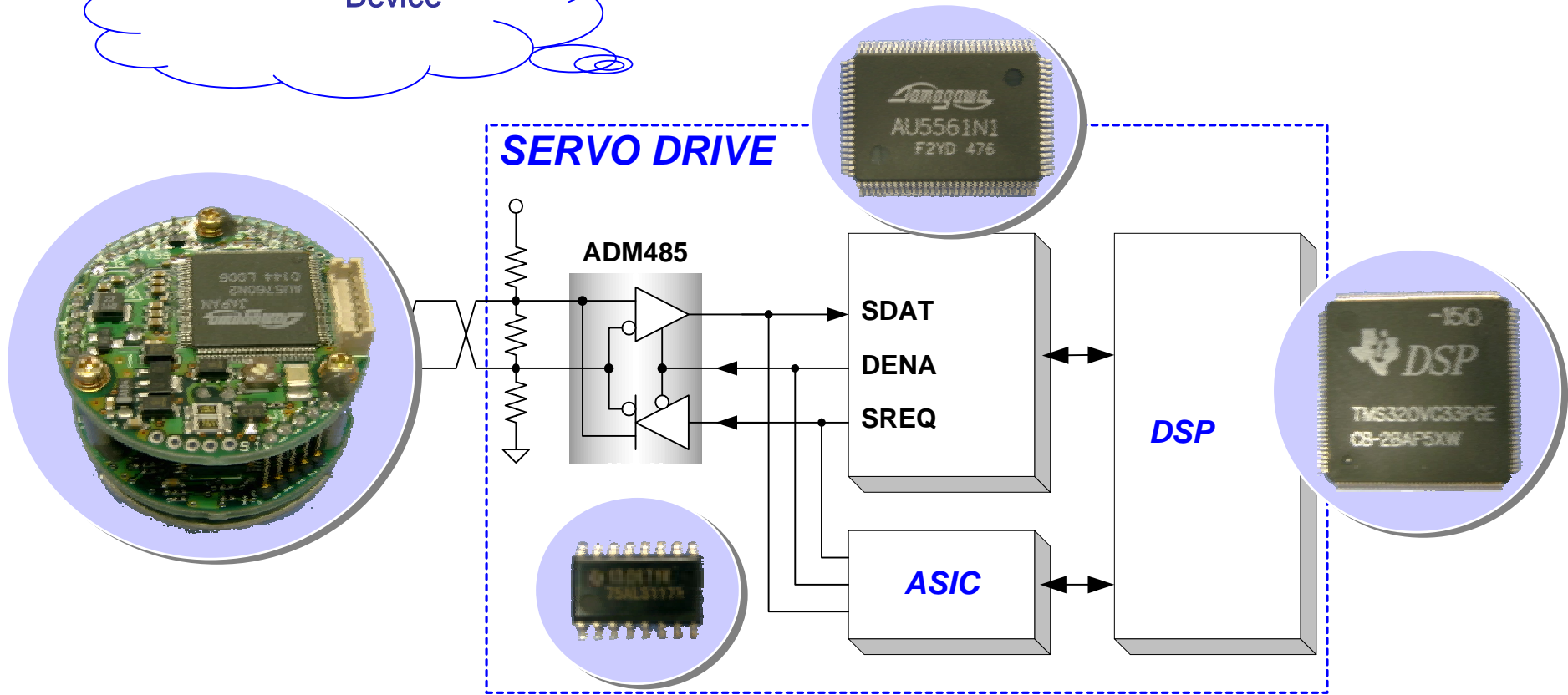
가

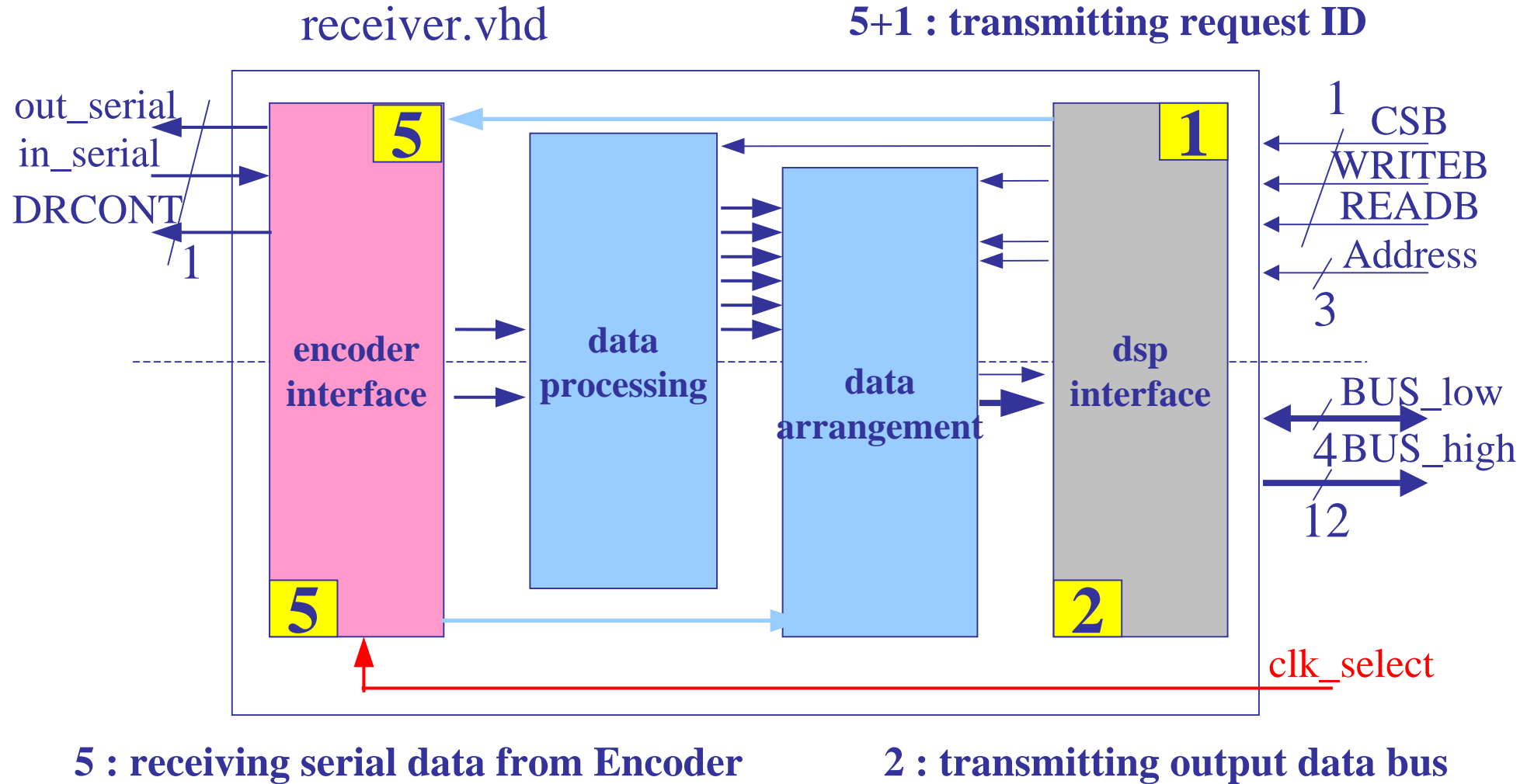
DISADVANTAGES





Device





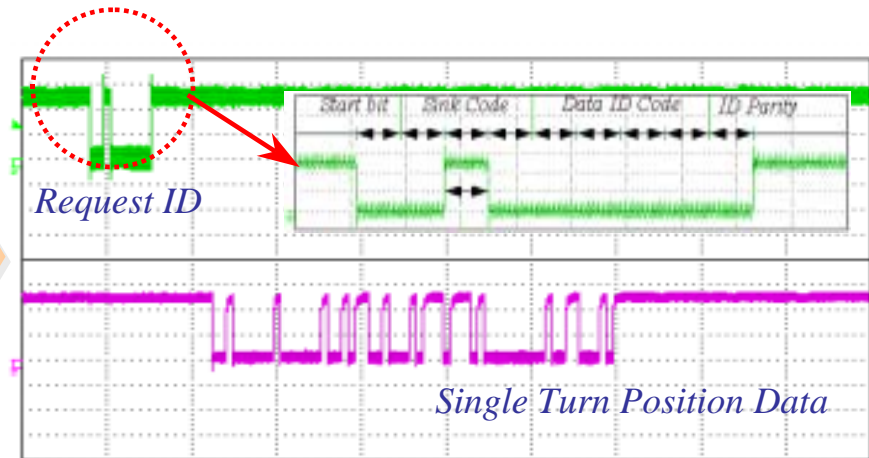
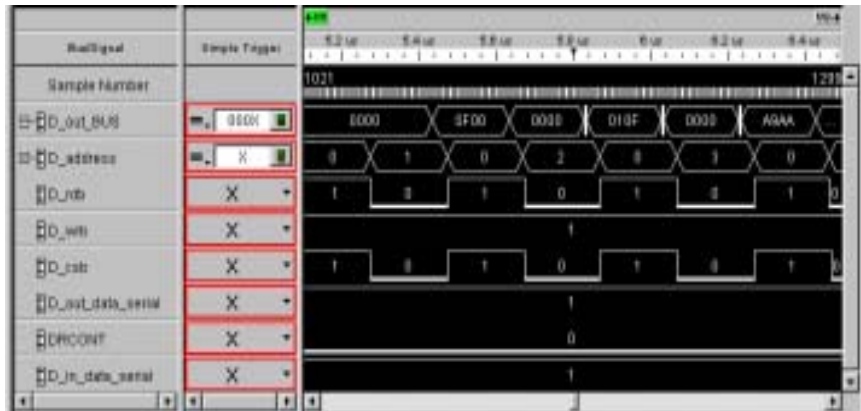
4.3

BRINGING SOLUTIONS TOGETHER

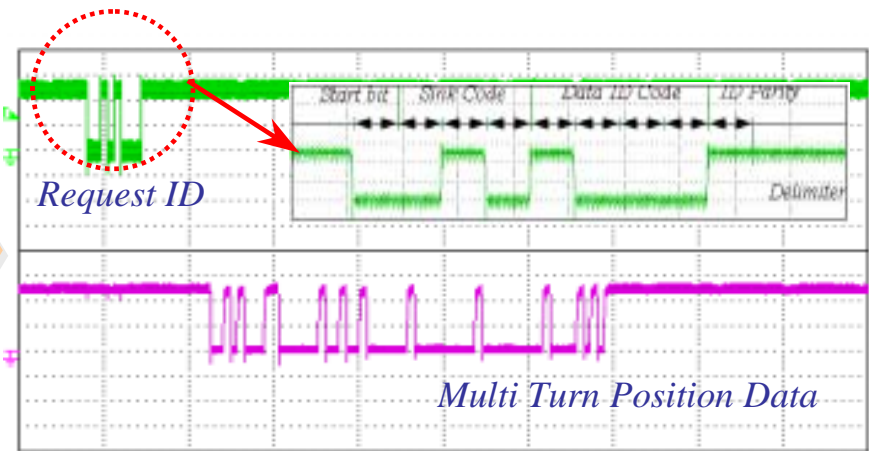


ID

Data Waveform (ID0) : Receiver → DSP



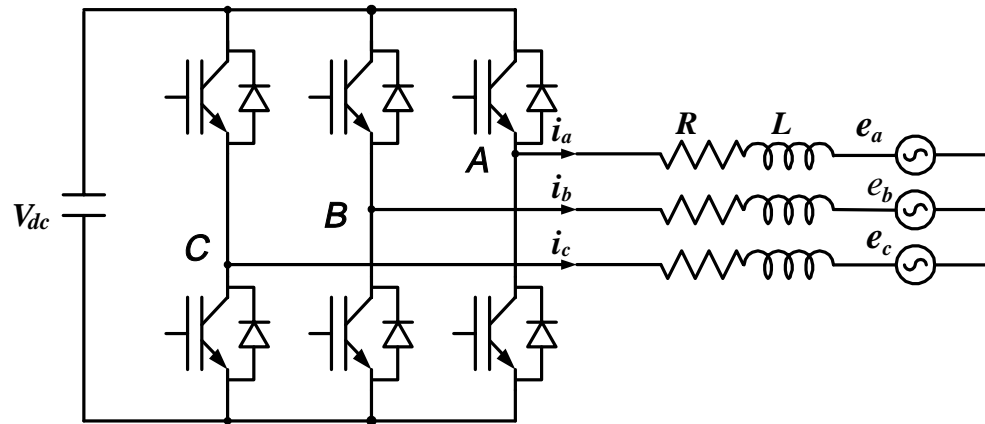
Data Waveform (ID1) : Receiver → DSP



5.3

d-q

BRINGING SOLUTIONS TOGETHER



- $$v_{abc} = Ri_{abc} + L \frac{d}{dt} i_{abc} + e_{abc} \Rightarrow \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R + pL & 0 & 0 \\ 0 & R + pL & 0 \\ 0 & 0 & R + pL \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

• 3 d-q :

- $T(0)$

$$T(0) \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = T(0) \begin{bmatrix} R + pL & 0 \\ 0 & R + pL \end{bmatrix} T^{-1}(0) T(0) \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + T(0) \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

→ $\begin{bmatrix} v_q^s \\ v_d^s \end{bmatrix} = \begin{bmatrix} R + pL & 0 \\ 0 & R + pL \end{bmatrix} \begin{bmatrix} i_q^s \\ i_d^s \end{bmatrix} + \begin{bmatrix} e_q^s \\ e_d^s \end{bmatrix}$

• d-q

d-q

BRINGING SOLUTIONS TOGETHER



-

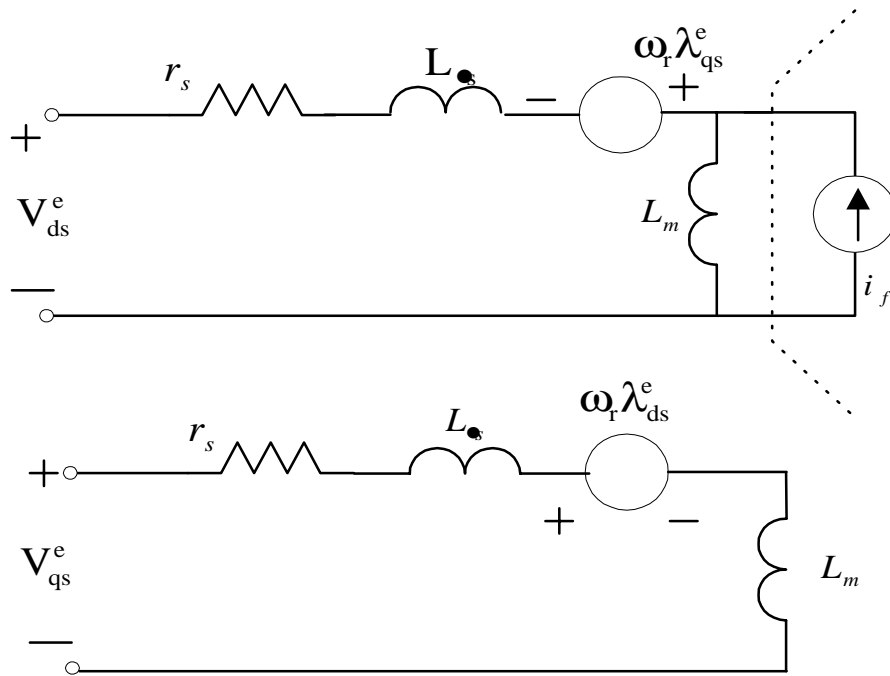
$R(\theta)$

$$R(\theta) \begin{bmatrix} v_q^s \\ v_d^s \end{bmatrix} = R(\theta) \begin{bmatrix} R + pL & 0 \\ 0 & R + pL \end{bmatrix} R^{-1}(\theta) R(\theta) \begin{bmatrix} i_q^s \\ i_d^s \end{bmatrix} + R(\theta) \begin{bmatrix} e_q^s \\ e_d^s \end{bmatrix}$$

\rightarrow

$$\begin{bmatrix} v_q^e \\ v_d^e \end{bmatrix} = \begin{bmatrix} R + pL & \omega L \\ -\omega L & R + pL \end{bmatrix} \begin{bmatrix} i_q^e \\ i_d^e \end{bmatrix} + \begin{bmatrix} e_q^e \\ e_d^e \end{bmatrix}$$

5.1



가

$$P_{out} = \frac{3}{2}(V_{ds}^e i_{ds}^e + V_{qs}^e i_{qs}^e)$$

$$= \frac{3}{2} R_s (i_{ds}^{e2} + i_{qs}^{e2}) + \frac{3}{2} \frac{L_s}{2} \frac{d}{dt} (i_{ds}^{e2} + i_{qs}^{e2}) + \frac{3}{2} \omega_r \phi_f i_{qs}^e$$



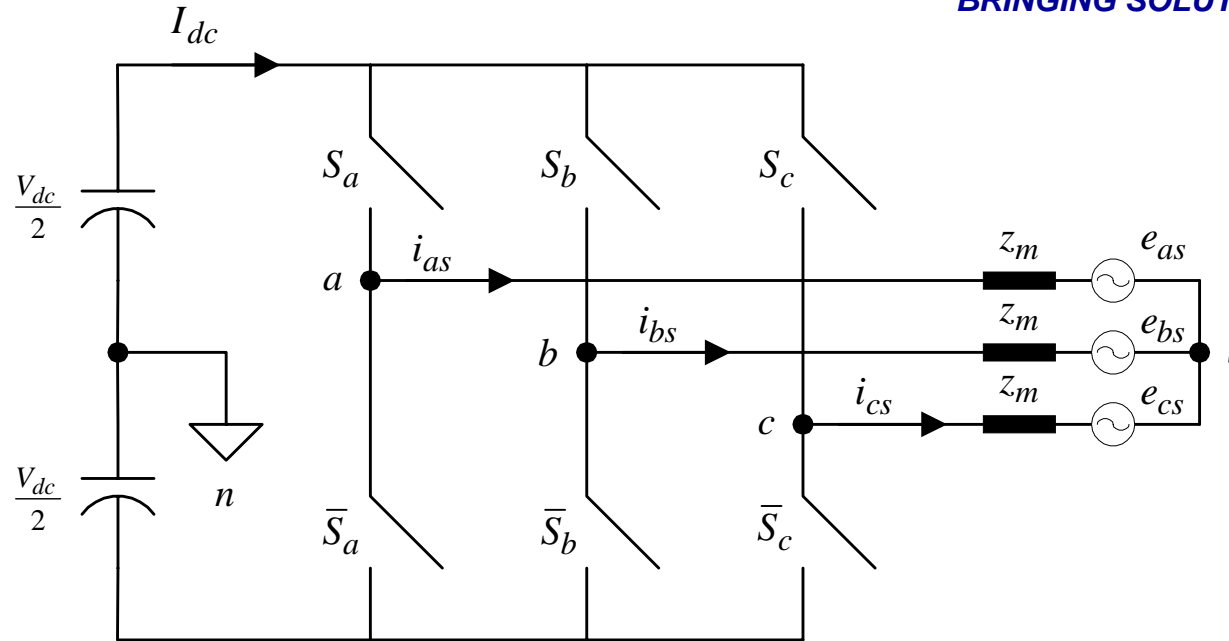
$$\frac{3}{2} \omega_r \phi_f i_{qs}^e = T_e \omega_{rm}$$



$$\omega_r = \frac{P}{2} \omega_{rm}$$

$$T_e = \frac{3}{2} \frac{P}{2} \phi_f i_{qs}^e = K_T i_{qs}^e$$

6. 3



$$\begin{aligned}
 V_{an} &= V_{as} + V_{sn} \\
 V_{bn} &= V_{bs} + V_{sn} \\
 V_{cn} &= V_{cs} + V_{sn}
 \end{aligned}$$

↙ ↑ ↘

$$V_{an} = \frac{V_{dc}}{2} (2S_a - 1)$$

$$V_{bn} = \frac{V_{dc}}{2} (2S_b - 1)$$

$$V_{cn} = \frac{V_{dc}}{2} (2S_c - 1)$$

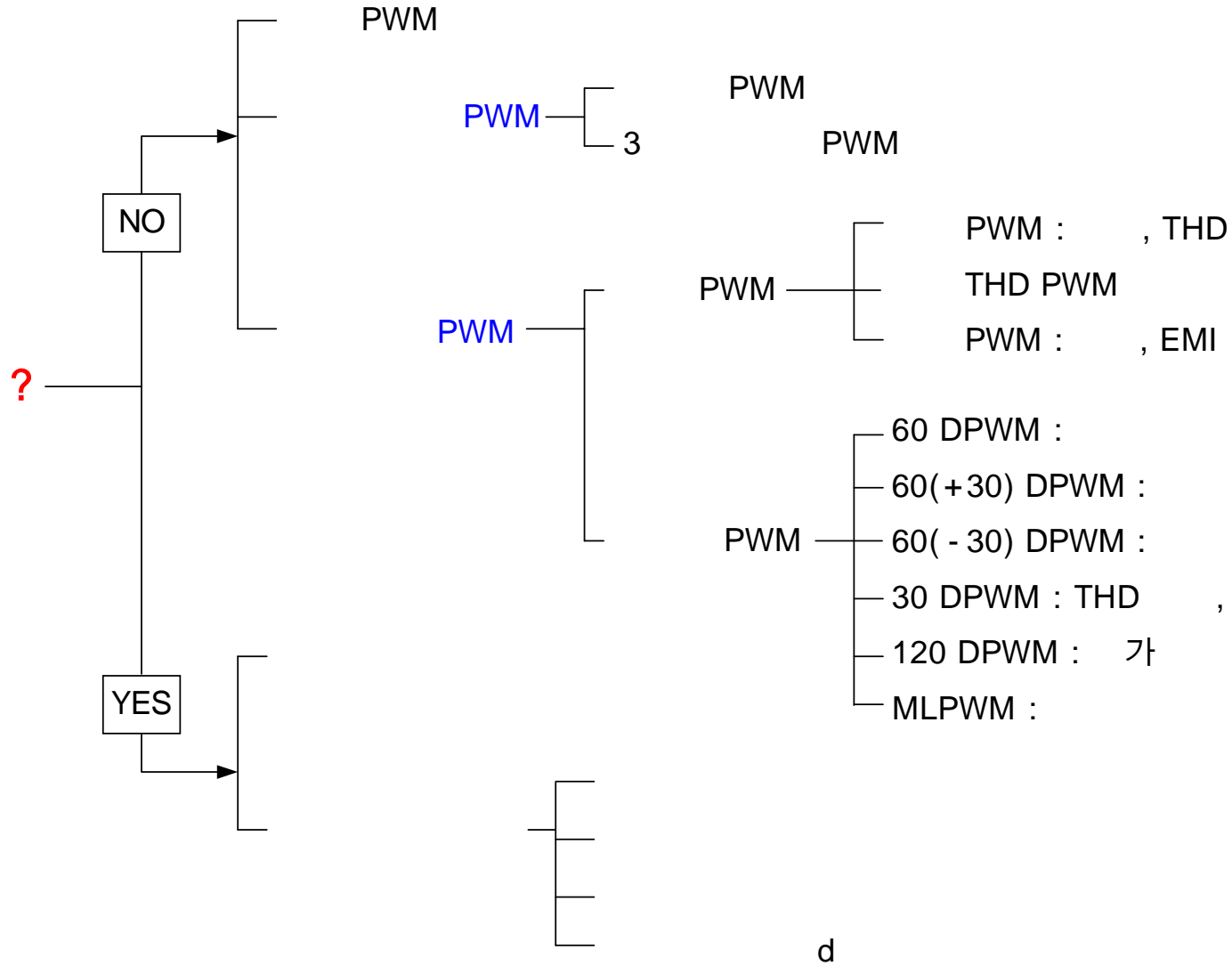
$$V_{as} = \frac{V_{dc}}{3} (2S_a - S_b - S_c)$$

$$V_{bs} = \frac{V_{dc}}{2} (2S_b - S_c - S_a)$$

$$V_{cs} = \frac{V_{dc}}{2} (2S_c - S_a - S_b)$$

$$V_{sn} = \frac{V_{an} + V_{bn} + V_{cn}}{3}$$

6.1 3



6.2

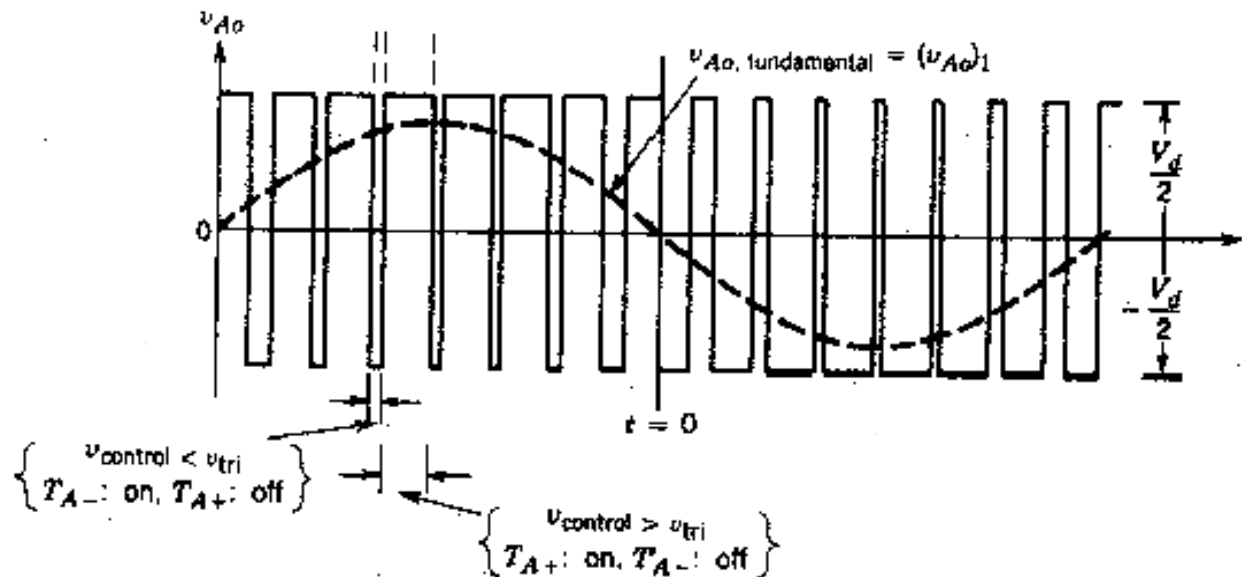
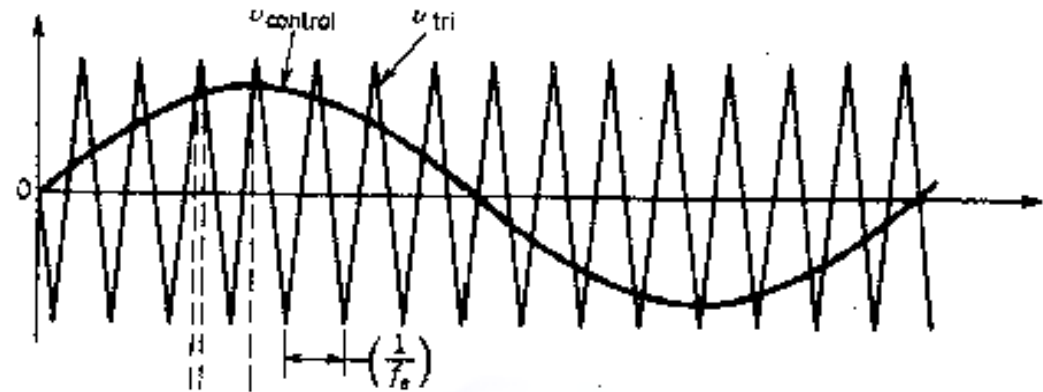
PWM

BRINGING SOLUTIONS TOGETHER



- carrier signal

PWM



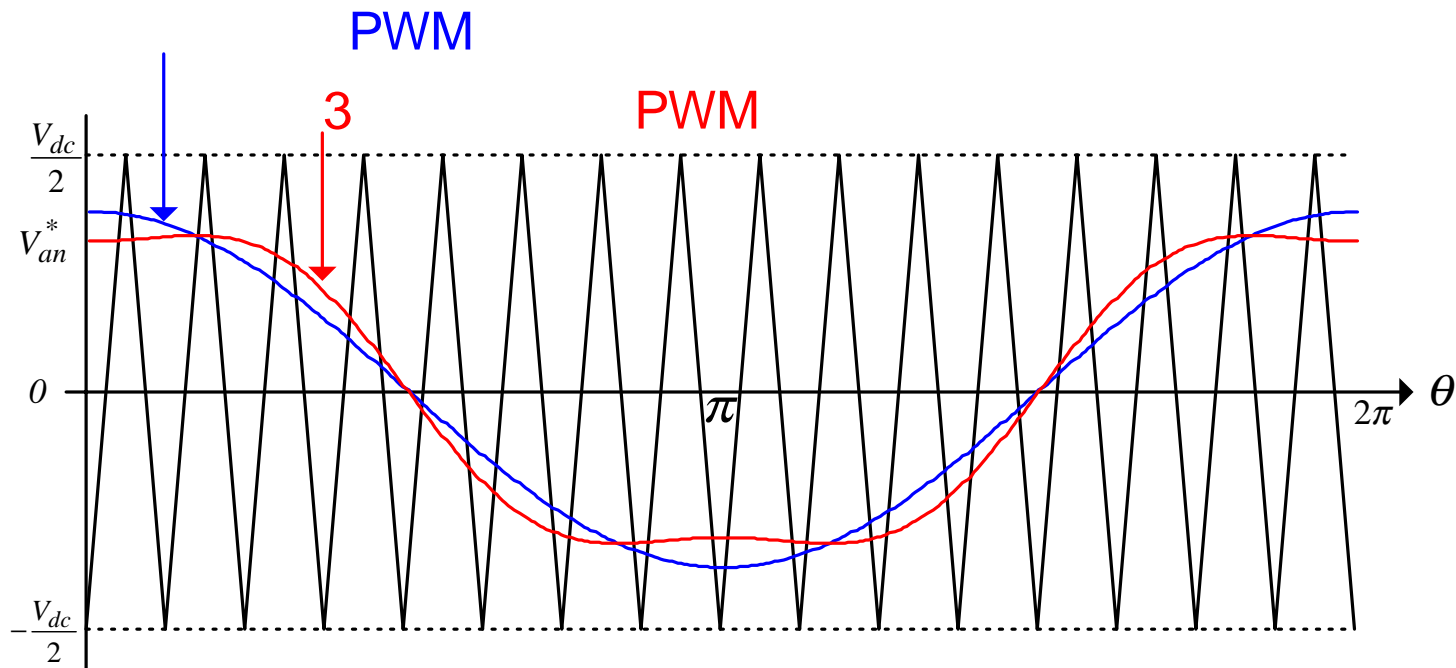
6.3

PWM

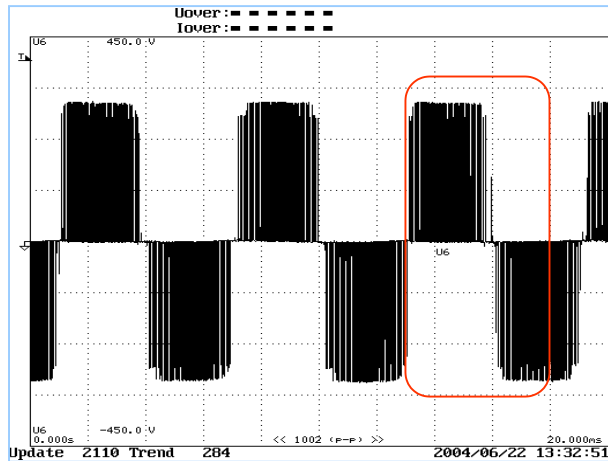
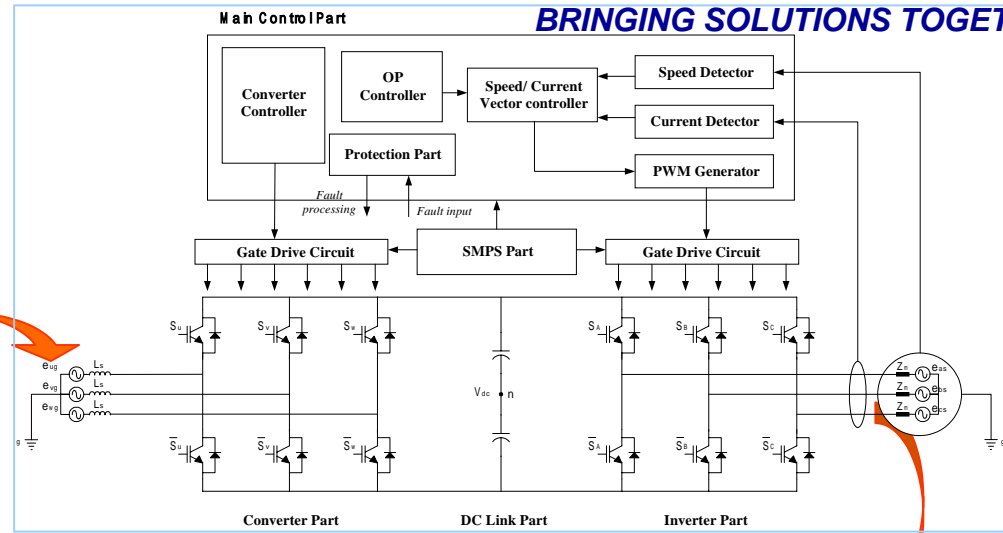
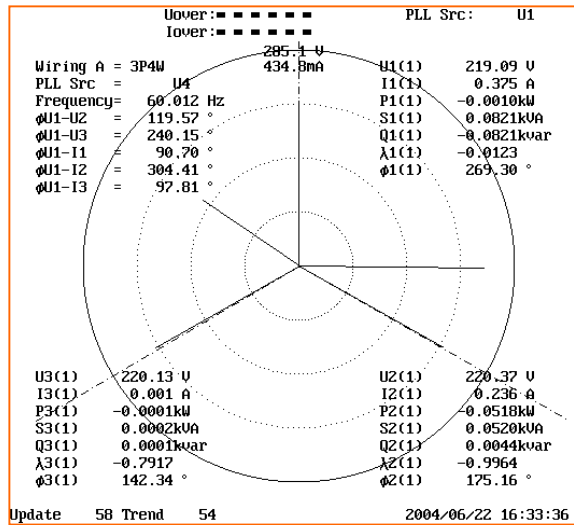
BRINGING SOLUTIONS TOGETHER



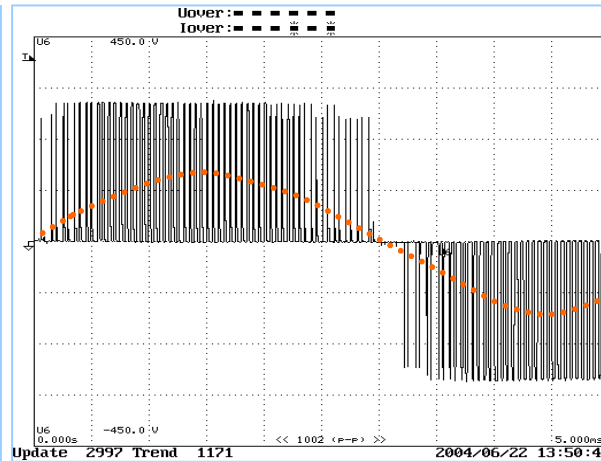
-
- PWM
-
- $(MI = \frac{|V^*|}{(V_{dc}/2)}) = 1$
- \Rightarrow
- 3 \Rightarrow



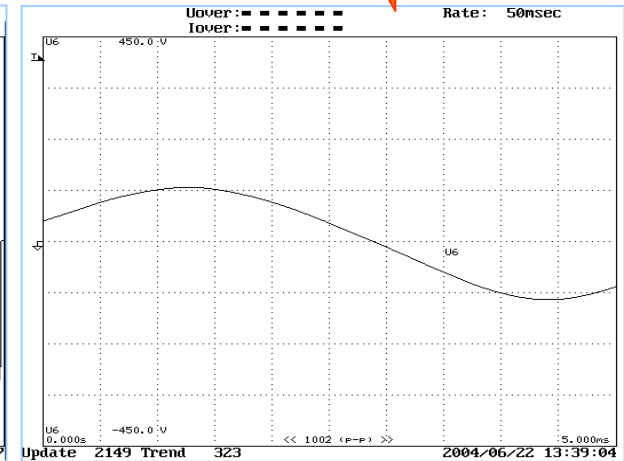
6.4 PWM



PWM



PWM ()



가

7.

DSP

BRINGING SOLUTIONS TOGETHER



- MR -J2S -100A(Mitsubishi) : HD64F7065F60(Hitachi)
- FDA -7000(OTIS.LG) : TMS320VC33(TI)

Device Feature	32PCM40	SH7065	VC33 -120
Data bit ALU	32 bit Floating Point	32 bit Fixed Point	32 bit Floating Point
Performance	20MIPS - 40MFLOPS	78MIPS	60MIPS -120MFLOPS
On Chip Memory for Program	512 Words External RAM	256K Byte ROM 8K Byte RAM	34K Words 16K × 2 + 1K × 2
Serial Ports	1 Channel	3 Channel	1 Channel
Timer	32bit - 2 Channel	16bit - 6 Channel	32bit - 2 Channel
ADC	No	10bit - 8 Channel	No
Supply Voltage	5V	3.3 / 5 V	3.3 V
Package	PQFP -144	LQFP -176	TQFP -144
Estimated Price /1kU	10.75 \$		11.74 \$ / 12.92 \$

7.1 TMS320F243/F241/C242

BRINGING SOLUTIONS TOGETHER

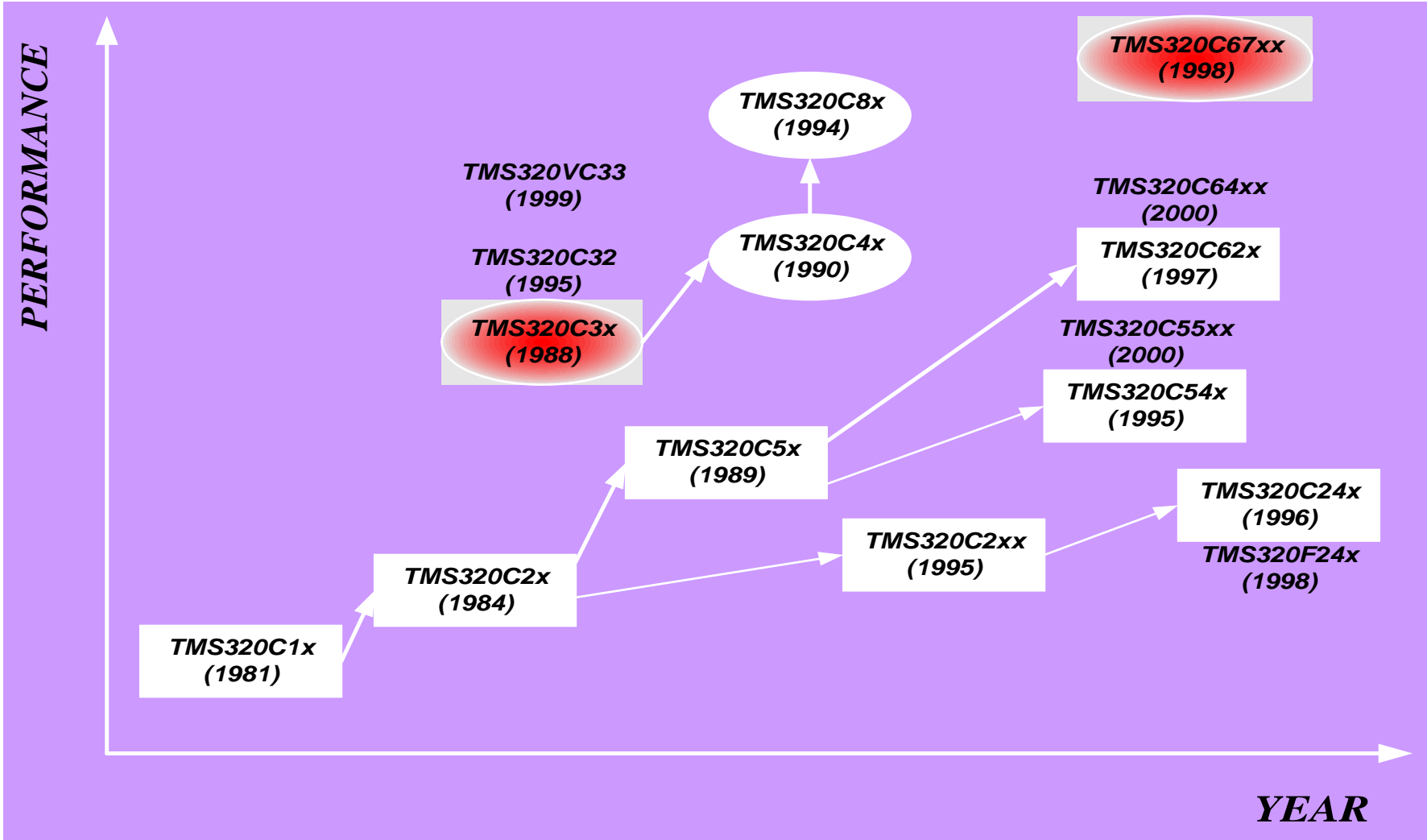


- F243 ': External memory interface and emulation tools
- F241 ': Not external memory interface has reduced GPIO pins
- C242 ': Minimum -cost motor control devices

Device Feature	'F243	'F241	'C242
C2xLP CPU with 544 Word DRAM + JTAG	Yes	Yes	Yes
5V Flash	8k × 16	8k × 16	4k × 16
Event Manager(EV2)	Yes	Yes	Yes
CAN	Yes	Yes	No
SPI	Yes	Yes	No
SCI	Yes	Yes	Yes
8channel ADC	Yes	Yes	Yes
GPIO	26 GPIO + 6 dedicated	26 GPIO	20 GPIO + 6 dedicated
External memory	Yes	No	No
Package	144 TQFP	64 - QFP / 68 - PLCC	64 - QFP / 68 - PLCC

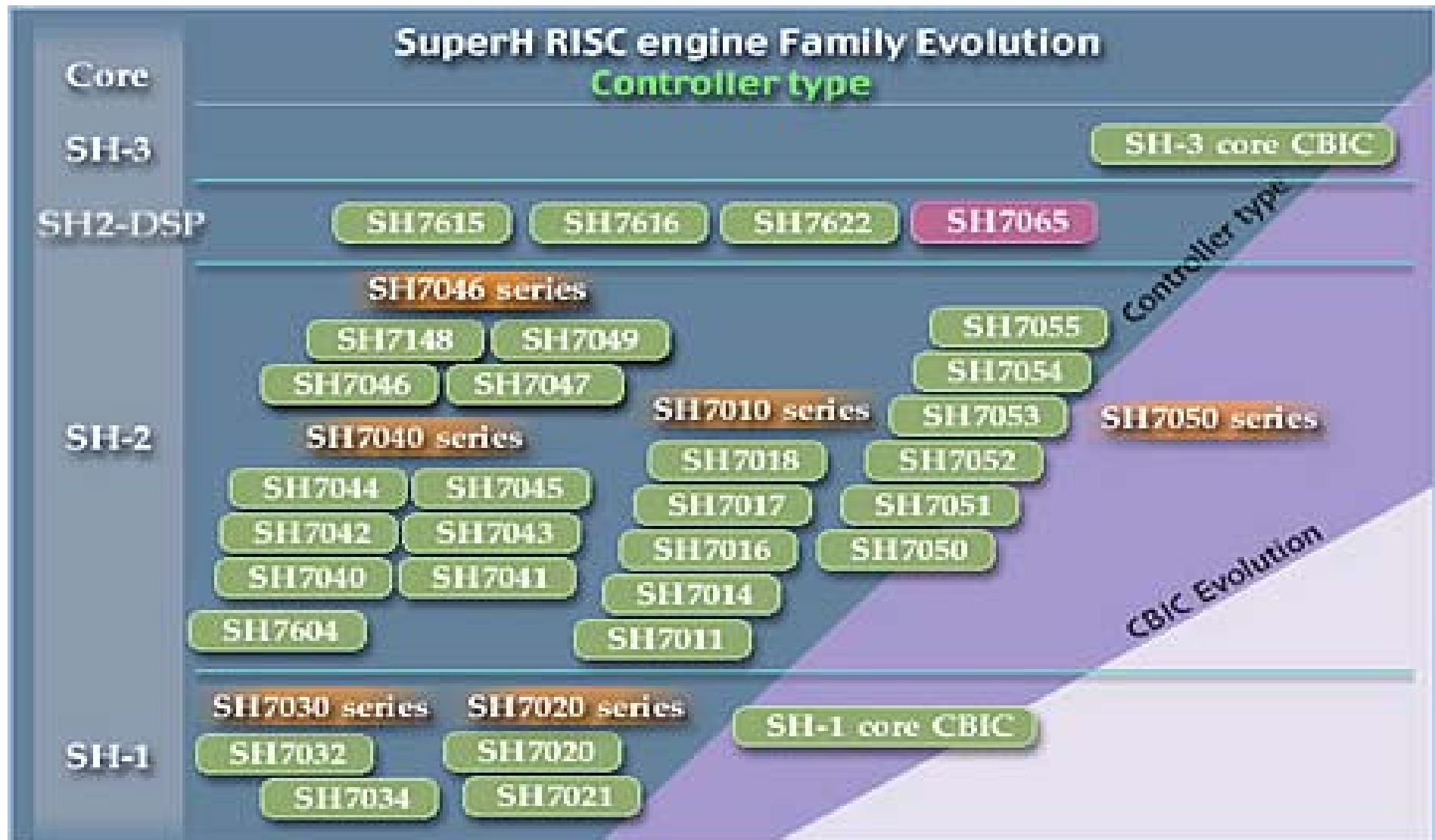
7.2 TI Processor

BRINGING SOLUTIONS TOGETHER



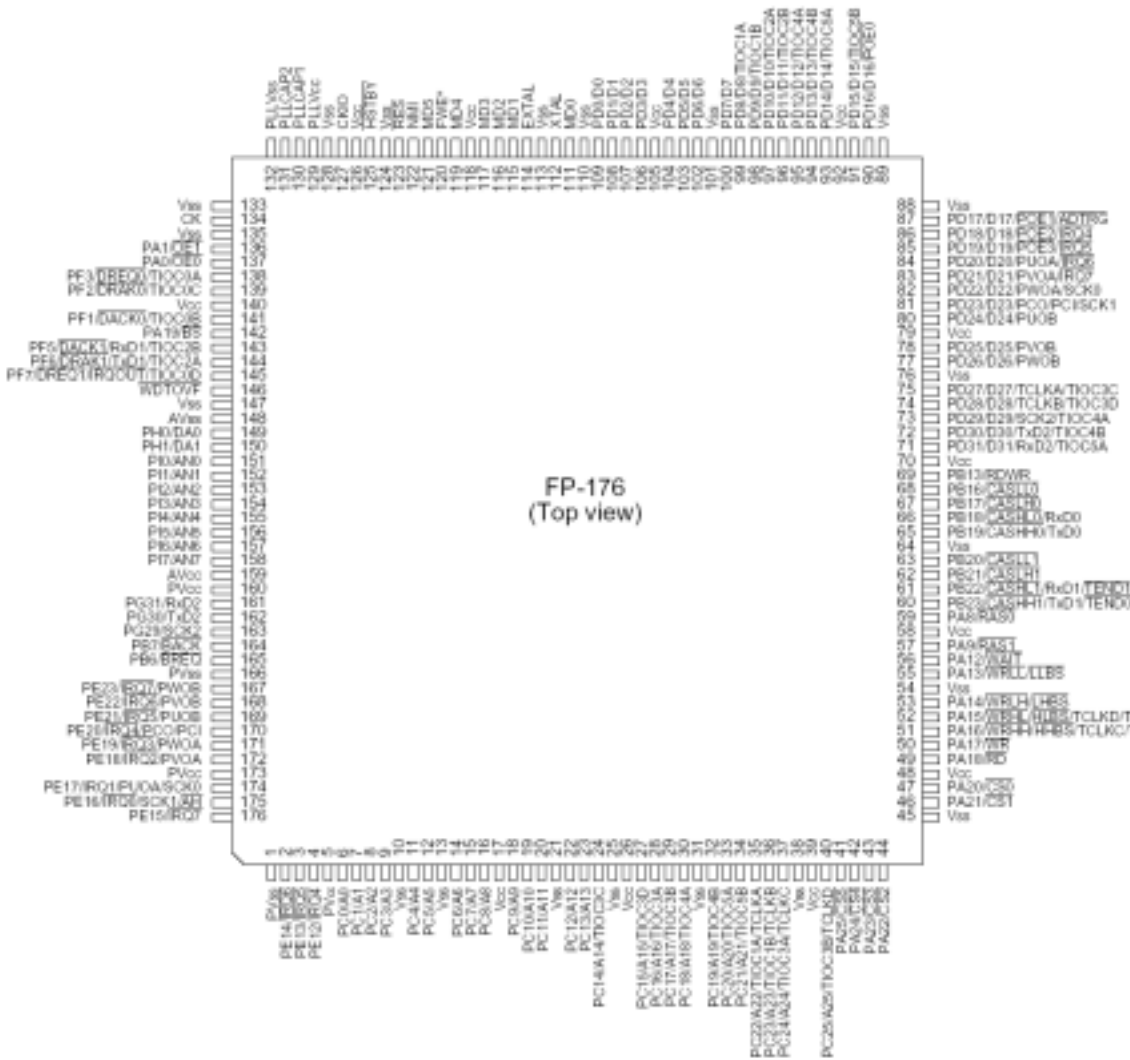
7.3 Hitachi Processor

BRINGING SOLUTIONS TOGETHER



7.4 HD64F7065

BRINGING SOLUTIONS TOGETHER



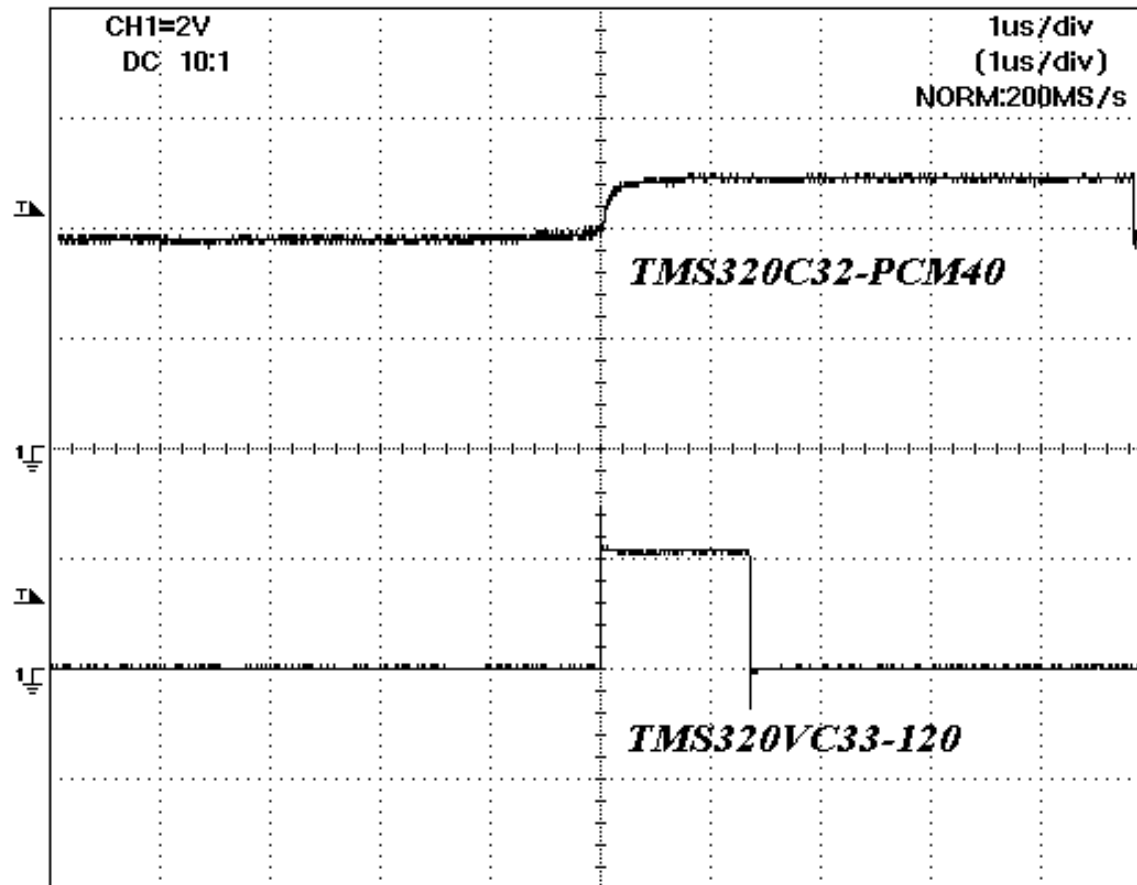
FP-176 (Top view)

Note: * Vss in the mask version (can be pulled down with a resistance of 5.0 kΩ to 10 kΩ)

- ### Main Features
- Hitachi Architecture : 16 bit Fixed Point
 - Maximum 60 MHz Clock
 - 60 MIPS, 17ns Instruction Cycle Time
 - 16 × 16 = 32 bit : 1 Cycle
 - 32 × 32 = 64 bit : 2 ~ 4 Cycle
 - 256KB On Chip Rom and 8 KB Ram
 - Various Clock Generator Modes
 - 110 I/O and 8 Input Ports
 - 8 External Interrupts and 15 Priorities
 - 8 Channels of 10 bit ADC : 6.7 us
 - 2 Channels of 8 bit DAC
 - 3 Channels of SCI and DMA
 - PWM and Encoder Counting
 - One Motor Management Timer(MMT)
 - 176 Pin LQFP Package
 - 3.3 V Core and 5V Operations

7.5 Speed Comparison

BRINGING SOLUTIONS TOGETHER



Comparison Results

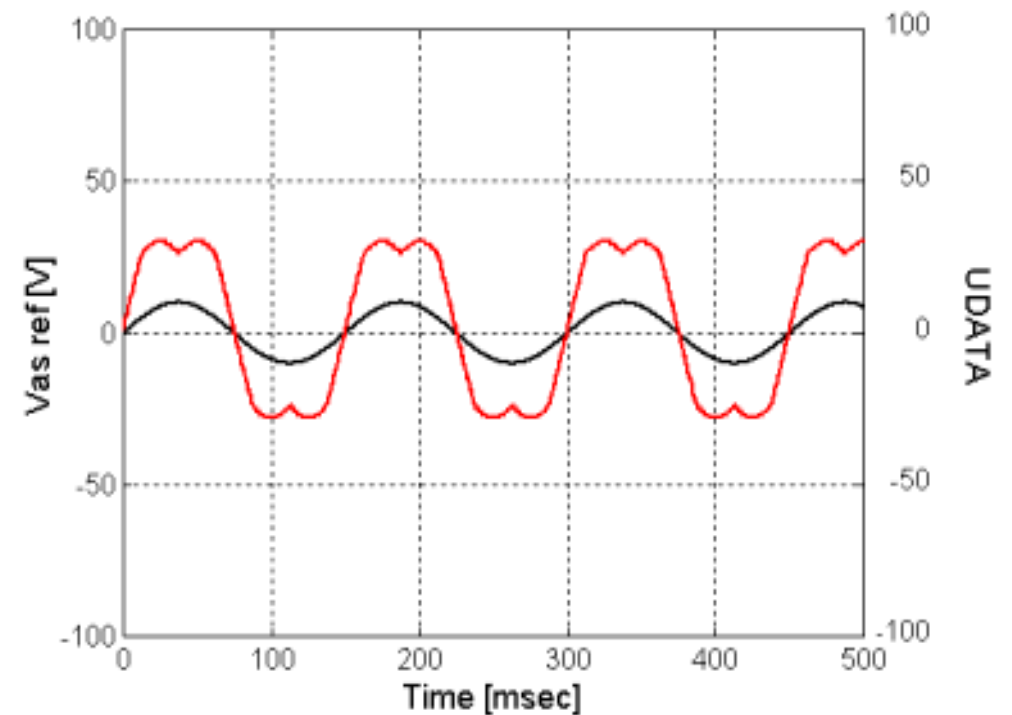
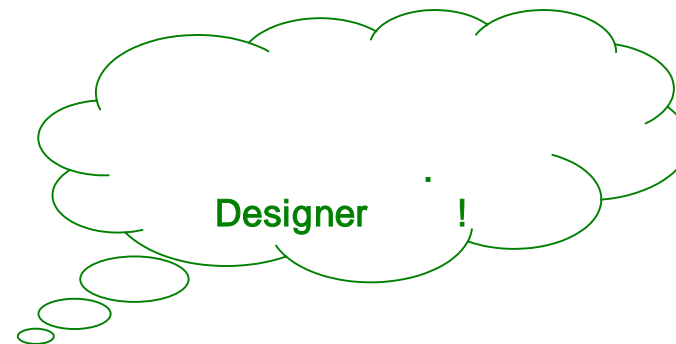
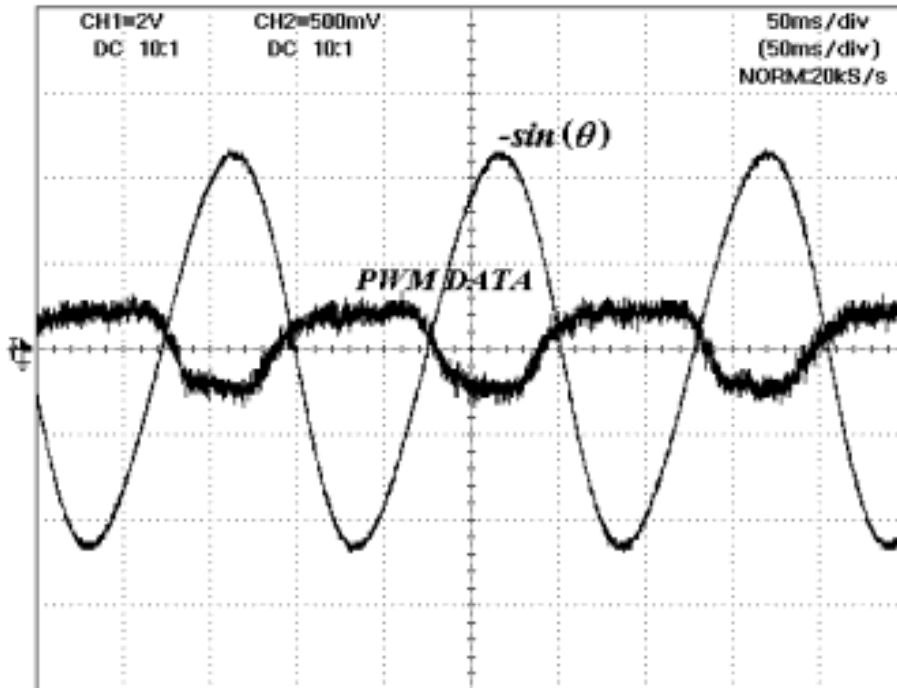
Comparison Code

-- Sine and Cosine Operation

- $a = \text{Theta} \times \text{Theta}$;
- $\text{Sin_Theta} = \text{SIN}(\text{Theta}, a)$;
- $\text{Cos_Theta} = \text{COS}(a)$;

7.6 PWM Resolution

BRINGING SOLUTIONS TOGETHER



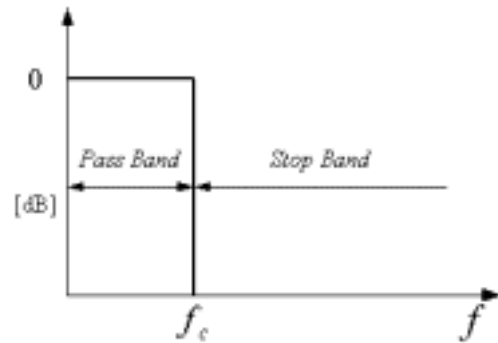
In Low Speed Range

- Measured Speed : 100 [rpm]
- Low Resolution of DC Link Voltage
- Low Resolution of PWM
- Current Distortion

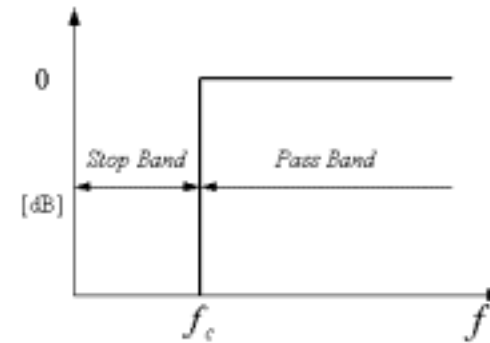
8. DIGITAL FILTER



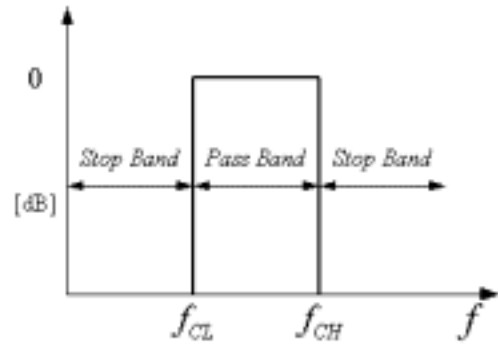
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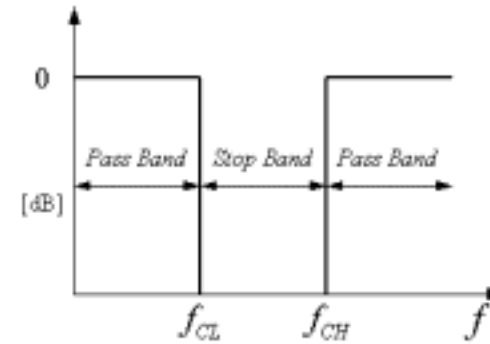
(a) Low Pass Filter



(b) High Pass Filter

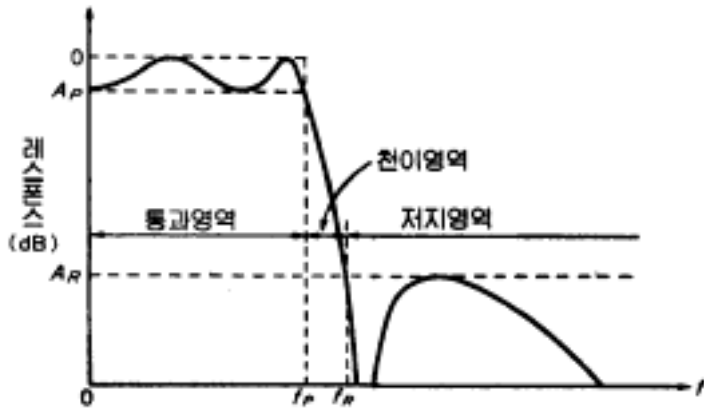


(c) Band Pass Filter

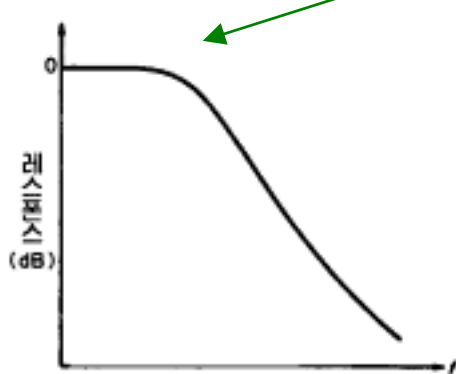


(d) Band Stop Filter

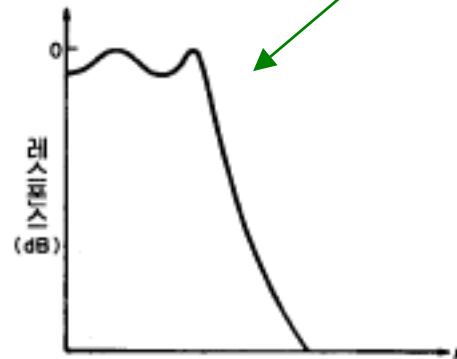
8.1 Low Pass Filter



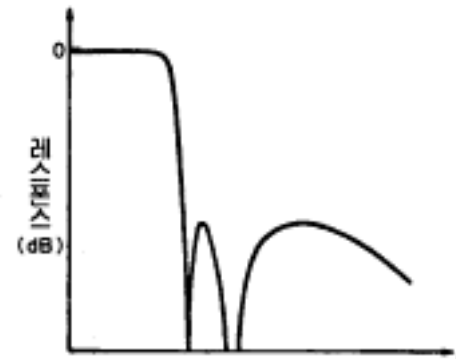
Butterworth :
Chebyshev :



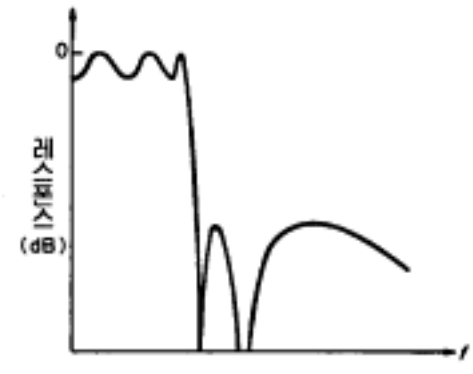
(a) Butterworth Filter



(b) Chebyshev Filter



(c) Chebyshev Filter



(d) Chebyshev Filter



$$s = \frac{1 - z^{-1}}{T_s}$$

Back \ward Difference Transform

$$s = \frac{1 - z^{-1}}{T_s z^{-1}}$$

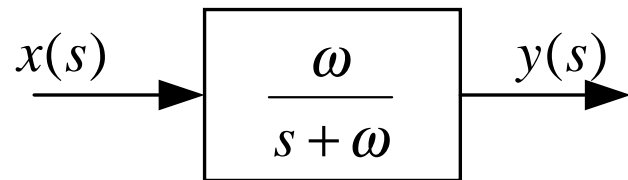
Forward Difference Transform

$$s = \left(\frac{2}{T_s} \right) \left(\frac{1 - z^{-1}}{1 + z^{-1}} \right)$$

Bilinear Difference Transform

8.3 LPF (Low Pass Filter)

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$$y(s) = \left(\frac{\omega}{s + \omega} \right) \bullet x(s) \quad \leftarrow \text{Bilinear Difference Transform} \quad s = \left(\frac{2}{T_s} \right) \left(\frac{1 - z^{-1}}{1 + z^{-1}} \right)$$

$$\left(\frac{2}{T_s} \right) \left(\frac{1 - z^{-1}}{1 + z^{-1}} \right) \bullet y(z) + \omega \bullet y(z) = \omega \bullet x(z)$$

$$2\{y(n) - y(n-1)\} + T_s \omega \{y(n) - y(n-1)\} = T_s \omega \{x(n) - x(n-1)\}$$

$$\begin{aligned} y(n) &= \left(\frac{2 - T_s \omega}{2 + T_s \omega} \right) \bullet y(n-1) + \left(\frac{T_s \omega}{2 + T_s \omega} \right) \bullet \{x(n) - x(n-1)\} \\ &= L_a y(n-1) + L_b \{x(n) - x(n-1)\} \end{aligned}$$

8.4 Butterworth LPF (1/3)

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$$G(s) = \frac{\omega_c^2}{s^2 + \sqrt{2}\omega_c s + \omega_c^2}$$

$$H(z) = \frac{\omega_c^2}{\left(\frac{z-1}{z+1}\right)^2 + \sqrt{2}\omega_c \left(\frac{z-1}{z+1}\right) + \omega_c^2}$$

$$s \rightarrow \frac{z-1}{z+1}$$

$$= \frac{\omega_c^2}{\frac{z^2 - 2z + 1}{z^2 + 2z + 1} + \sqrt{2}\omega_c \left(\frac{z-1}{z+1}\right) + \omega_c^2}$$

$$H(z) = \frac{\omega_c^2 \cdot (z^2 + 2z + 1)}{(1 + \sqrt{2}\omega_c + \omega_c^2)z^2 + 2(\omega_c^2 - 1)z + (\omega_c^2 - \sqrt{2}\omega_c + 1)}$$

$$?, (1 + \sqrt{2}\omega_c + \omega_c^2) \cdot z^2 = K_{LPF} \cdot z^2$$

$$H(z) = \frac{\frac{\omega_c^2}{K_{LPF}} + 2\frac{\omega_c^2}{K_{LPF}}z^{-1} + \frac{\omega_c^2}{K_{LPF}}z^{-2}}{1 + 2\frac{(\omega_c^2 - 1)}{K_{LPF}}z^{-1} + \frac{(\omega_c^2 - \sqrt{2}\omega_c + 1)}{K_{LPF}}z^{-2}}$$

$$\omega_c = (2 \cdot \pi \cdot f_c) = \tan(\pi \times F_D \times T_{smp})$$

8.4 Butterworth LPF (2/3)

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1[kHz],

가 100[us]

$$\omega_A = \tan(\pi \cdot F_D \cdot T)$$

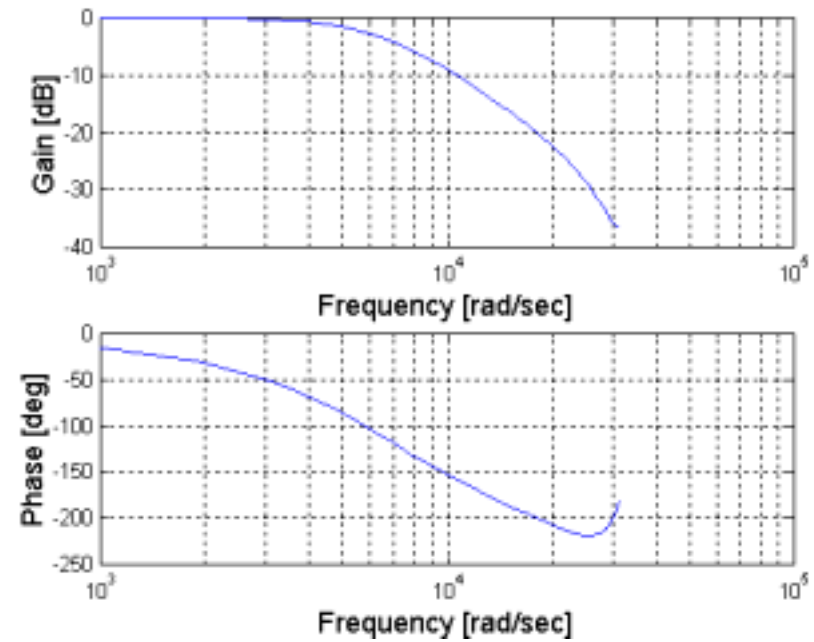
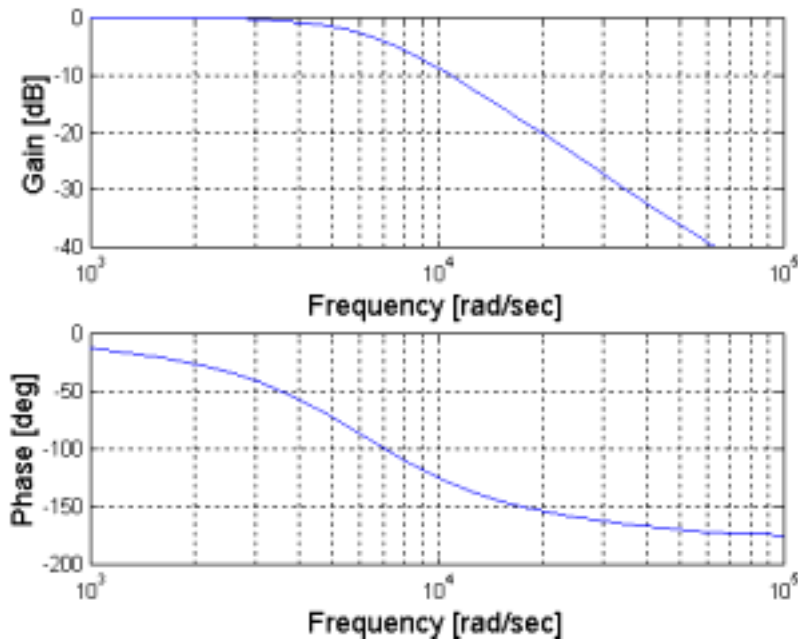
$$f_A = \frac{1}{2\pi} \tan(\pi \cdot F_D \cdot T)$$

$$f_A = \frac{1}{2\pi} \tan(\pi \times 1000 \times 0.0001) = 0.0517126$$

$$H(z) = \frac{0.06746 + 0.13491z^{-1} + 0.06746z^{-2}}{1 - 1.142980z^{-1} + 0.412802z^{-2}}$$

8.4 Butterworth LPF (3/3)

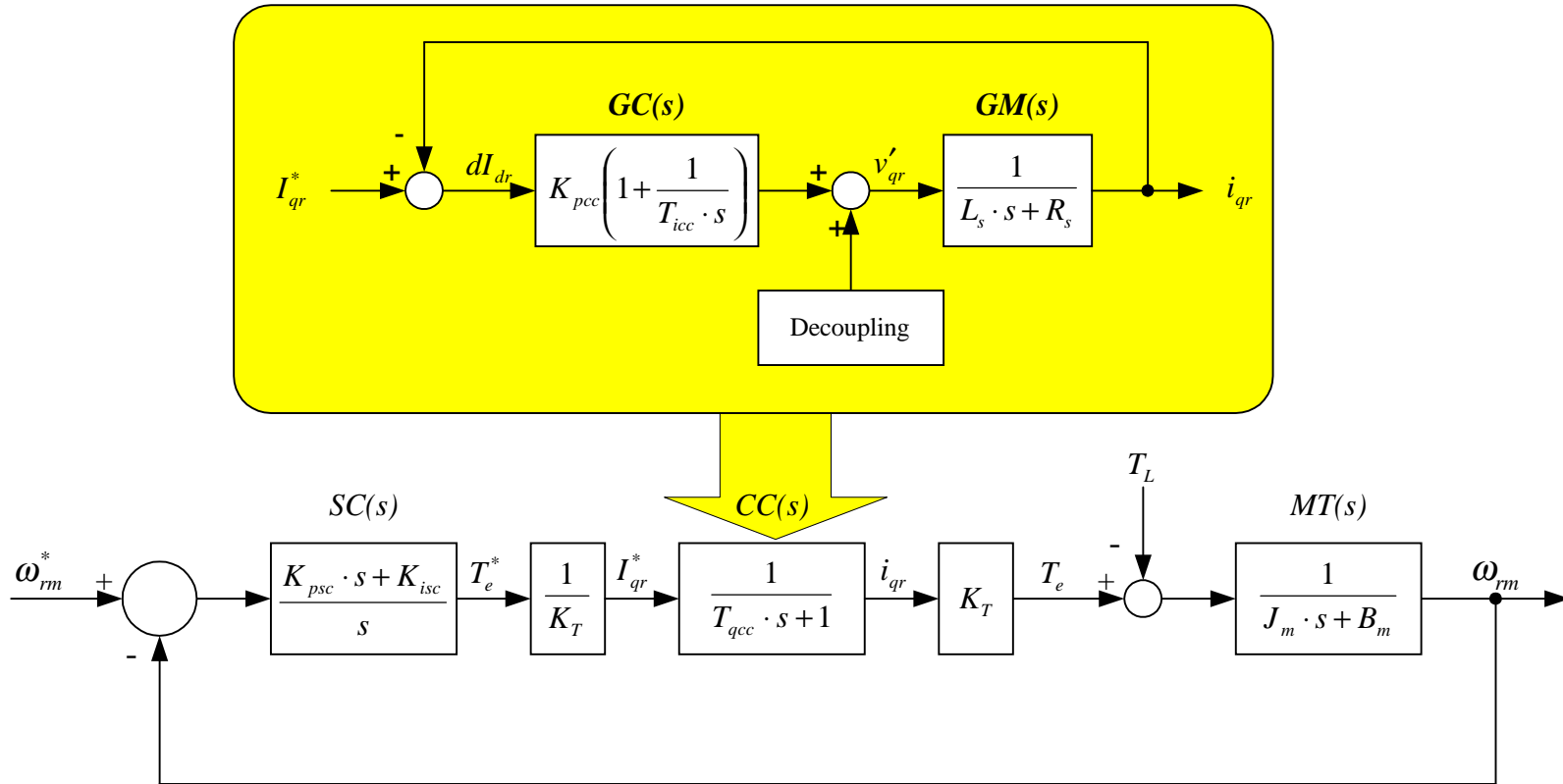
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Butterworth IIR 2

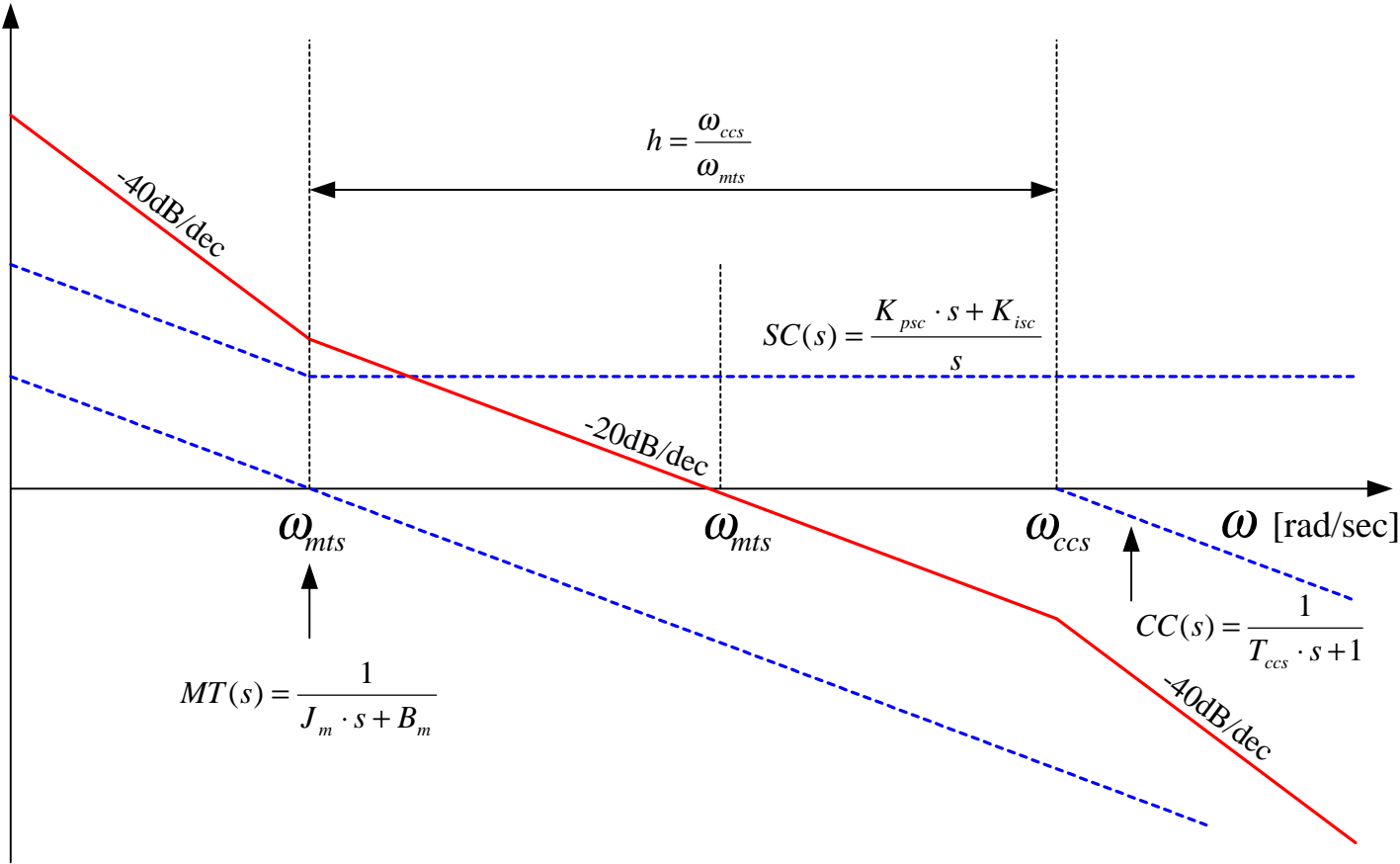
9.

9.1 1



$$\omega_{ccs} = \frac{1}{T_{qcc}} \text{ [rad / sec]}$$

$$\frac{\omega_{rm}(s)}{\omega_{rm}^*(s)} = SC(s) \cdot CC(s) \cdot MT(s) = \left(\frac{K_{psc} \cdot s + K_{isc}}{s} \right) \cdot \left(\frac{1}{T_{ccs} \cdot s + 1} \right) \cdot \left(\frac{1}{J_m \cdot s + B_m} \right)$$



$$\frac{\omega_{ccs}}{\omega_{scs}} = \frac{2 \cdot h}{h+1} \quad \frac{\omega_{scs}}{\omega_{mts}} = \frac{h+1}{2}$$



Least Peak value of Close-Loop Amplitude

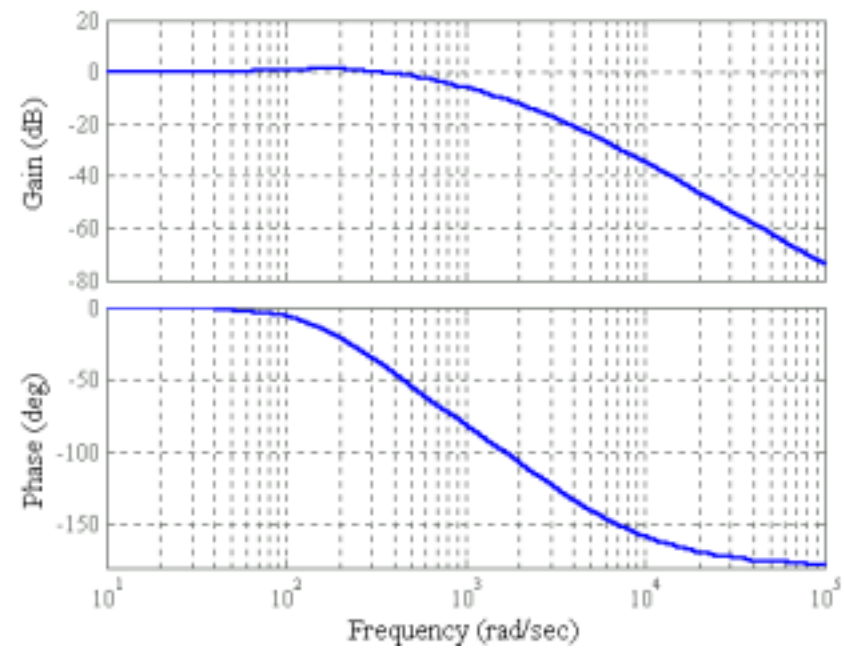
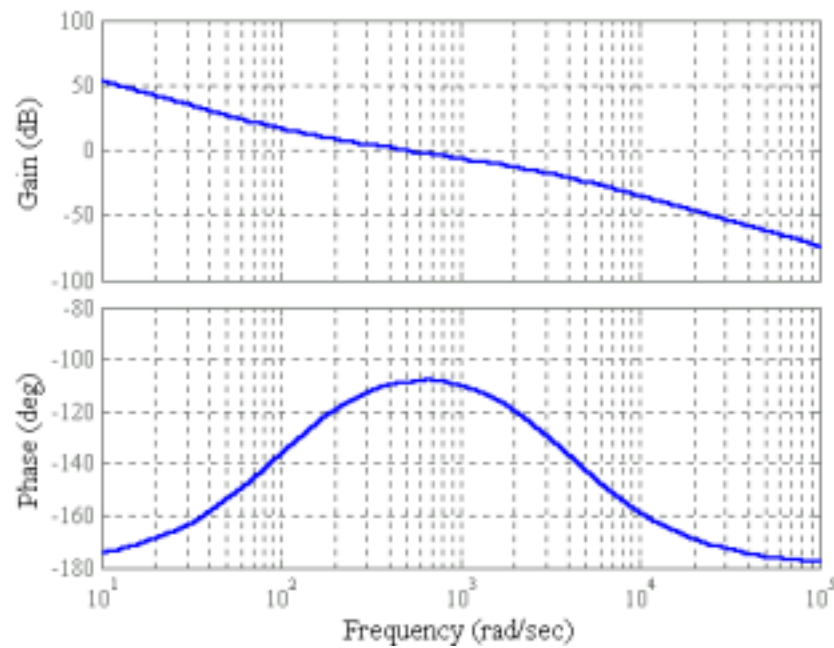
$$\frac{h+1}{h-1}$$



$$\frac{\omega_{rm}(s)}{\omega_{rm}^*(s)} = SC(s) \cdot CC(s) \cdot MT(s) = \left(\frac{K_{psc} \cdot s + K_{isc}}{s} \right) \cdot \left(\frac{1}{T_{ccs} \cdot s + 1} \right) \cdot \left(\frac{1}{J_m \cdot s + B_m} \right)$$

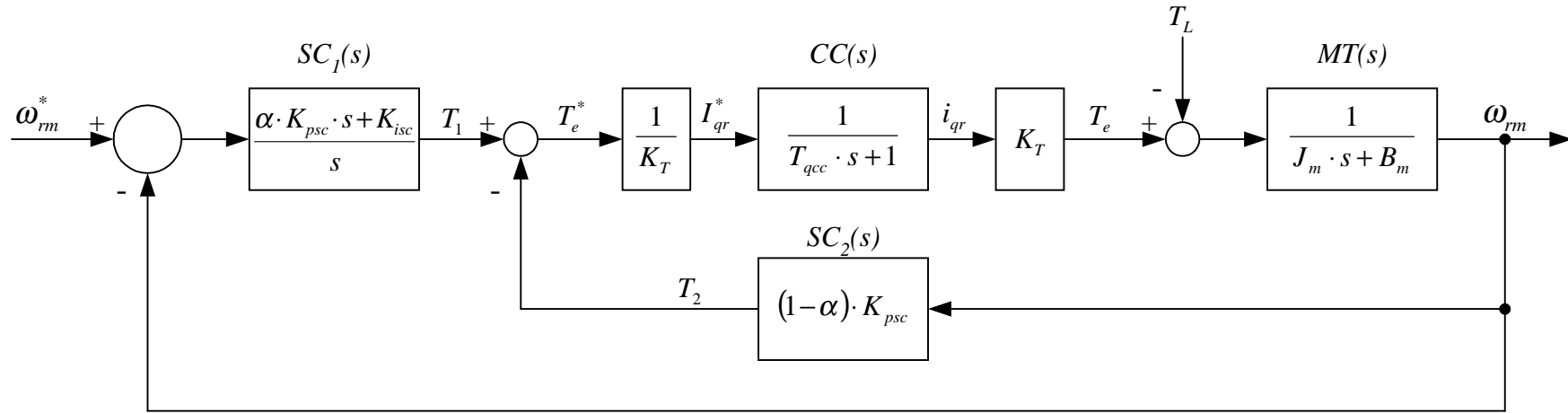
$$\frac{\omega_{rm}(s)}{\omega_{rm}^*(s)} = \frac{SC(s) \cdot CC(s) \cdot MT(s)}{SC(s) \cdot CC(s) \cdot MT(s) + 1} = \frac{K_{psc} \cdot s + K_{isc}}{J_m \cdot T_{ccs} \cdot s^3 + (J_m + B_m \cdot T_{ccs}) \cdot s^2 + (B_m + K_{psc}) \cdot s + K_{isc}}$$

$$J_m = 15.984 [Nms^2] \quad \omega_{scs} = 500 [rad/sec] \quad \omega_{ccs} = 4000 [rad/sec]$$



9.2 PI - IP

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$$T_e^* = T_1 - T_2$$

$$\omega_{err} = \omega_{rm}^* - \omega_{rm}$$

$$\omega_{rm} = T_e^* \cdot CC(s) \cdot MT(s)$$

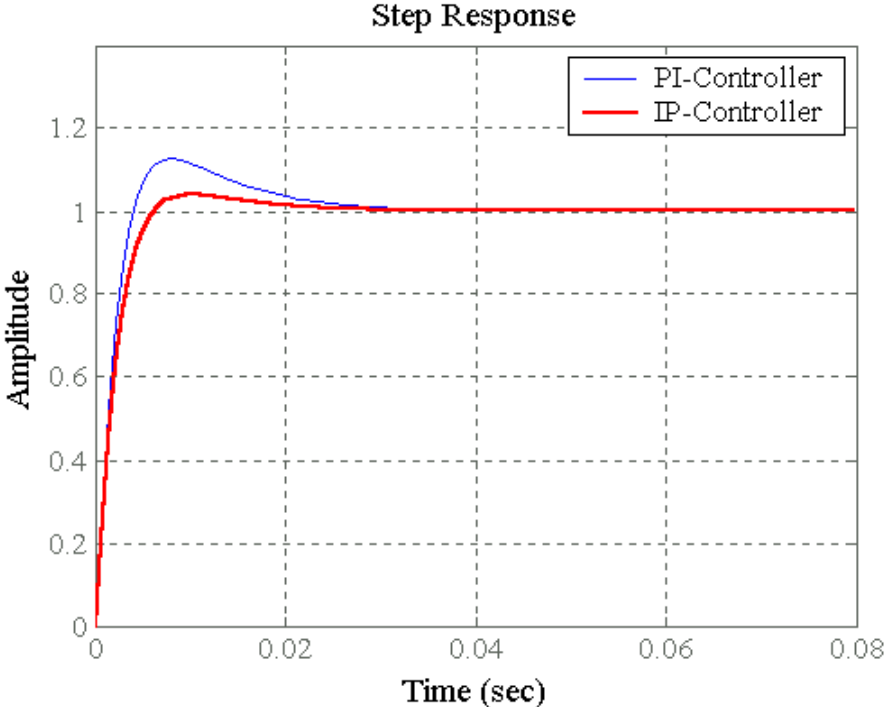
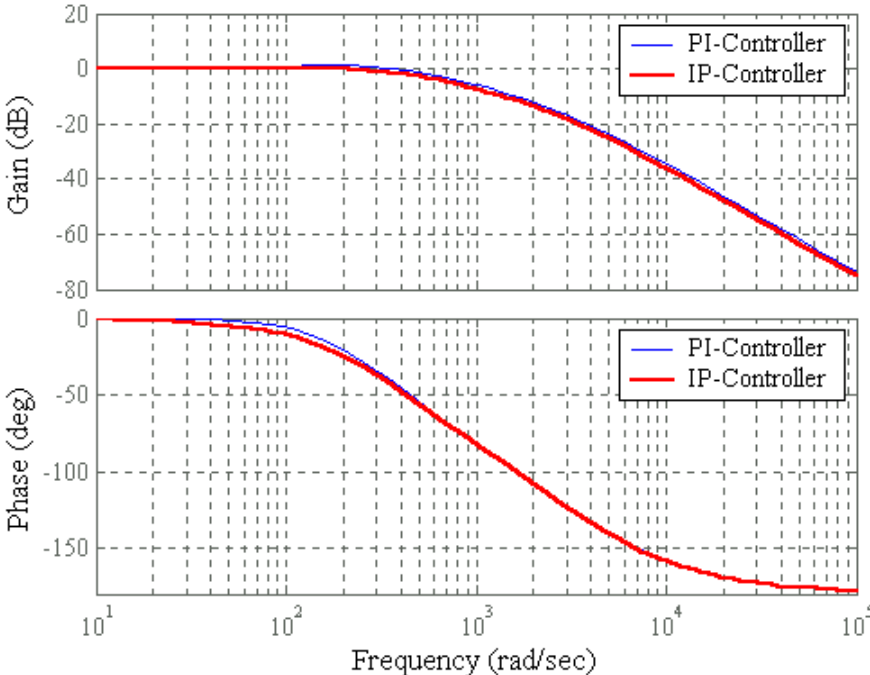
$$\omega_{rm} = (\omega_{err} \cdot SC_1(s) - \omega_{rm} \cdot SC_2(s)) \cdot CC(s) \cdot MT(s)$$

$$\omega_{err} = \omega_{rm} \cdot \left(\frac{1}{CC(s) \cdot MT(s) \cdot SC_1(s)} + \frac{SC_2(s)}{SC_1(s)} \right)$$

$$\frac{\omega_{rm}(s)}{\omega_{rm}^*(s)} = \frac{CC(s) \cdot MT(s) \cdot SC_1(s)}{CC(s) \cdot MT(s) \cdot (SC_1(s) + SC_2(s)) + 1}$$

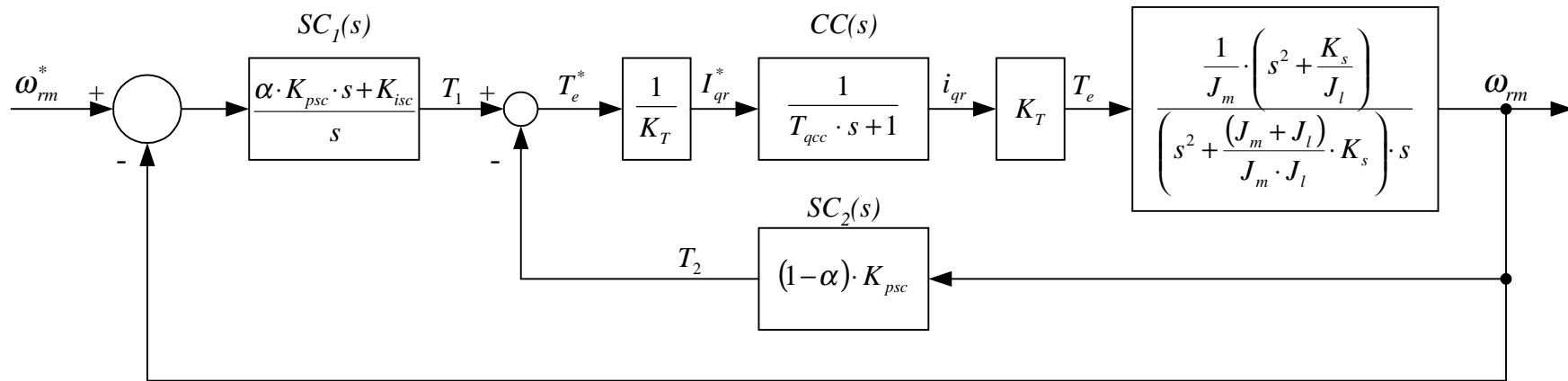


$W_{ccs} = 4000[\text{rad/sec}]$
 $W_{scs} = 500 [\text{rad/sec}]$
 $\text{Alpha} = 0.85$



9.3 PI - IP 2

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$$T_e^* = T_1 - T_2$$

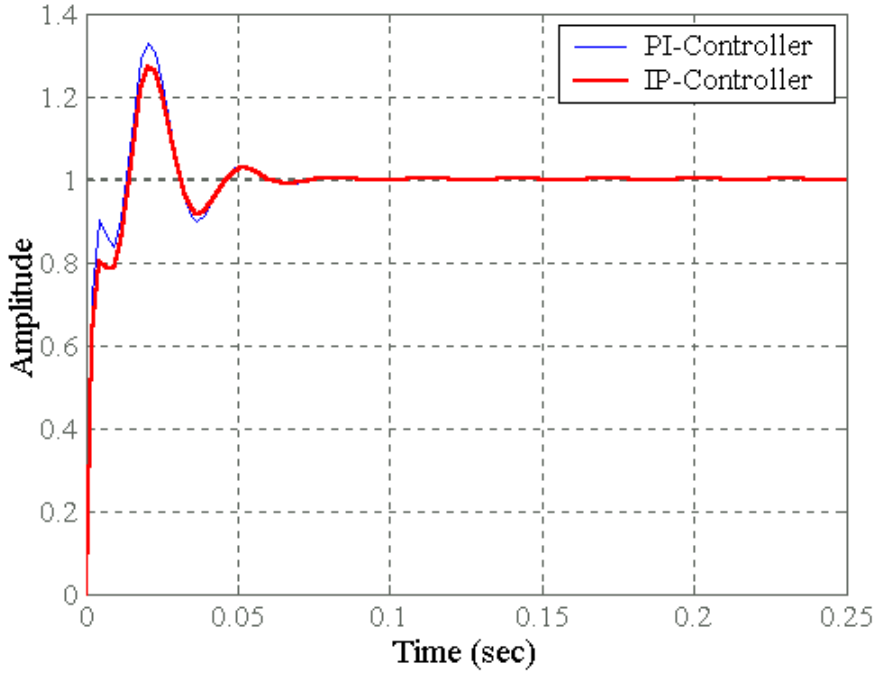
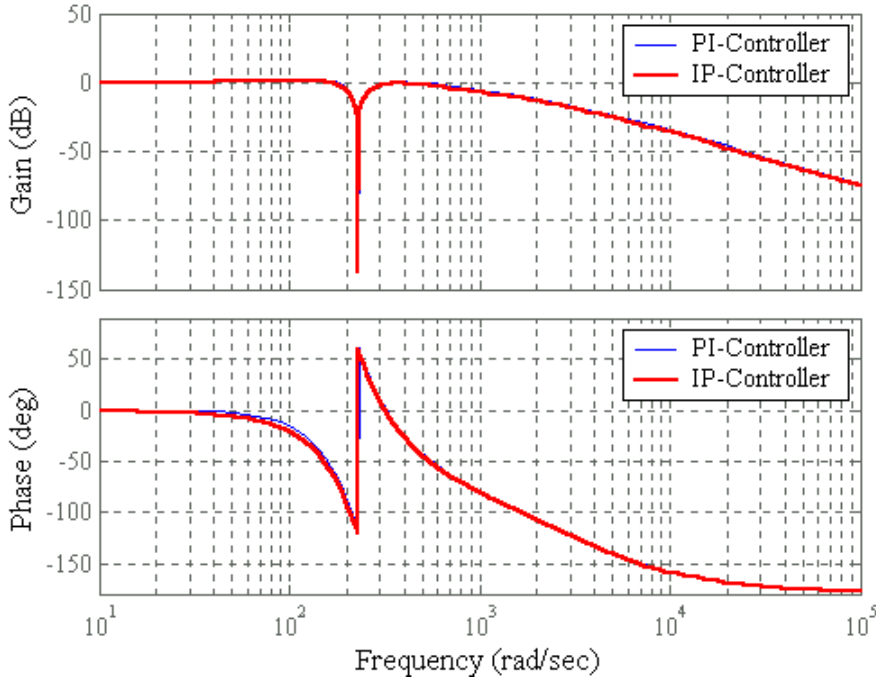
$$\omega_{err} = \omega_{rm}^* - \omega_{rm}$$

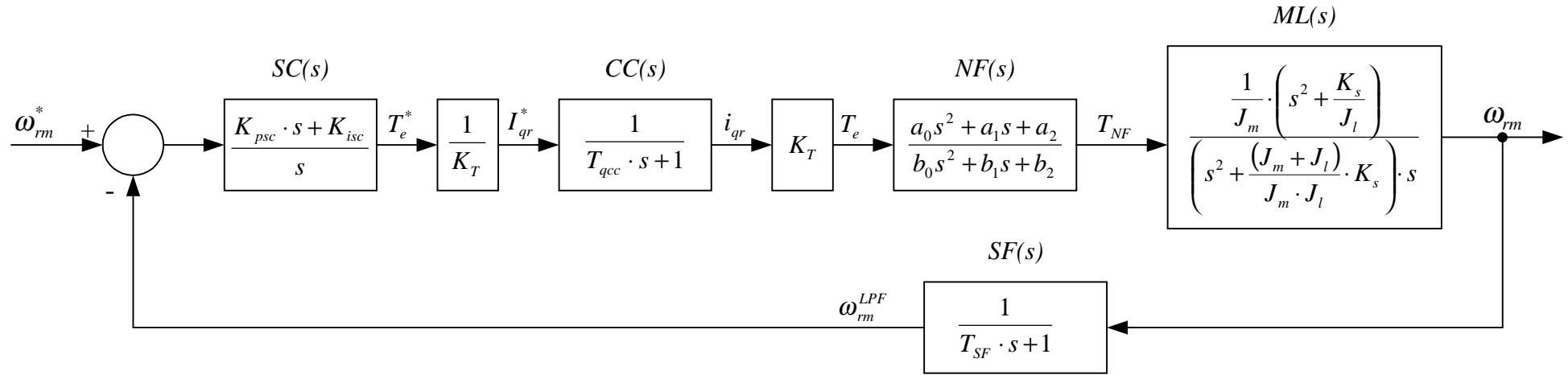
$$\omega_{rm} = T_e^* \cdot CC(s) \cdot ML(s)$$

$$\omega_{rm} = (\omega_{err} \cdot SC_1(s) - \omega_{rm} \cdot SC_2(s)) \cdot CC(s) \cdot ML(s)$$

$$\omega_{err} = \omega_{rm} \cdot \left(\frac{1}{CC(s) \cdot ML(s) \cdot SC_1(s)} + \frac{SC_2(s)}{SC_1(s)} \right)$$

$$\frac{\omega_{rm}(s)}{\omega_{rm}^*(s)} = \frac{CC(s) \cdot ML(s) \cdot SC_1(s)}{CC(s) \cdot ML(s) \cdot (SC_1(s) + SC_2(s)) + 1}$$





$$\omega_{err} = \omega_{rm}^* - \omega_{rm}^{LPF}$$

$$\omega_{rm} = \omega_{err} \cdot SC(s) \cdot CC(s) \cdot NF(s) \cdot ML(s)$$

$$\omega_{rm}^{LPF} = \omega_{rm} \cdot SF(s)$$

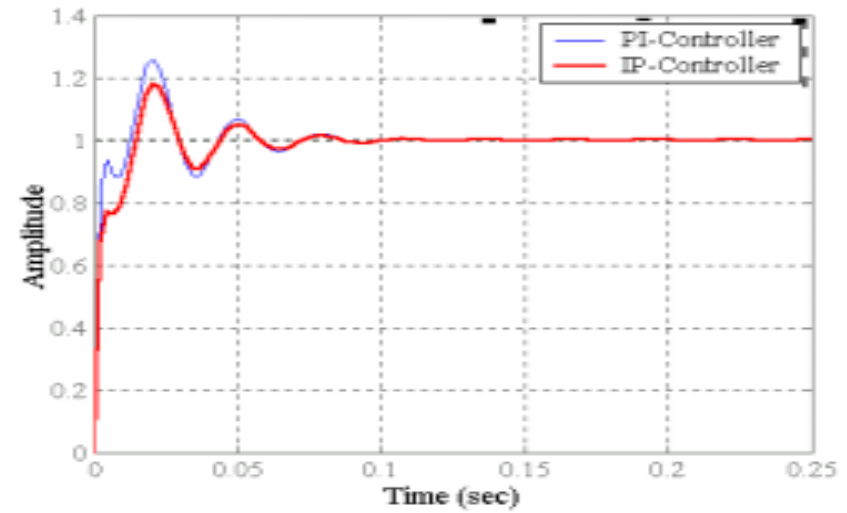
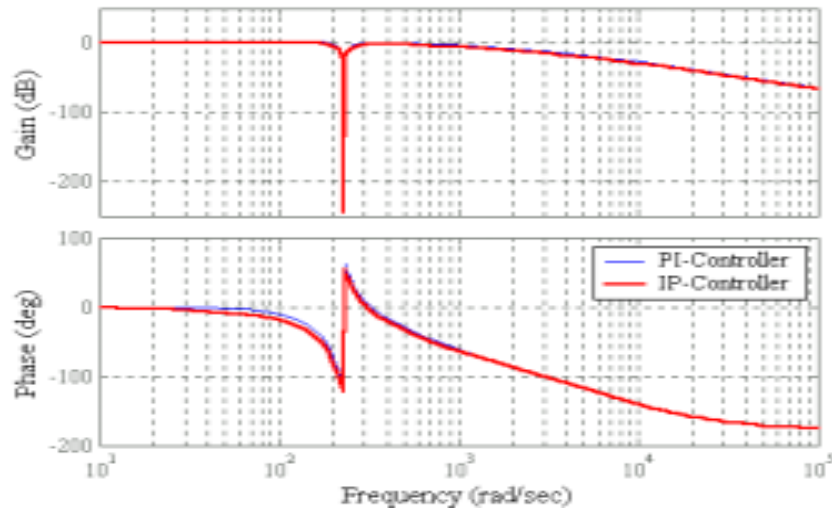
$$\omega_{rm} = \omega_{err} \cdot SC(s) \cdot NF(s) \cdot CC(s) \cdot ML(s)$$

$$\omega_{err} = \omega_{rm} \cdot \left(\frac{1}{CC(s) \cdot NF(s) \cdot ML(s) \cdot SC(s)} \right)$$

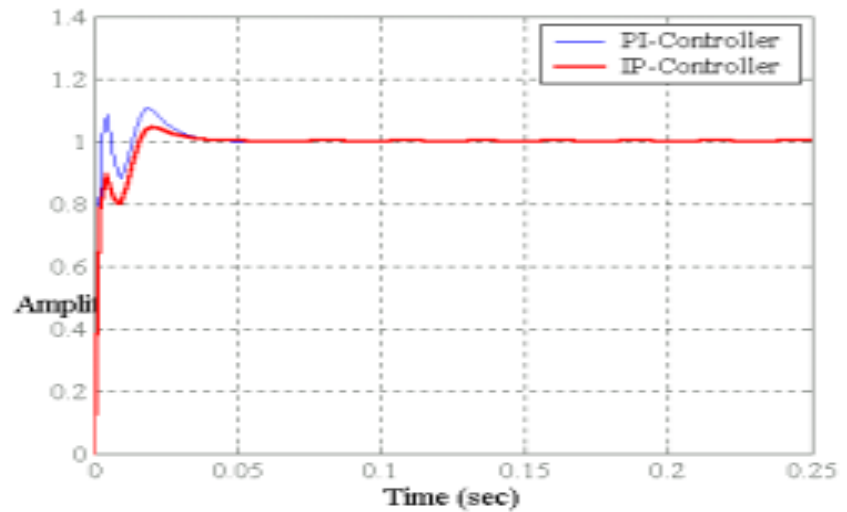
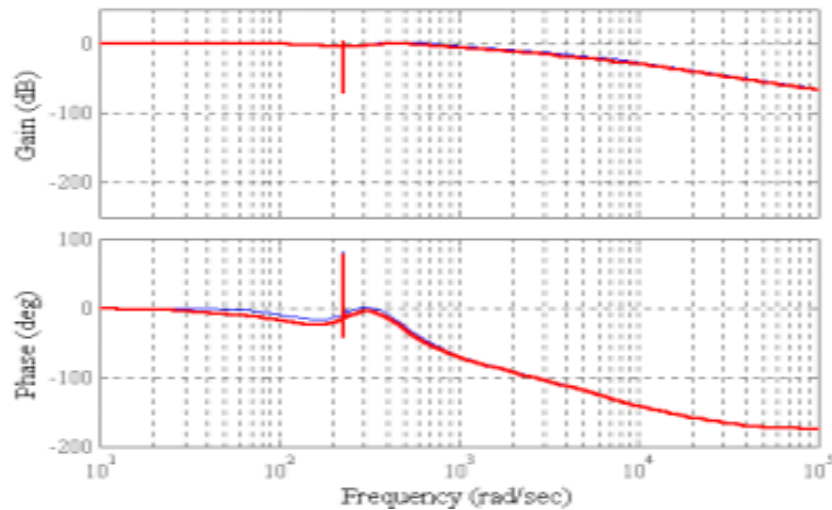
$$\frac{\omega_{rm}(s)}{\omega_{rm}^*(s)} = \frac{CC(s) \cdot NF(s) \cdot ML(s) \cdot SC(s)}{SC(s) \cdot CC(s) \cdot NF(s) \cdot ML(s) \cdot SF(s) + 1}$$



Without Notch Filter NF(s)



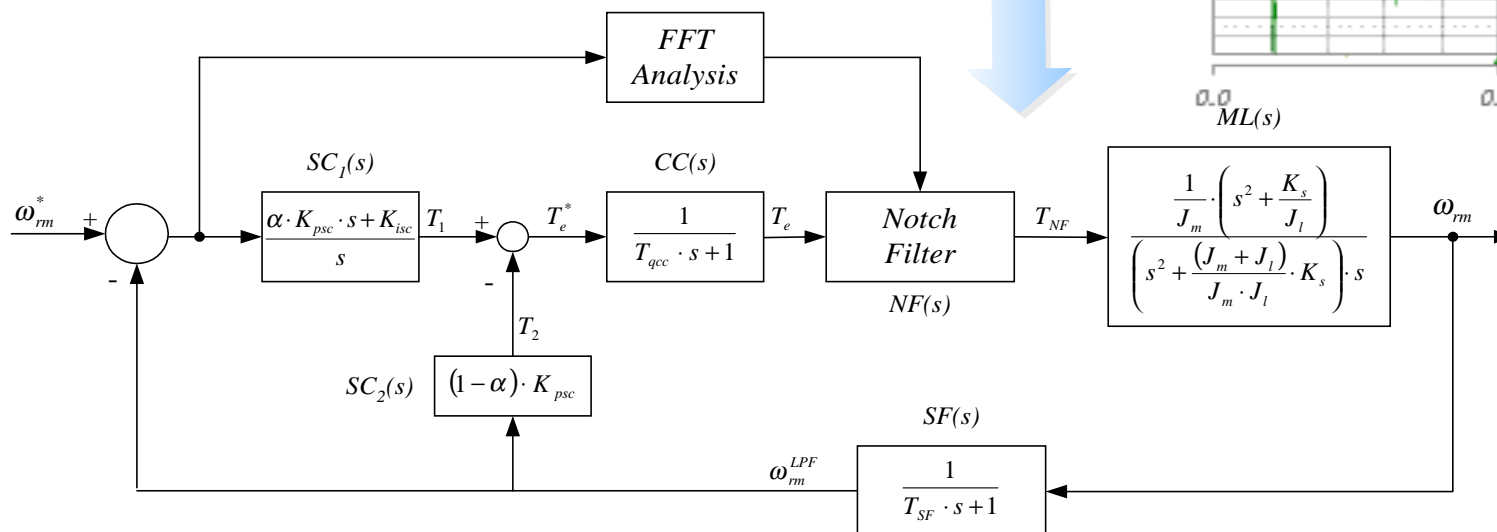
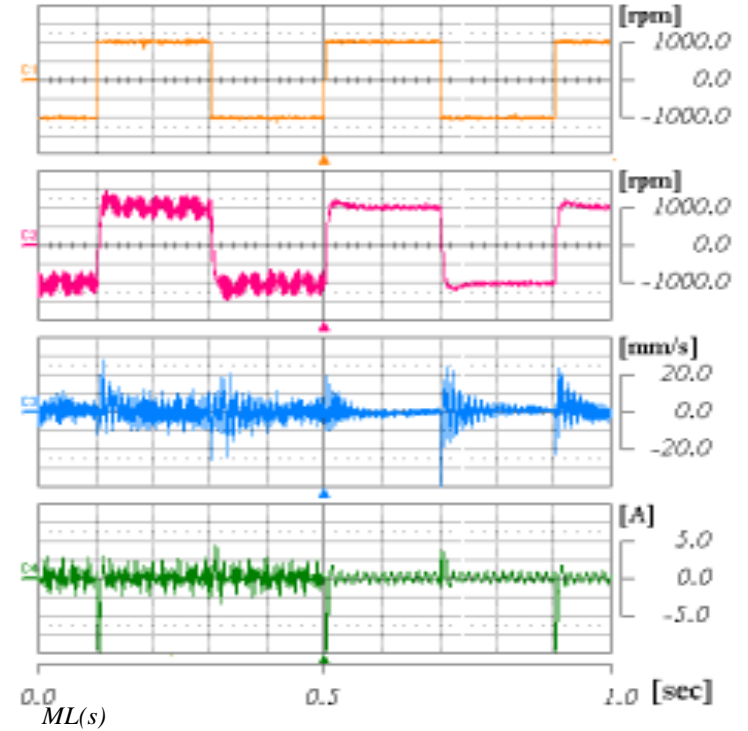
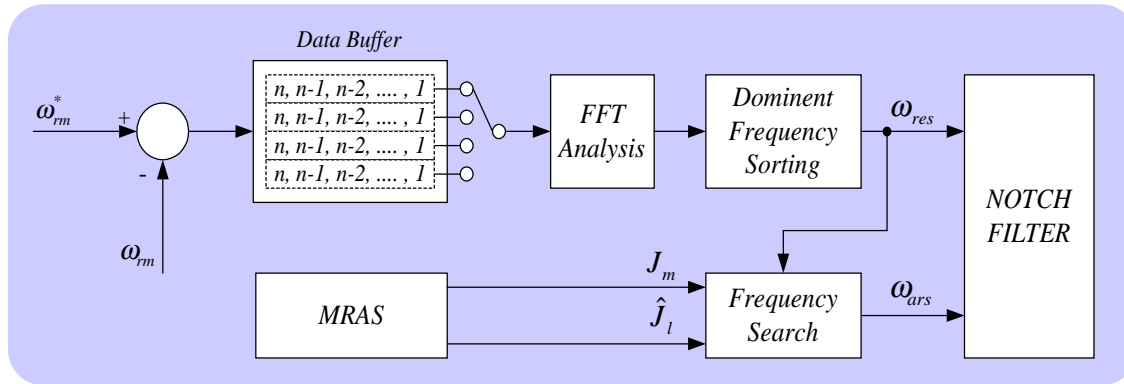
With Notch Filter NF(s)



9.5



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Thank You !

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