

德州儀器 C28xx DSP

-- 為基礎之高度整合與高效能之
馬達數位控制系統

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旺陽電企業股份有限公司
Value Provider International Corp

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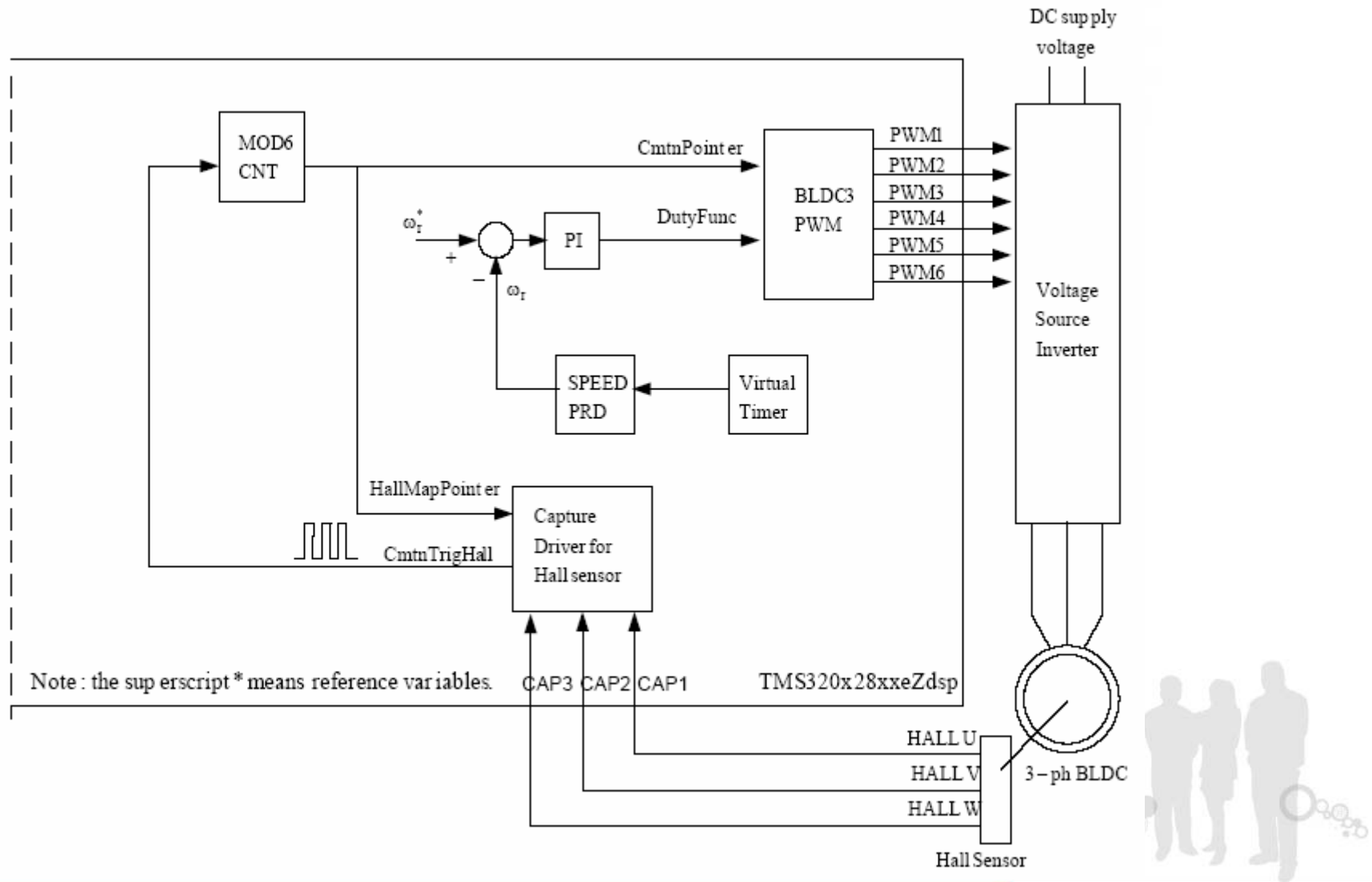
議程

- ❑ **BLDC motor control**
- ❑ **PMSM motor control**
- ❑ **德州儀器 C2000 DSP 簡介與特色**
- ❑ **C28x DSP 之發展工具**
- ❑ **F280x & F2801x**
 - 周邊功能更強大且極具價格優勢之
 - C28 DSP 的新寵兒 –**
- ❑ **C28x DSP 之應用領域**

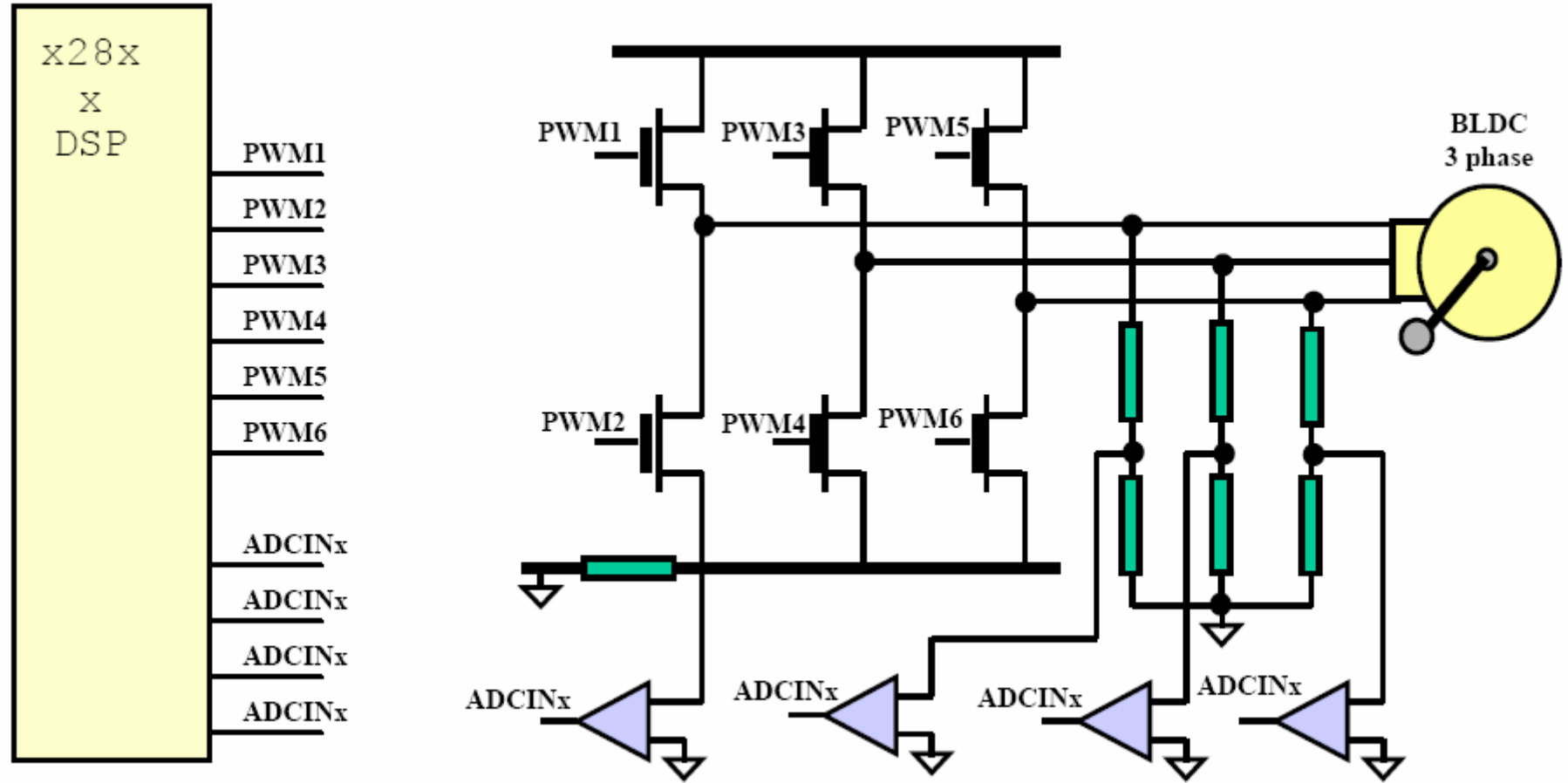
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BLDC Control Using Hall Sensor



Sensorless BLDC Drive

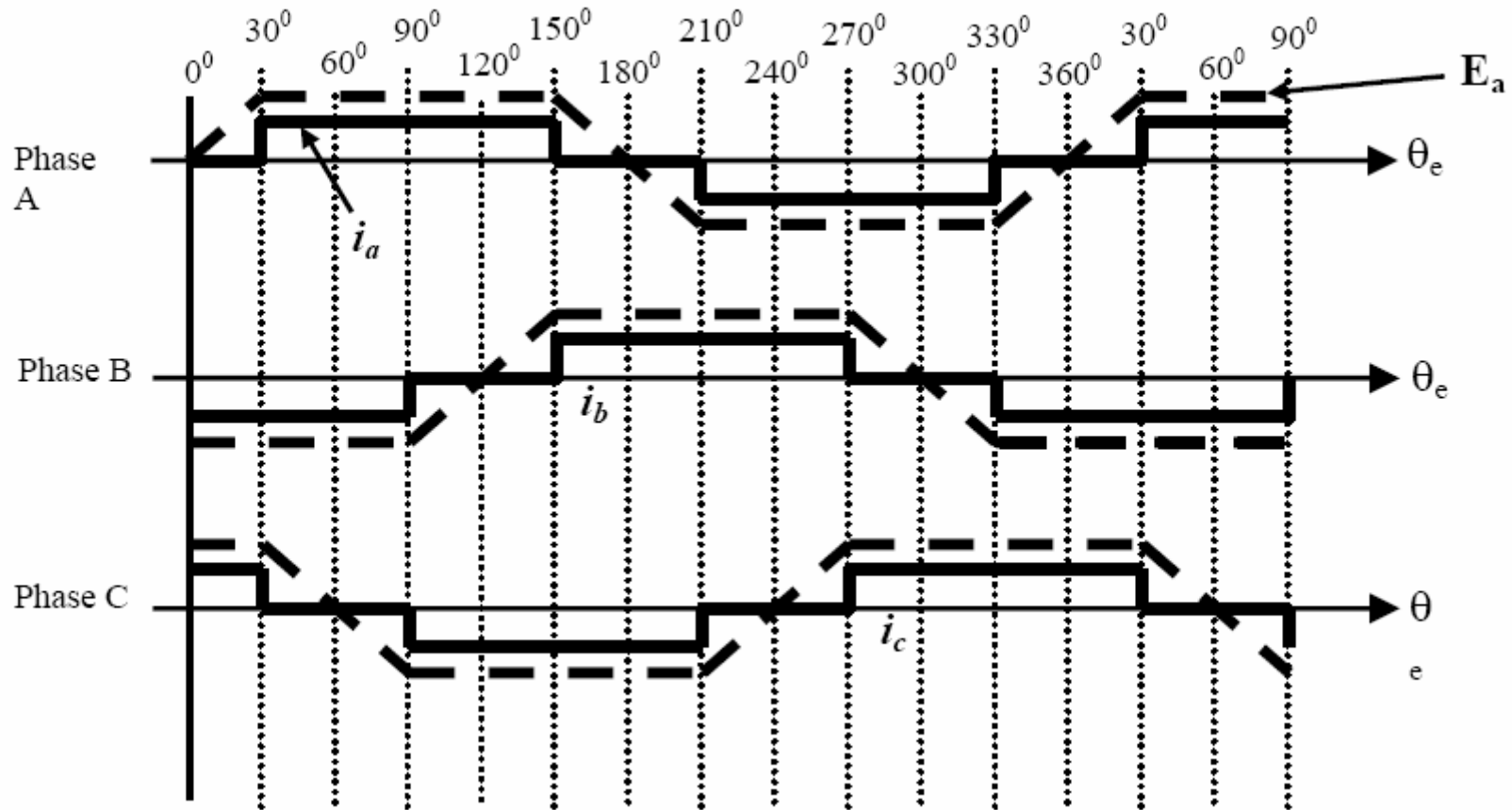


A 3-ph Brushless DC motor drive implementation

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Sensorless BLDC Drive

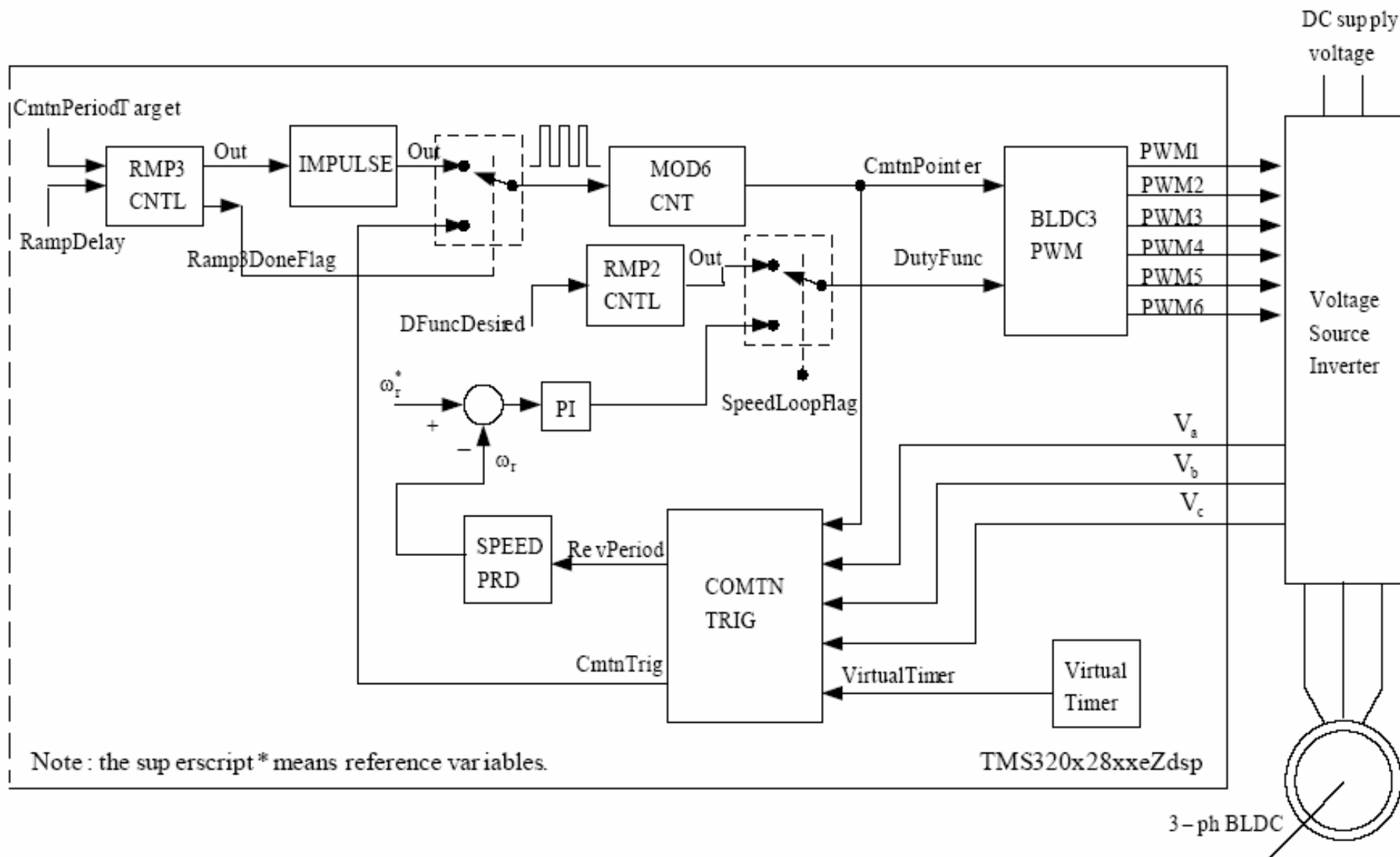


Typical Current and BEMF waveforms in BLDC Motor Drive

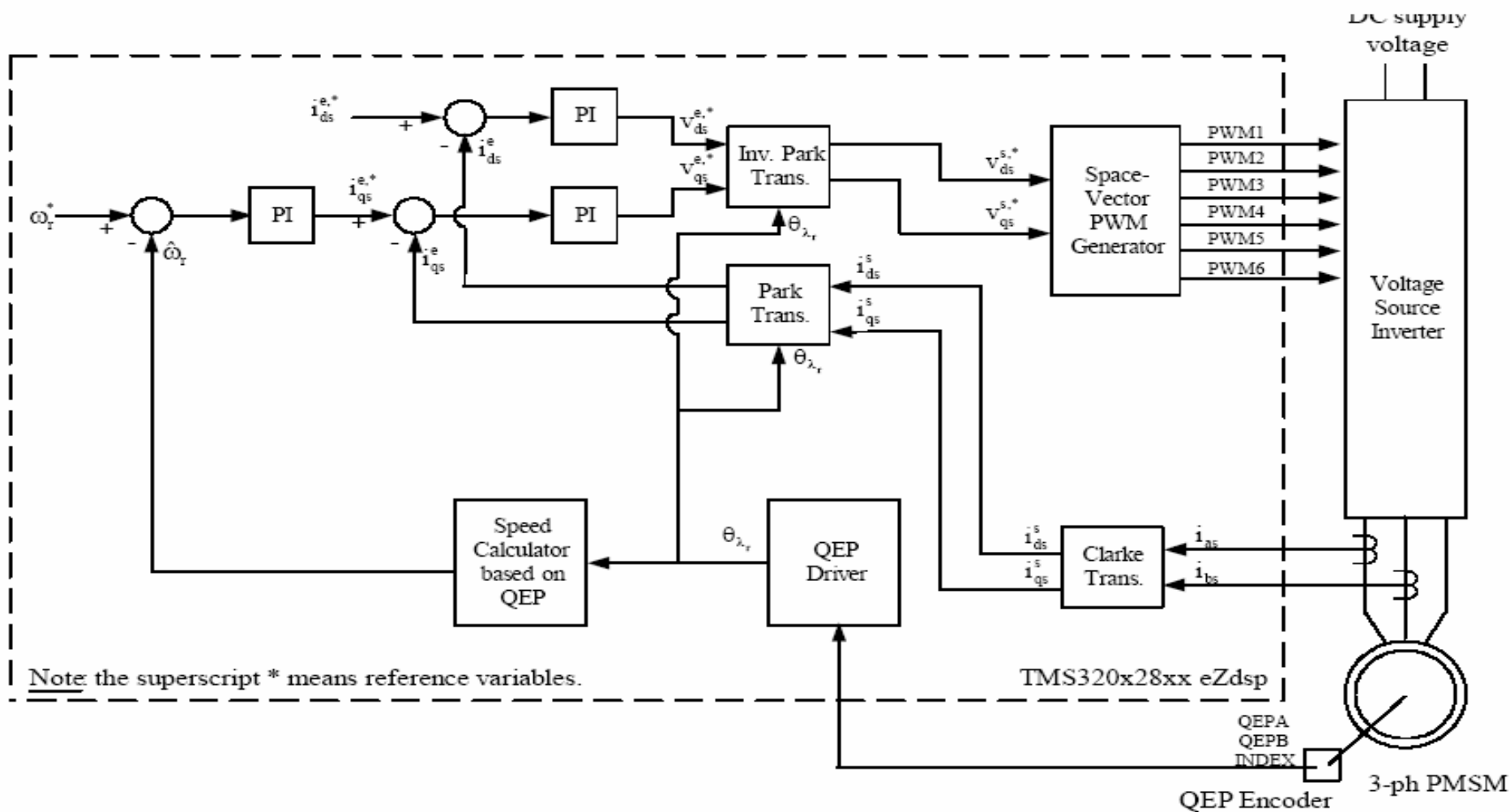
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Sensorless BLDC Drive

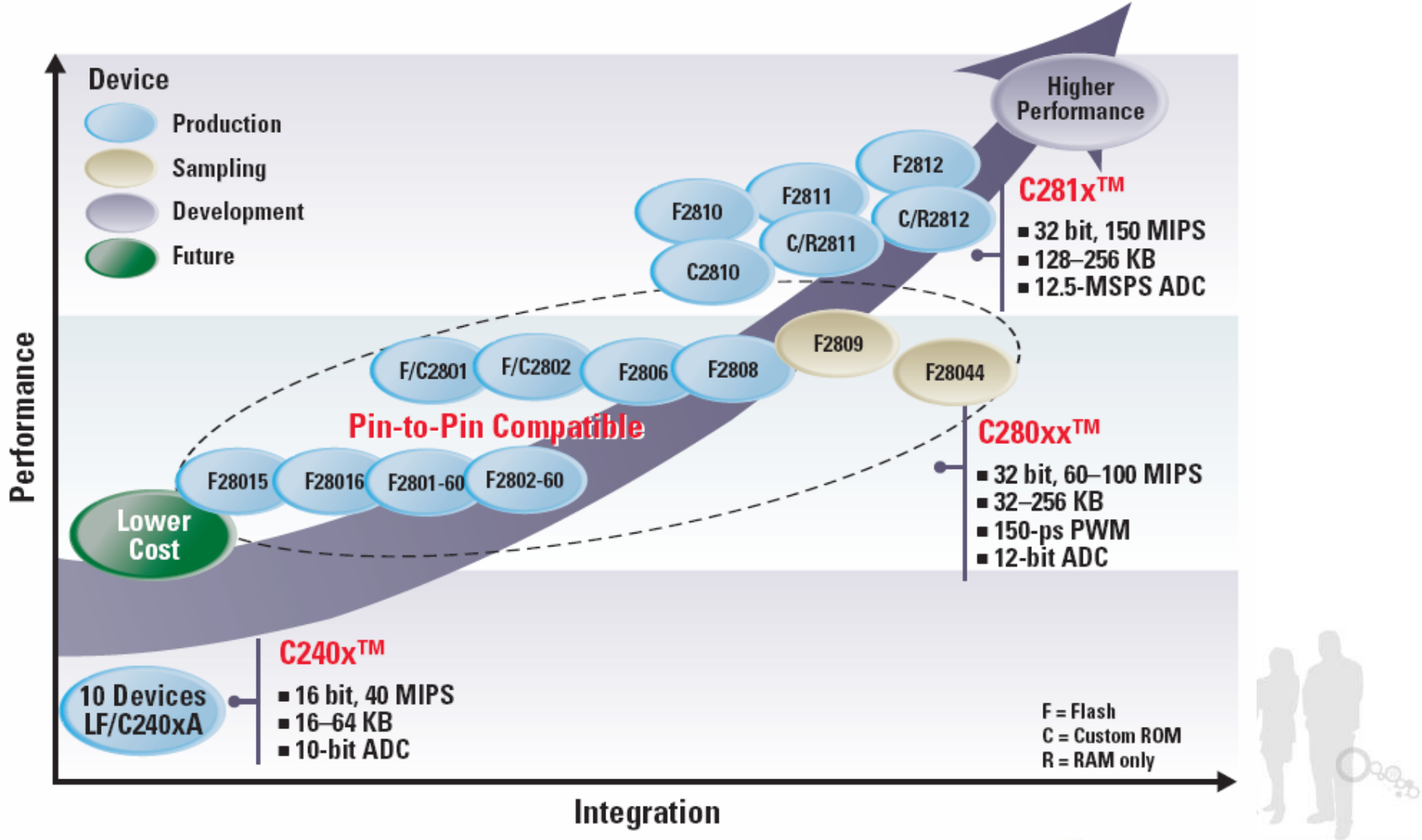


Field Oriented Control of PMSM



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 世界上控制最佳化的 **DSPs**



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Device ¹ (F) Flash (R) RAM-Only (C) ROM	MIPS	Boot ROM	RAM	Flash/ ROM	Timers	CAP/ QEP	PWM Channels	# HiRes PWM	12-Bit A/D Chs/ Conversion Time (ns)
TMS320F28015 - PZA/S/Q	60	8 KB	12 KB	32 KB	9	2/0	8 + 2	4	16 ch/267
TMS320F28016 - PZA/S/Q	60	8 KB	12 KB	32 KB	9	2/0	8 + 2	4	16 ch/267
TMS320F2801-60 - PZA/S/Q	60	8 KB	12 KB	32 KB	9	2/1	6 + 2	3	16 ch/267
TMS320F2802-60 - PZA/S/Q	60	8 KB	12 KB	64 KB	9	2/1	6 + 2	3	16 ch/267
TMS320F2801-PZA/S/Q	100	8 KB	12 KB	32 KB	9	2/1	6 + 2	3	16 ch/160
TMS320F2801-GGMA/S ² , ZGMA/S	100	8 KB	12 KB	32 KB	9	2/1	6 + 2	3	16 ch/160
TMS320F2802-PZA/S/Q	100	8 KB	12 KB	64 KB	9	2/1	6 + 2	3	16 ch/160
TMS320F2802-GGMA/S ² , ZGMA/S	100	8 KB	12 KB	64 KB	9	2/1	6 + 2	3	16 ch/160
TMS320F2806-PZA/S/Q	100	8 KB	20 KB	64 KB	15	4/2	12 + 4	4	16 ch/160
TMS320F2806-GGMA/S ² , ZGMA/S	100	8 KB	20 KB	64 KB	15	4/2	12 + 4	4	16 ch/160
TMS320F28044-PZA/S	100	8 KB	20 KB	128 KB	19	0/0	16	16	16 ch/80
TMS320F2808-PZA/S/Q	100	8 KB	36 KB	128 KB	15	4/2	12 + 4	4	16 ch/160
TMS320F2808-GGMA/S ² , ZGMA/S	100	8 KB	36 KB	128 KB	15	4/2	12 + 4	4	16 ch/160
TMS320F2809-PZA/S/Q	100	8 KB	36 KB	256 KB	15	4/2	12 + 4	6	16 ch/80
TMS320F2809-GGMA/S ² , ZGMA/S	100	8 KB	36 KB	256 KB	15	4/2	12 + 4	6	16 ch/80
TMS320F2810-PBKA/S/Q	150	8 KB	36 KB	128 KB	7	6/2	16	-	16 ch/80
TMS320F2811-PBKA/S/Q	150	8 KB	36 KB	256 KB	7	6/2	16	-	16 ch/80
TMS320F2812-GHHA/S ² , ZHHA/S	150	8 KB	36 KB	256 KB	7	6/2	16	-	16 ch/80
TMS320F2812-PGFA/S/Q	150	8 KB	36 KB	256 KB	7	6/2	16	-	16 ch/80



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Device ¹ (F) Flash (R) RAM-Only (C) ROM	EMIF	WD Timer	Comm Ports				I/O Pins	Core Voltage (V)	Packaging	1 KU (\$U.S.) [*]
			Other	SPI	SCI	CAN				
TMS320F28015 - PZA/S/Q	-	Y	I ² C	1	1	0	35	1.8	100 LQFP	3.25
TMS320F28016 - PZA/S/Q	-	Y	I ² C	1	1	1	35	1.8	100 LQFP	3.50
TMS320F2801-60 - PZA/S/Q	-	Y	I ² C	2	1	1	35	1.8	100 LQFP	3.95
TMS320F2802-60 - PZA/S/Q	-	Y	I ² C	2	1	1	35	1.8	100 LQFP	4.75
Table Separator										
TMS320F2801-PZA/S/Q	-	Y	I ² C	2	1	1	35	1.8	100 LQFP	5.80
TMS320F2801-GGMA/S ² , ZGMA/S	-	Y	I ² C	2	1	1	35	1.8	100 BGA	5.80
TMS320F2802-PZA/S/Q	-	Y	I ² C	2	1	1	35	1.8	100 LQFP	7.10
TMS320F2802-GGMA/S ² , ZGMA/S	-	Y	I ² C	2	1	1	35	1.8	100 BGA	7.10
TMS320F2806-PZA/S/Q	-	Y	I ² C	4	2	1	35	1.8	100 LQFP	8.70
TMS320F2806-GGMA/S ² , ZGMA/S	-	Y	I ² C	4	2	1	35	1.8	100 BGA	8.70
TMS320F28044-PZA/S	-	Y	I ² C	1	1	0	35	1.8	100 LQFP	9.95
TMS320F2808-PZA/S/Q	-	Y	I ² C	4	2	2	35	1.8	100 LQFP	11.60
TMS320F2808-GGMA/S ² , ZGMA/S	-	Y	I ² C	4	2	2	35	1.8	100 BGA	11.60
TMS320F2809-PZA/S/Q	-	Y	I ² C	4	2	2	35	1.8	100 LQFP	12.95
TMS320F2809-GGMA/S ² , ZGMA/S	-	Y	I ² C	4	2	2	35	1.8	100 BGA	12.95
Table Separator										
TMS320F2810-PBKA/S/Q	-	Y	McBSP	1	2	1	56	1.9	128 LQFP	13.85
TMS320F2811-PBKA/S/Q	-	Y	McBSP	1	2	1	56	1.9	128 LQFP	14.75
TMS320F2812-GHHA/S ² , ZHHA/S	Y	Y	McBSP	1	2	1	56	1.9	179 BGA	15.65
TMS320F2812-PGFA/S/Q	Y	Y	McBSP	1	2	1	56	1.9	176 LQFP	15.65



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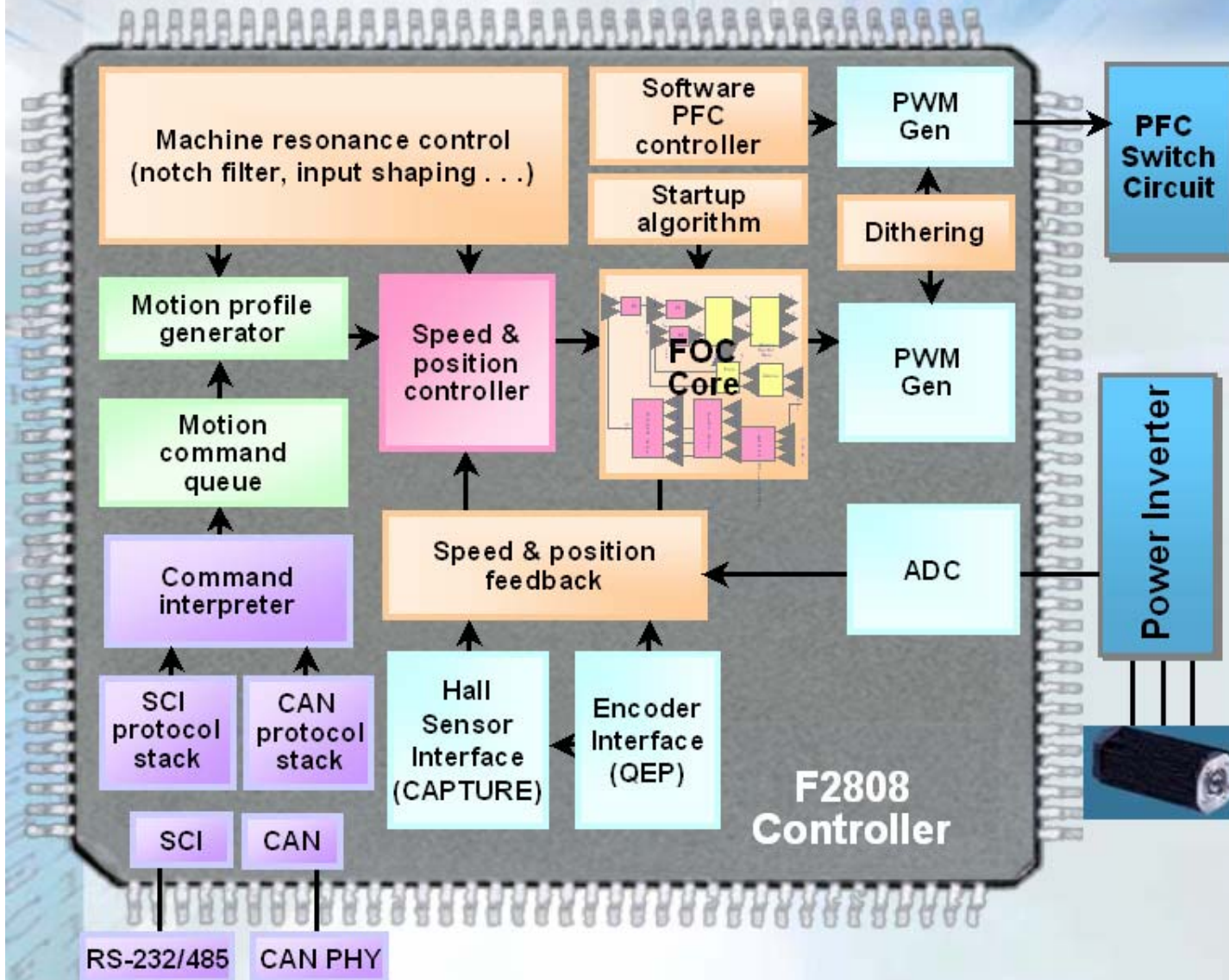
FEATURE		F2809	F2808	F2806	F2802	F2801
Instruction cycle (at 100 MHz)		10 ns	10 ns	10 ns	10 ns	10 ns
Single-access RAM (SARAM) (16-bit word)		18K (L0, L1, M0, M1, H0)	18K (L0, L1, M0, M1, H0)	10K (L0, L1, M0, M1)	6K (L0, M0, M1)	6K (L0, M0, M1)
3.3-V on-chip flash (16-bit word)		128K	64K	32K	32K	16K
On-chip ROM (16-bit word)		-	-	-	-	-
Code security for on-chip flash/SARAM/OTP blocks		Yes	Yes	Yes	Yes	Yes
Boot ROM (4K X16)		Yes	Yes	Yes	Yes	Yes
One-time programmable (OTP) ROM (16-bit word)		1K	1K	1K	1K	1K
PWM outputs		ePWM1/2/3/4/5/6	ePWM1/2/3/4/5/6	ePWM1/2/3/4/5/6	ePWM1/2/3	ePWM1/2/3
HRPWM channels		ePWM1A/2A/3A/ 4A/5A/6A	ePWM1A/2A/ 3A/4A	ePWM1A/2A/ 3A/4A	ePWM1A/2A/3A	ePWM1A/2A/3A
32-bit CAPTURE inputs or auxiliary PWM outputs		eCAP1/2/3/4	eCAP1/2/3/4	eCAP1/2/3/4	eCAP1/2	eCAP1/2
32-bit QEP channels (four inputs/channel)		eQEP1/2	eQEP1/2	eQEP1/2	eQEP1	eQEP1
Watchdog timer		Yes	Yes	Yes	Yes	Yes
12-Bit ADC channels		16	16	16	16	16
32-Bit CPU timers		3	3	3	3	3
Serial Peripheral Interface (SPI)		SPI-A/B/C/D	SPI-A/B/C/D	SPI-A/B/C/D	SPI-A/B	SPI-A/B
Serial Communications Interface (SCI)		SCI-A/B	SCI-A/B	SCI-A/B	SCI-A	SCI-A
Enhanced Controller Area Network (eCAN)		eCAN-A/B	eCAN-A/B	eCAN-A	eCAN-A	eCAN-A
Inter-Integrated Circuit (I ² C)		I ² C-A	I ² C-A	I ² C-A	I ² C-A	I ² C-A
Digital I/O pins (shared)		35	35	35	35	35
External interrupts		3	3	3	3	3
Supply voltage	1.8-V Core, 3.3-V I/O	Yes	Yes	Yes	Yes	Yes
Packaging	100-Pin PZ	Yes	Yes	Yes	Yes	Yes
	100-Ball GGM, ZGM	Yes	Yes	Yes	Yes	Yes
Temperature options	A: -40°C to 85°C	(PZ, GGM, ZGM)	(PZ, GGM, ZGM)	(PZ, GGM, ZGM)	(PZ, GGM, ZGM)	(PZ, GGM, ZGM)
	S: -40°C to 125°C	(PZ, GGM, ZGM)	(PZ, GGM, ZGM)	(PZ, GGM, ZGM)	(PZ, GGM, ZGM)	(PZ, GGM, ZGM)
	Q: -40°C to 125°C	(PZ)	(PZ)	(PZ)	(PZ)	(PZ)
Product status ⁽¹⁾		TMX	TMS	TMS	TMS	TMS

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FEATURE		F2802-60	F2801-60	F28016	F28015
Instruction cycle (at 60 MHz)		16.67 ns	16.67 ns	16.67 ns	16.67 ns
Single-access RAM (SARAM) (16-bit word)		6K (L0, M0, M1)	6K (L0, M0, M1)	6K (L0, M0, M1)	6K (L0, M0, M1)
3.3-V on-chip flash (16-bit word)		32K	16K	16K	16K
On-chip ROM (16-bit word)		-	-	-	-
Code security for on-chip flash/SARAM/OTP blocks		Yes	Yes	Yes	Yes
Boot ROM (4K X16)		Yes	Yes	Yes	Yes
One-time programmable (OTP) ROM (16-bit word)		1K	1K	1K	1K
PWM outputs		ePWM1/2/3	ePWM1/2/3	ePWM1/2/3/4	ePWM1/2/3/4
HRPWM channels		ePWM1A/2A/3A	ePWM1A/2A/3A	ePWM1A/2A/3A/4A	ePWM1A/2A/3A/4A
32-bit CAPTURE inputs or auxiliary PWM outputs		eCAP1/2	eCAP1/2	eCAP1/2	eCAP1/2
32-bit QEP channels (four inputs/channel)		eQEP1	eQEP1	-	-
Watchdog timer		Yes	Yes	Yes	Yes
12-Bit ADC	No. of channels	16	16	16	16
	MSPS	3.75	3.75	3.75	3.75
	Conversion time	267 ns	267 ns	267 ns	267 ns
32-Bit CPU timers		3	3	3	3
Serial Peripheral Interface (SPI)		SPI-A/B	SPI-A/B	SPI-A	SPI-A
Serial Communications Interface (SCI)		SCI-A	SCI-A	SCI-A	SCI-A
Enhanced Controller Area Network (eCAN)		eCAN-A	eCAN-A	eCAN-A	
Inter-Integrated Circuit (I ² C)		I ² C-A	I ² C-A	I ² C-A	I ² C-A
Digital I/O pins (shared)		35	35	35	35
External interrupts		3	3	3	3
Supply voltage		1.8-V Core, 3.3-V I/O	1.8-V Core, 3.3-V I/O	1.8-V Core, 3.3-V I/O	1.8-V Core, 3.3-V I/O
Packaging	100-Pin PZ	Yes	Yes	Yes	Yes
Temperature options	A: -40°C to 85°C	(PZ)	(PZ)	(PZ)	(PZ)
	S: -40°C to 125°C	(PZ)	(PZ)	(PZ)	(PZ)
	Q: -40°C to 125°C	(PZ)	(PZ)	(PZ)	(PZ)
Product status ⁽¹⁾		TMS	TMS	TMS	TMS



Reducing System Costs in DMC Systems



- ◆ Discrete PFC controller eliminated
- ◆ Replaced trapezoidal or sine commutation with FOC → Enhanced performance
- ◆ Machine resonance control → Performance enhancement & cost saving on damper
- ◆ Moved motion profile processing into same processor → Eliminates second microprocessor
- ◆ Added Spread spectrum PWM Generation → Reduces size of EMI filter (cost savings)

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C28 DSP 新寵兒 --

發展工具 : F2808 eZdsp



C28 DSP 新寵兒 → F280x

周邊功能更強大且極具價格優勢

- ❑ 與F281x 相容之核心架構, 記憶體, 周邊等等
- ❑ Atomic instructions , IQ math, Interrupt Latency
- ❑ Peripheral enhancement
 - 4 HRPWM
 - 12 Enhanced PWM outputs
 - PWM chopper module
 - Trip-zone module
 - 4 Enhanced Capture
 - 2 Enhanced QEP
 - 6 32-bit timers
 - 6 16-bit timers
 - 1 I²C, 4 SPI, 2 SCI, 2 eCAN
 - 35 GPIO
 -
- ❑ F2808, F2806, F2801 are pin-to-pin.



ADC module

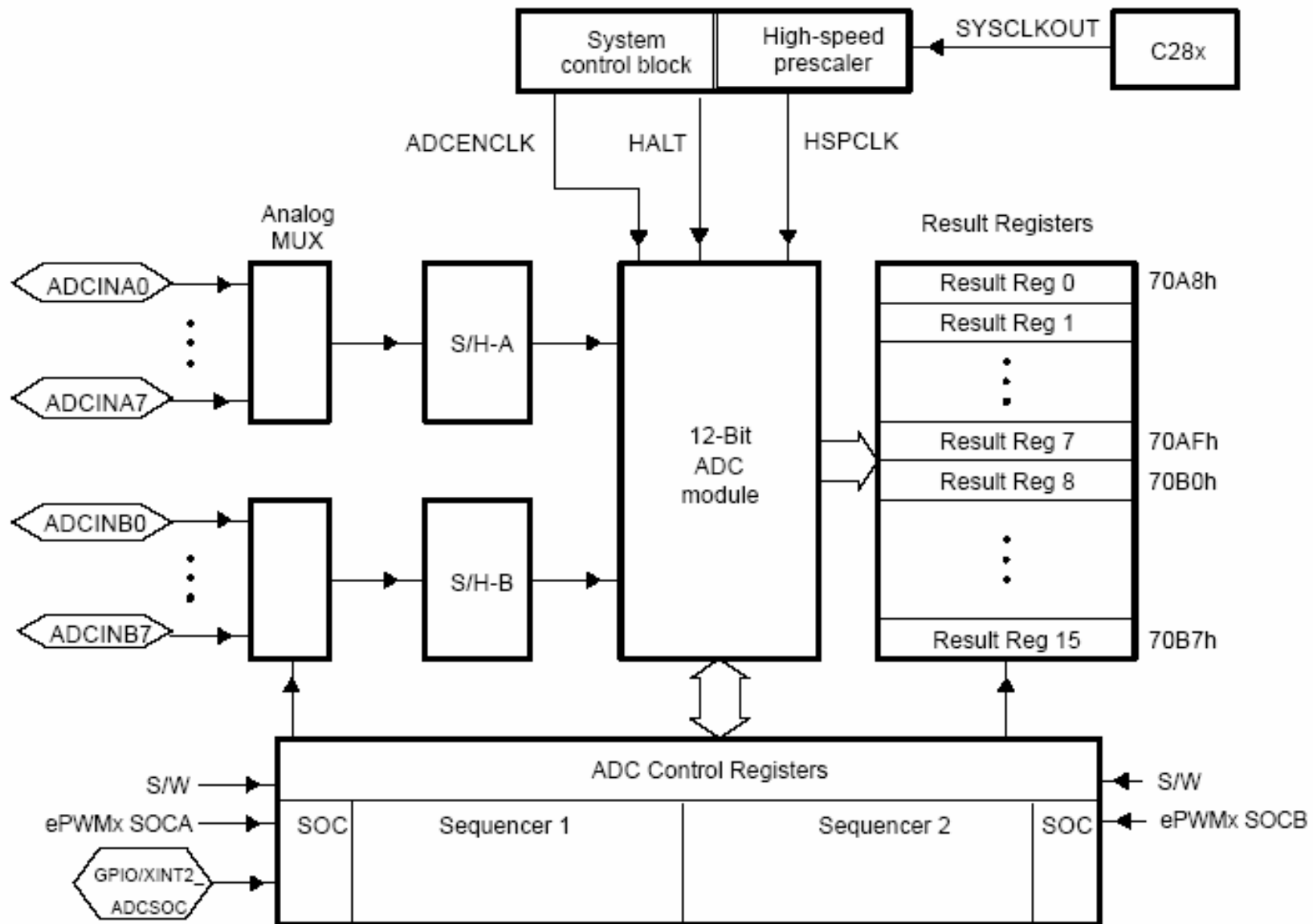


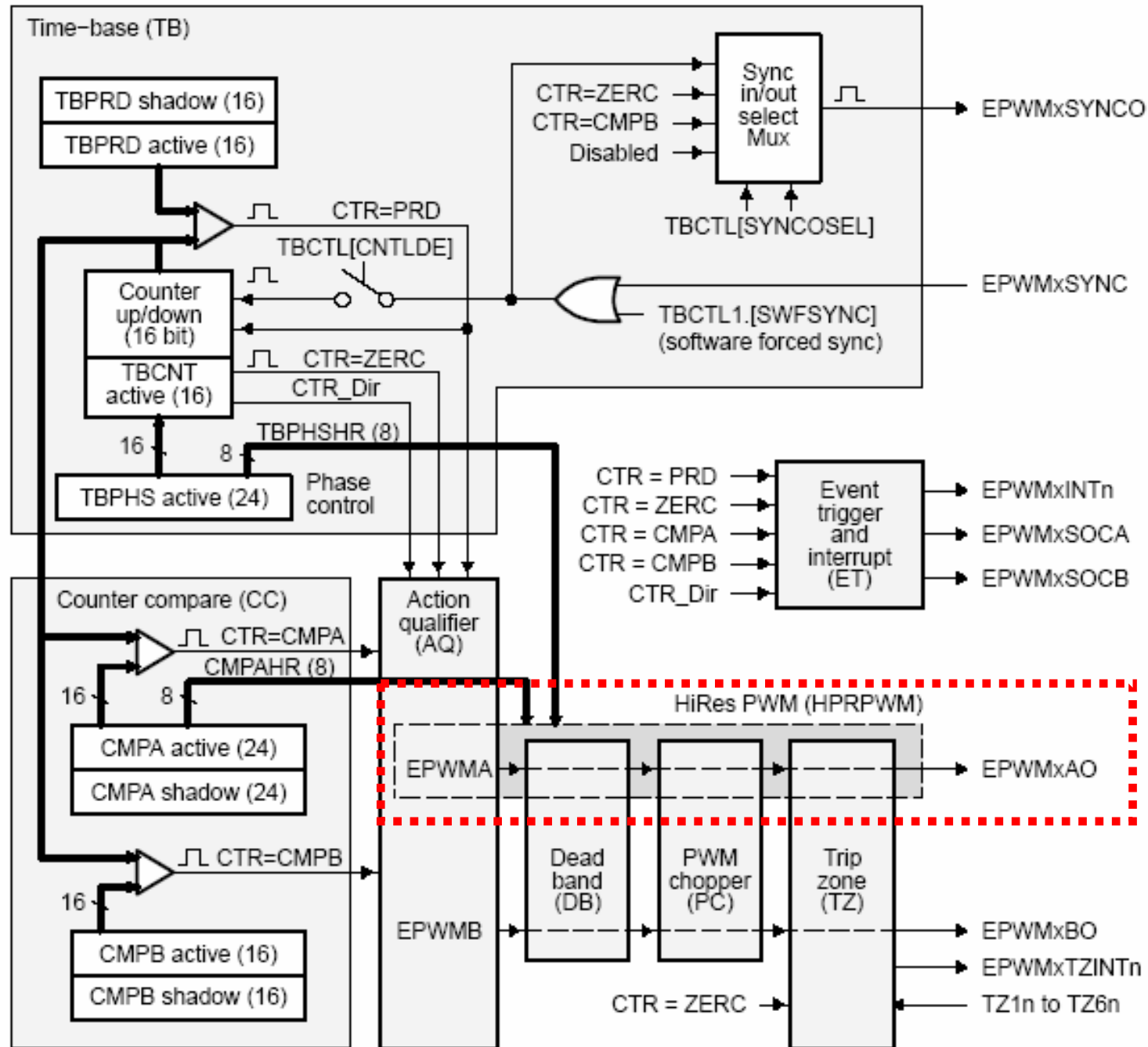
Table 1-1. Resolution for PWM and HRPWM

PWM Freq (KHz)	Regular Resolution (PWM)		High Resolution (HRPWM)	
	Bits	%	Bits	%
20	12.3	0.0	18.1	0.000
50	11.0	0.0	16.8	0.001
100	10.0	0.1	15.8	0.002
150	9.4	0.2	15.2	0.003
200	9.0	0.2	14.8	0.004
250	8.6	0.3	14.4	0.005
500	7.6	0.5	13.8	0.007
1000	6.6	1.0	12.4	0.018
1500	6.1	1.5	11.9	0.027
2000	5.6	2.0	11.4	0.036

Although each application may differ, typical low frequency PWM operation (below 250 KHz) may not require HRPWM. HRPWM capability is most useful for high frequency PWM requirements of power conversion topologies such as:

- Single-Phase Buck, Boost, and Flyback
- Multi-Phase Buck, Boost, and Flyback
- Phase-Shifted Full Bridge
- Direct modulation of D-Class Power Amplifiers

Figure 2-3. HRPWM System Interface



Enhanced PWM

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Figure 1-2. Sub-Modules and Signal Connections for an ePWM Module

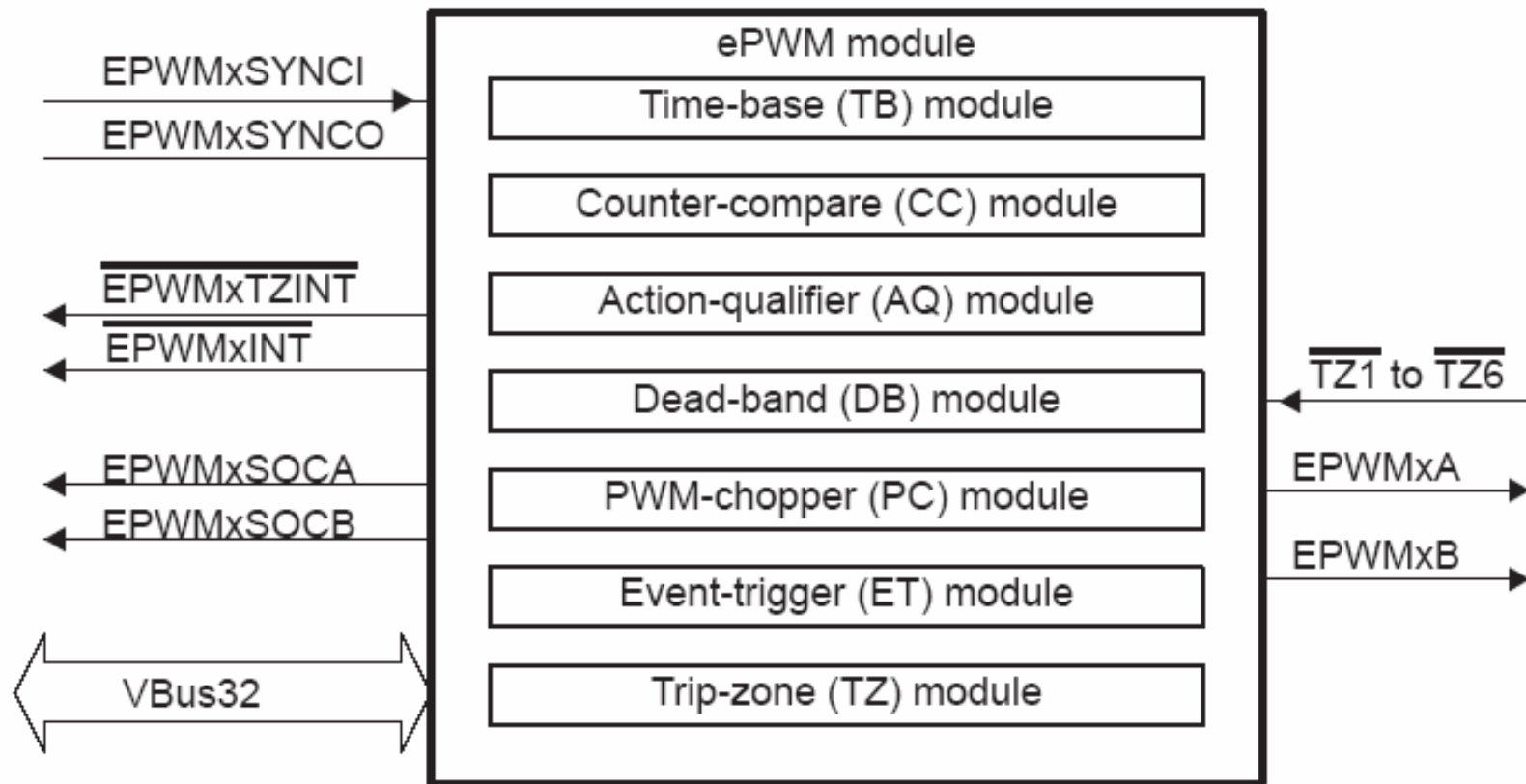
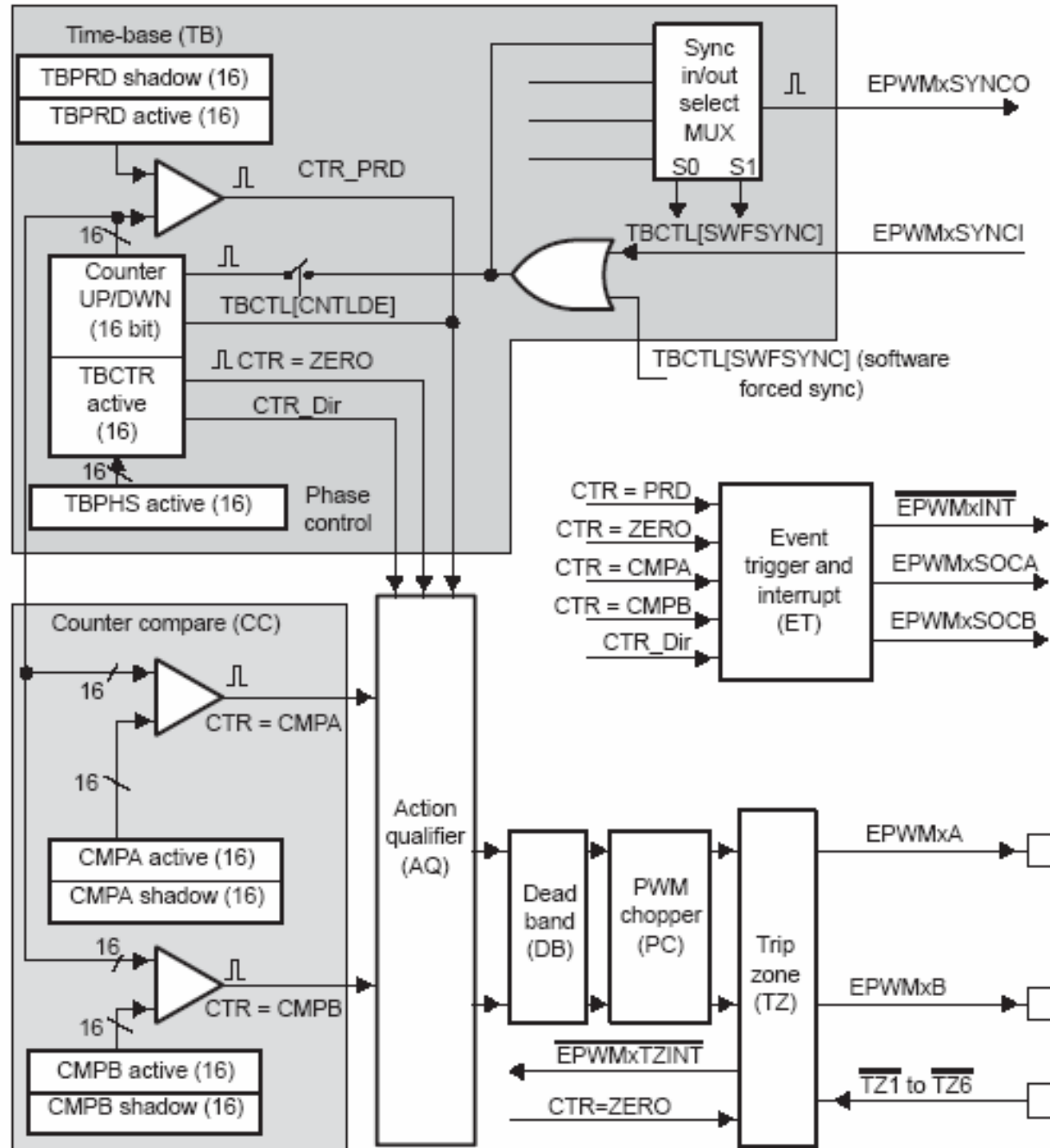


Figure 1-3. ePWM Sub-Modules Showing Critical Internal Signal Interconnects



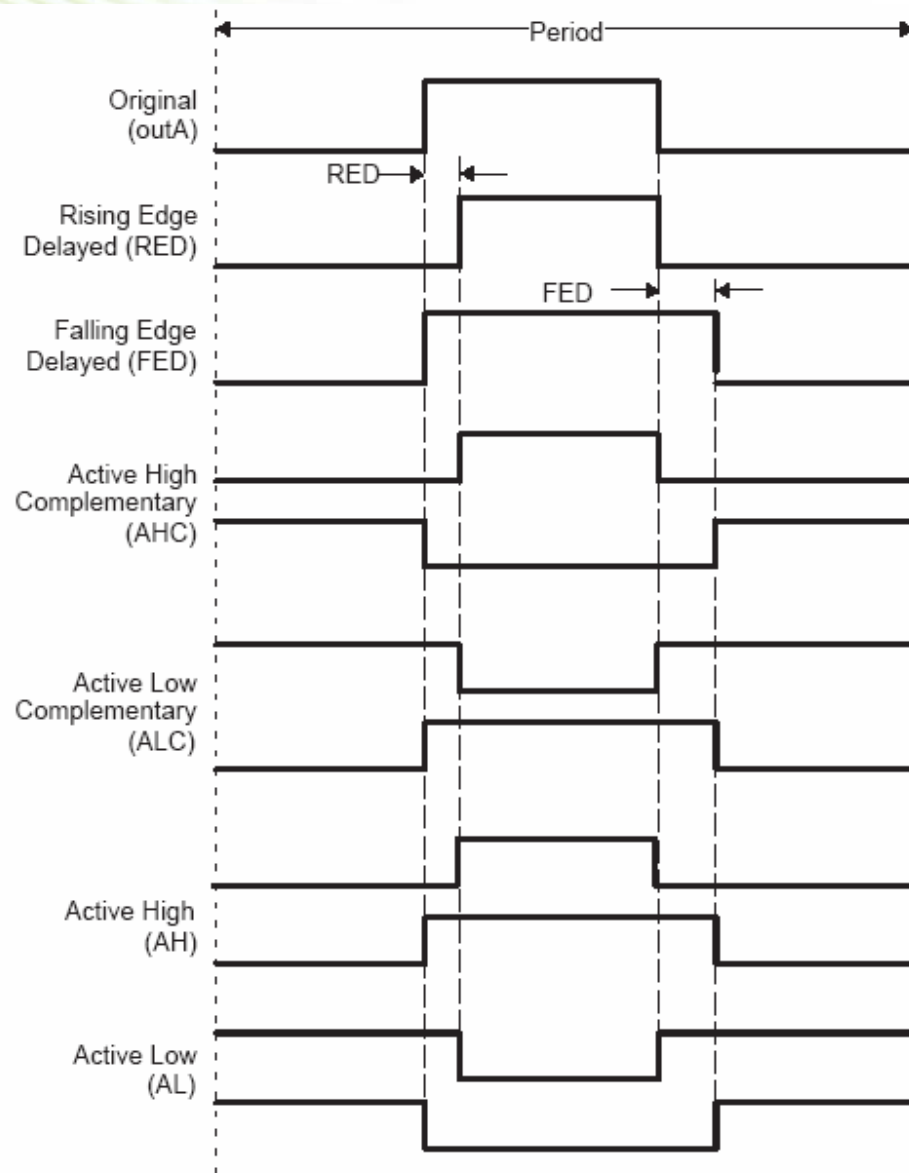
Each Enhanced PWM Module Has

- Dedicated 16-bit time base with Freq control
- Asynchronous override (forcing) control of PWM signal via software
- Programmable phase-control support for lag or lead operation relative to other ePWM modules
- Hardware-locked(Synchronized) phase relationship
- Dead-band generation with independent rising & falling edge delay control
- Trip → High, Low or high impedance state.
- All events can trigger both CPU interrupts and ADC SOC
- PWM chopping by high-freq carrier signal, useful for pulse transformer gate drives

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Dead Band Module Waveforms



Action-Qualifier (AQ) module

Purpose of the AQ Module

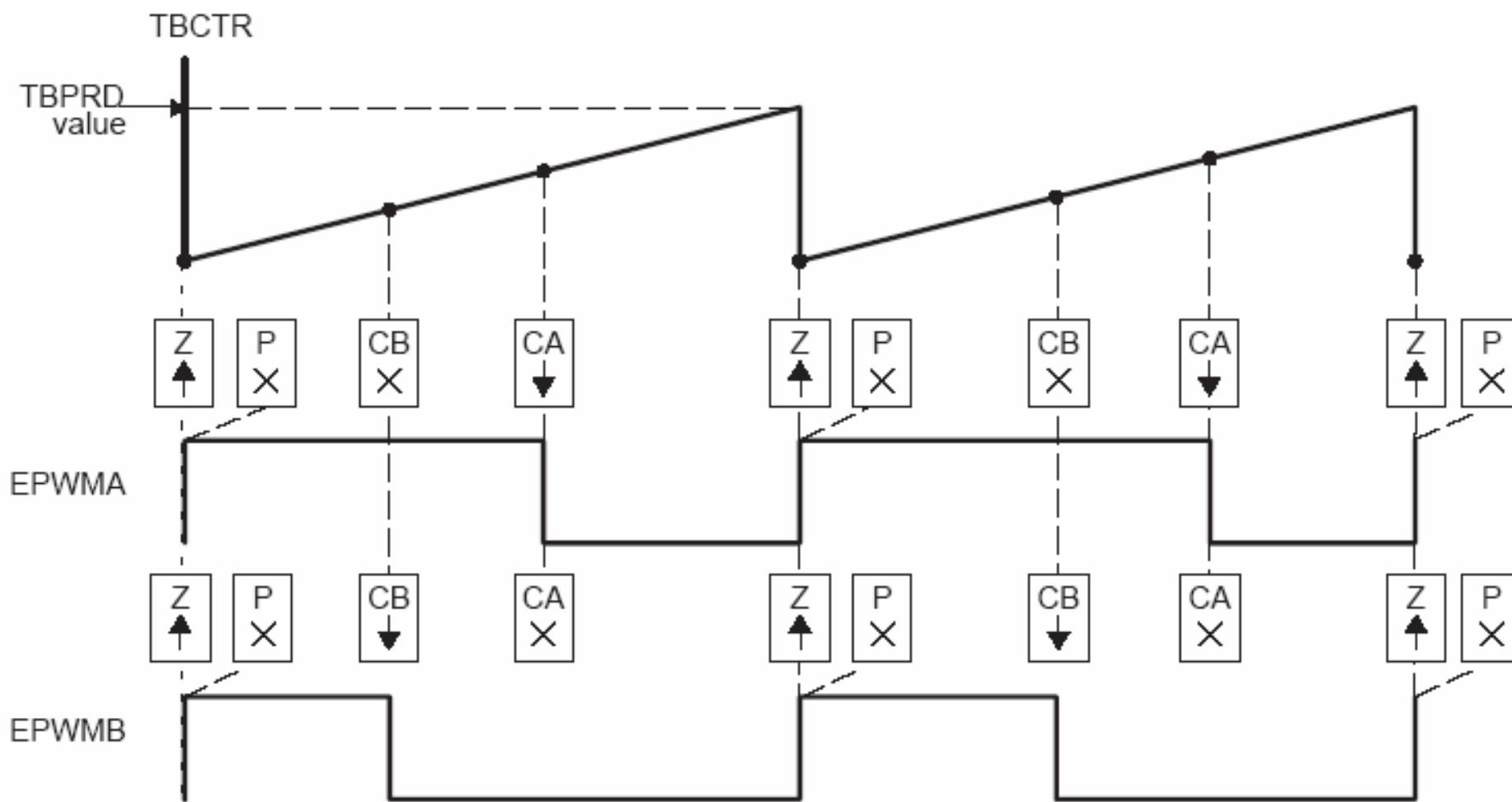
The AQ module is responsible for the following:

- Qualifying and generating actions (set, clear, toggle) based on the following input events:
 - CTR = PRD
 - CTR = Zero
 - CTR = CMPA
 - CTR = CMPB
- Managing priority when these events occur concurrently
- Using the time-base direction information (CTR_dir) as a further qualifier, to allow for independent control of up events and down events



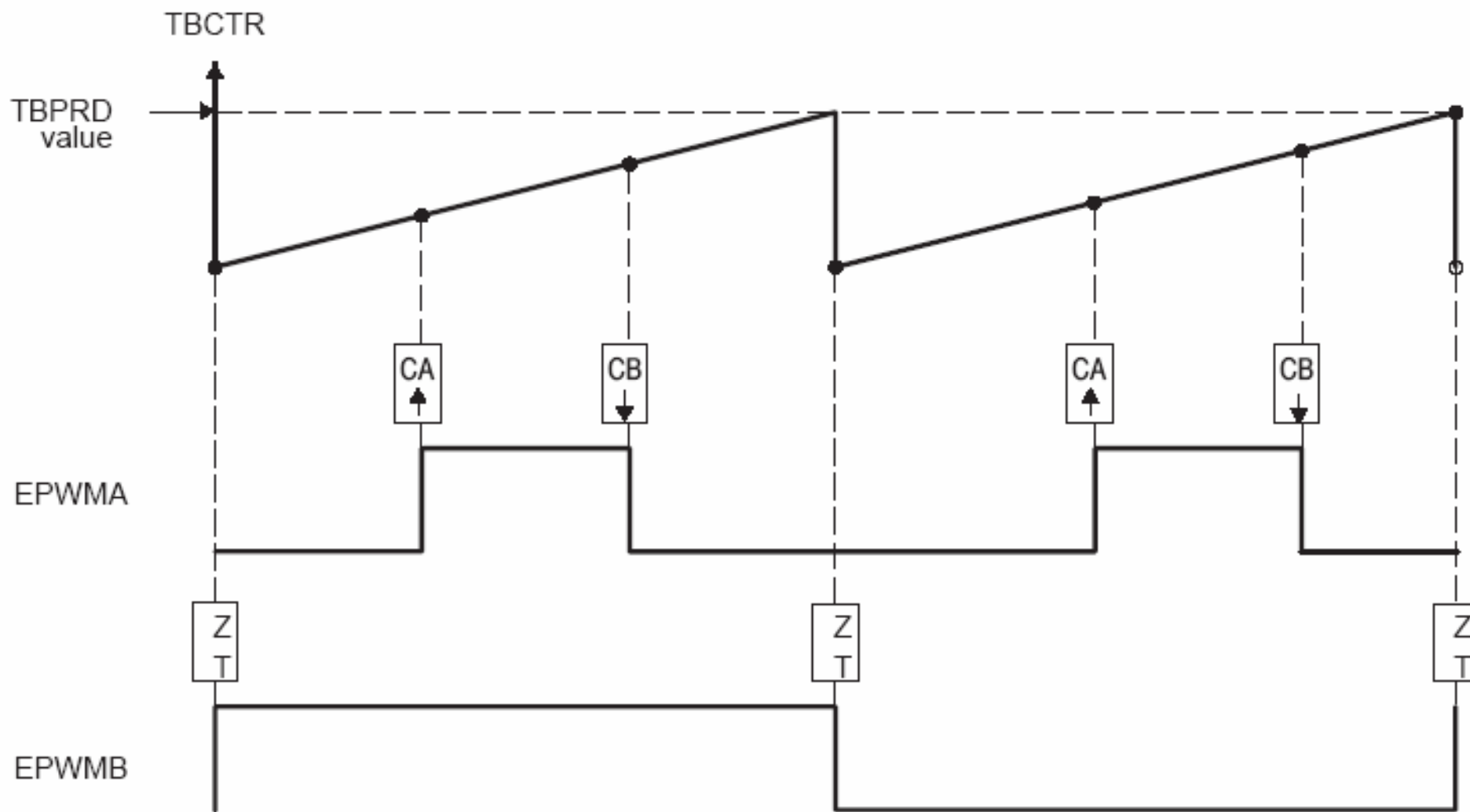
Figure 2-16. Set of AQ Qualifier Actions Possible for EPWMA and EPWMB

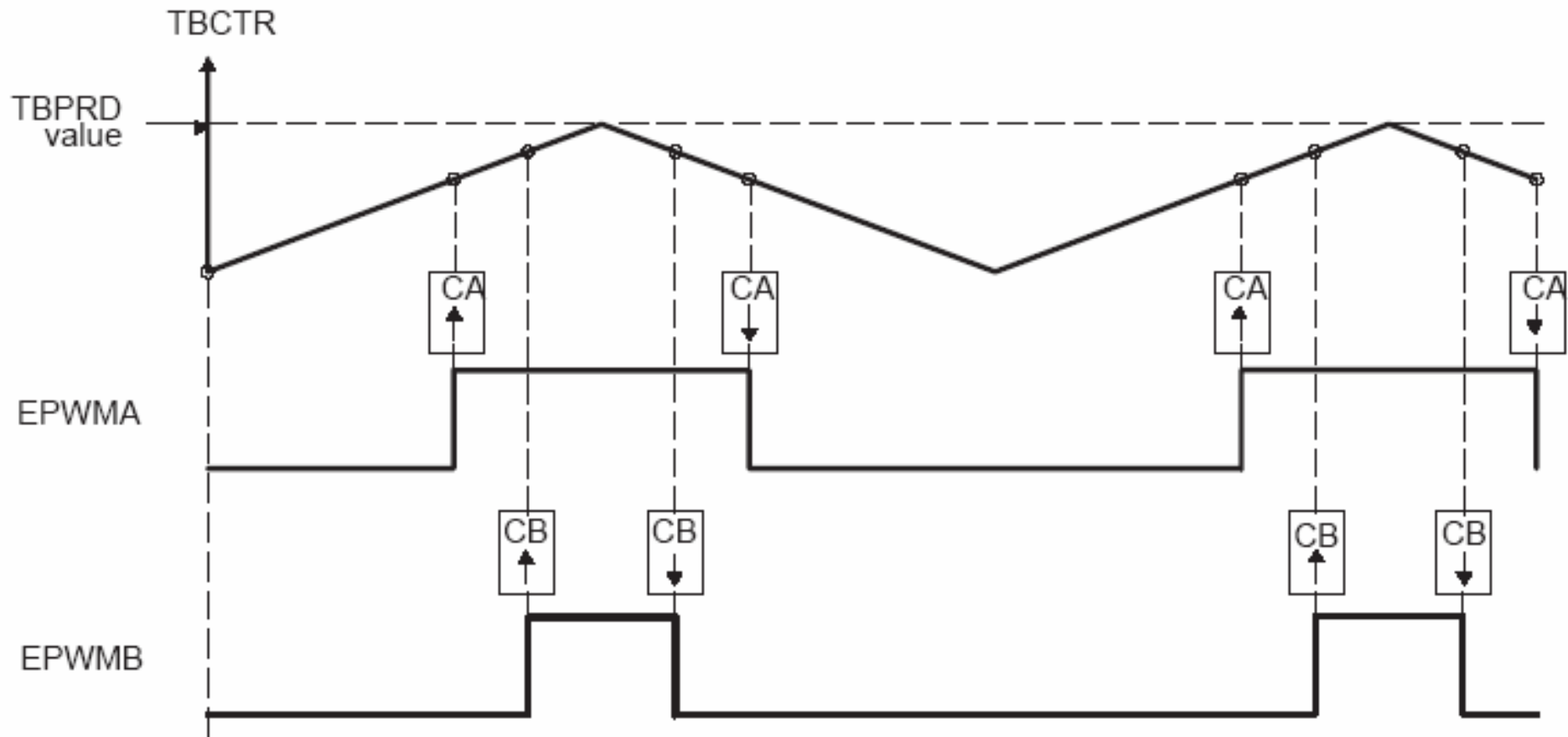
S/W force	TB Counter equals:				Actions
	Zero	Comp A	Comp B	Period	
SW X	Z X	CA X	CB X	P X	Do Nothing
SW ↓	Z ↓	CA ↓	CB ↓	P ↓	Clear Low
SW ↑	Z ↑	CA ↑	CB ↑	P ↑	Set High
SW T	Z T	CA T	CB T	P T	Toggle



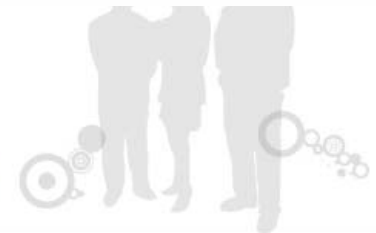
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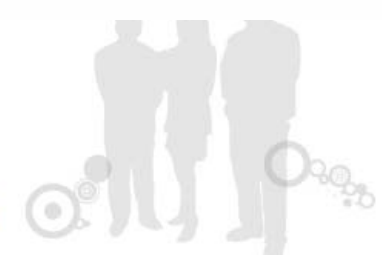
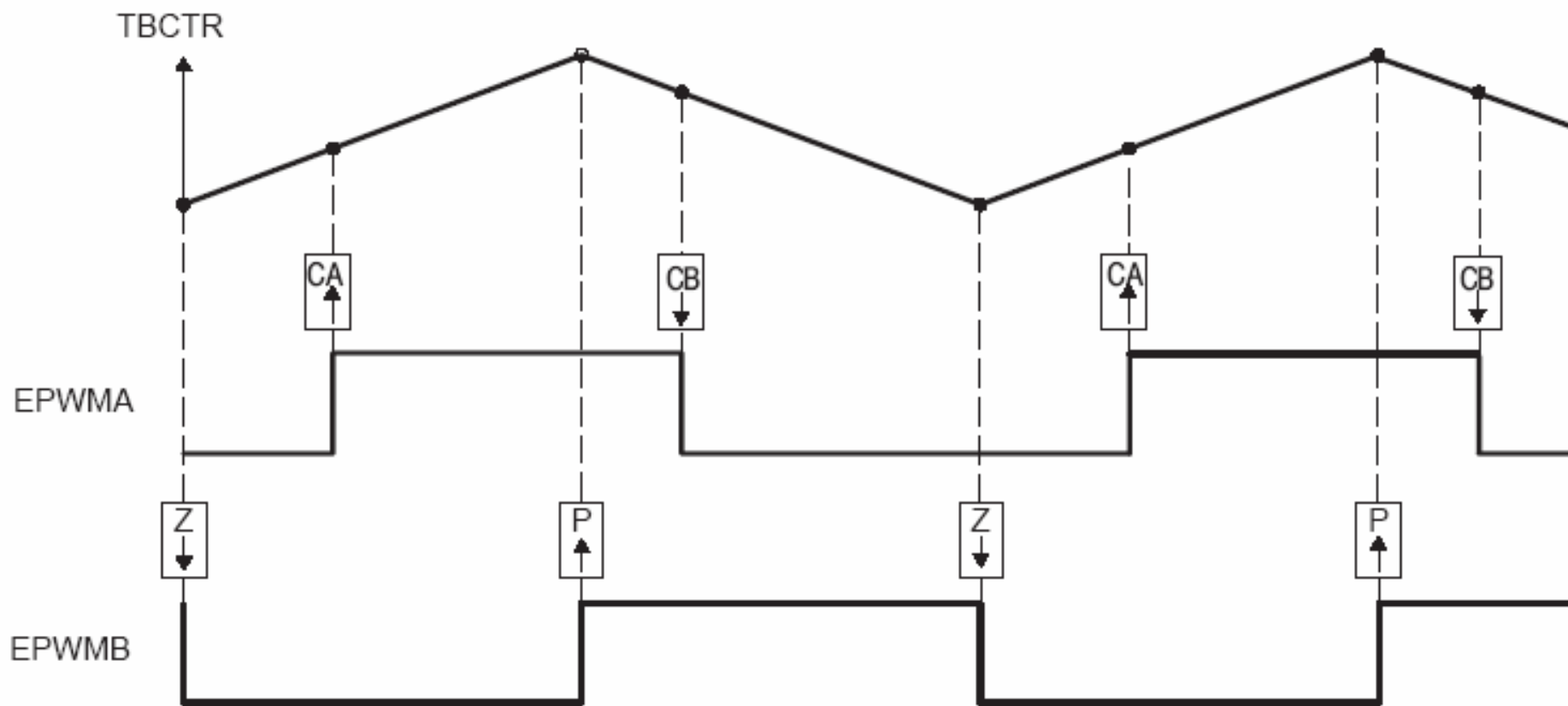






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Purpose of the TZ Module

The key functions of the TZ module are:

- ❑ Trip inputs \overline{TZn} (i.e., $\overline{TZ1}$ to $\overline{TZ6}$) can be flexibly mapped to any ePWM module.
- ❑ Upon a fault condition, outputs EPWMxA and EPWMxB can be forced to one of the following:
 - High
 - Low
 - Hi-Z (high impedance)
 - No action taken

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Purpose of the PC Module

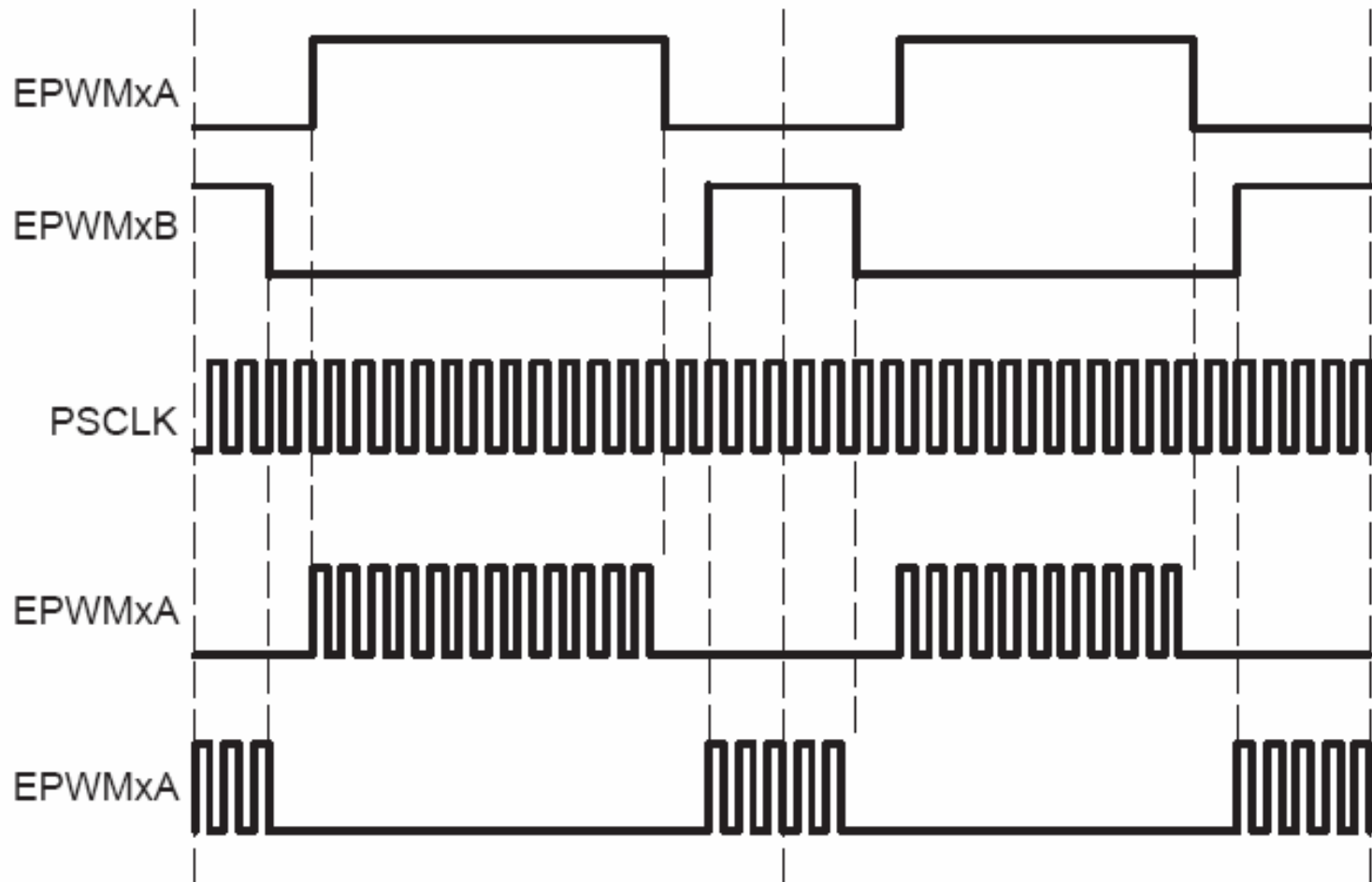
The key functions of the PC module are:

- Programmable chopping (carrier) frequency
- Programmable pulse width of first pulse
- Programmable duty cycle of second and subsequent pulses
- Can be fully bypassed if not required

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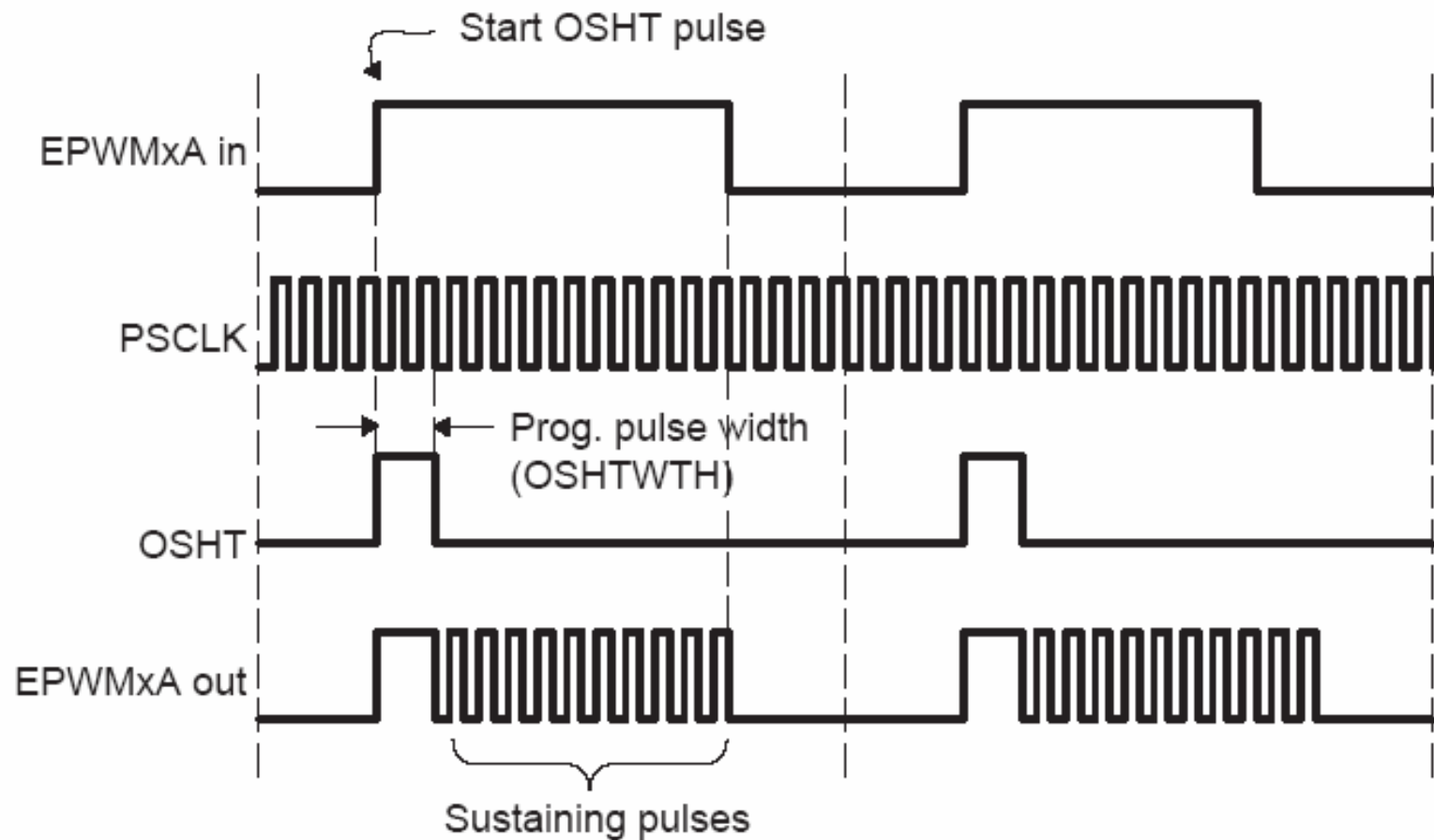
Figure 2-28. Simple PC Module Waveforms Showing Chopping Action Only



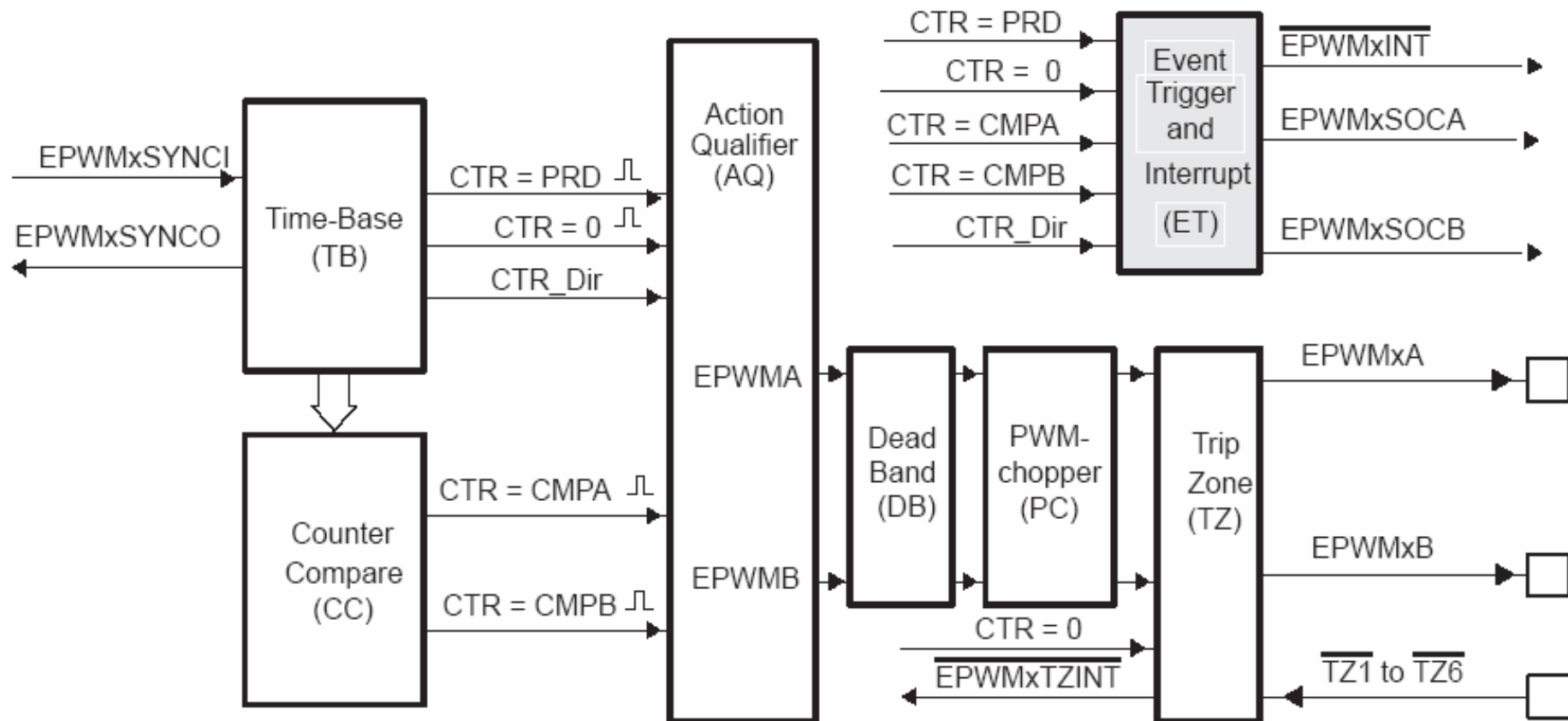
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Figure 2–29. PC Module Waveforms Showing the First Pulse and Subsequent Sustaining Pulses



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 Figure 2-34. ET Module



The ET module manages the events generated by the TB module and the CC module to generate an interrupt to the CPU and/or a start of conversion pulse to the ADC when a selected event occurs.

Purpose of the ET Module

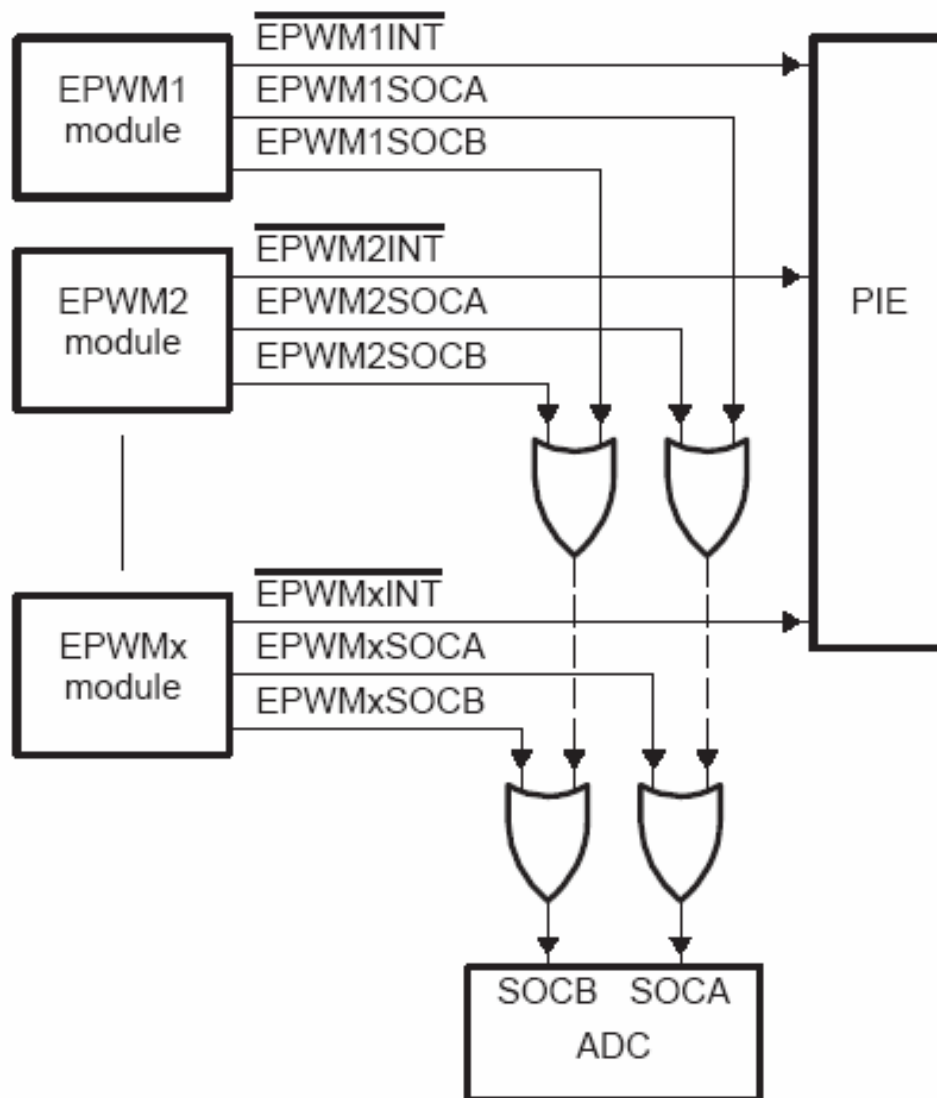
The key functions of the **ET module** are:

- Receives event inputs generated by the TB and CC modules
- Uses the TB direction information for up/down event qualification
- Uses prescaling logic to issue interrupt requests and ADC SOC at:
 - Every event
 - Every second event
 - Every third event
- Provides full visibility of event generation via event counters and flags
- Allows software forcing of Interrupts and ADC SOC

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ET Module Inter-Module Connectivity of SOC and Interrupt Signals



Enhanced Capture

Uses for eCAP include:

- Speed measurements of rotating machinery (e.g., toothed sprockets sensed via Hall sensors)
- Elapsed time measurements between position sensor pulses
- Period and duty cycle measurements of pulse train signals
- Decoding current or voltage amplitude derived from duty cycle encoded current/voltage sensors

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The eCAP module described in this guide includes the following features:

- 32-bit time base with 10-nS time resolution with a 100-MHz system clock
- 4-event time-stamp registers (each 32 bits)
- Edge polarity selection for up to four sequenced time-stamp capture events
- Interrupt on either of the four events
- Single shot capture of up to four event time-stamps
- Continuous mode capture of time-stamps in a four-deep circular buffer
- Absolute time-stamp capture
- Difference (Delta) mode time-stamp capture
- All above resources dedicated to a single input pin
- When not used in capture mode, the ECAP module can be configured as a single channel PWM output



Figure 1. Multiple eCAP Modules In A 28x System

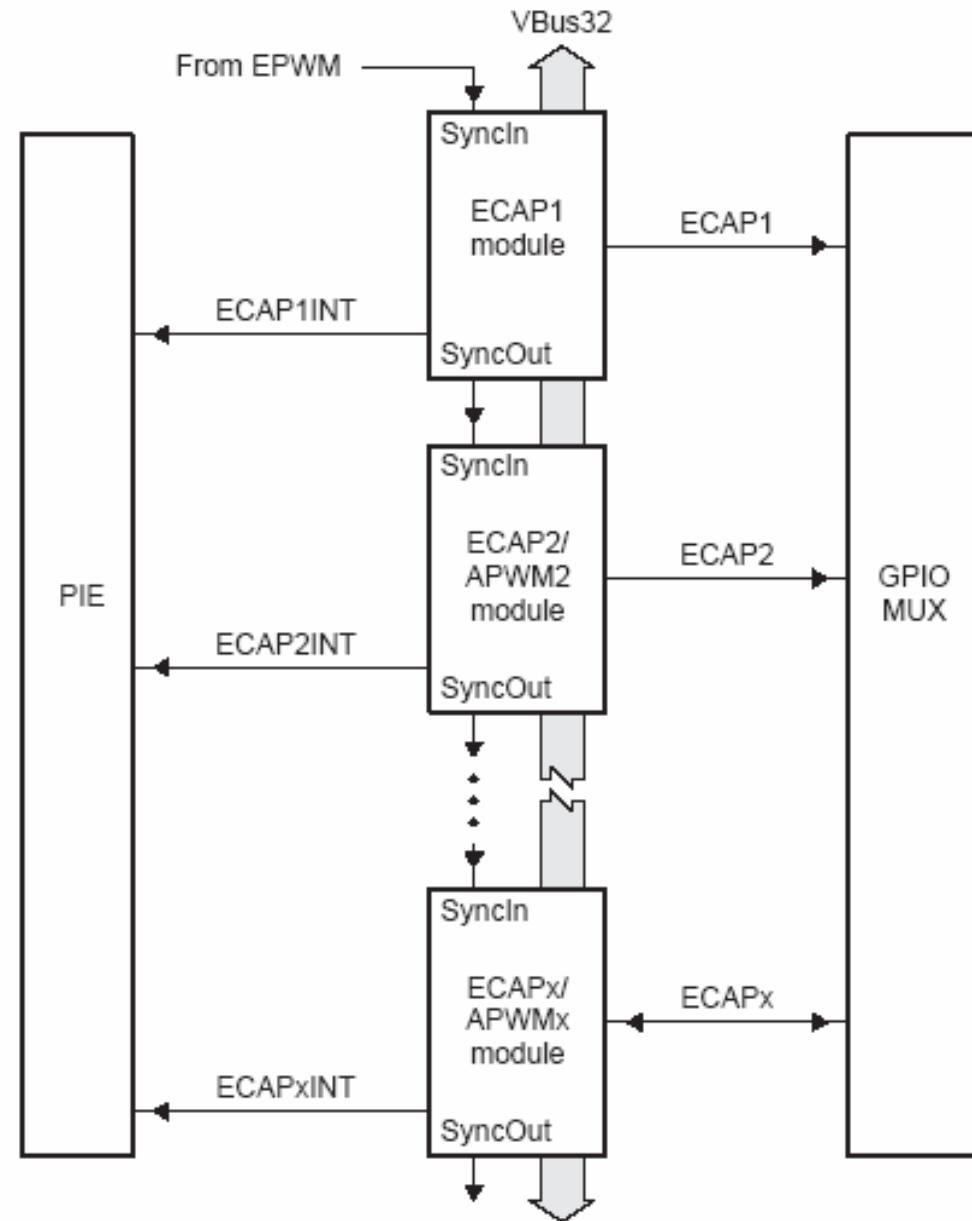
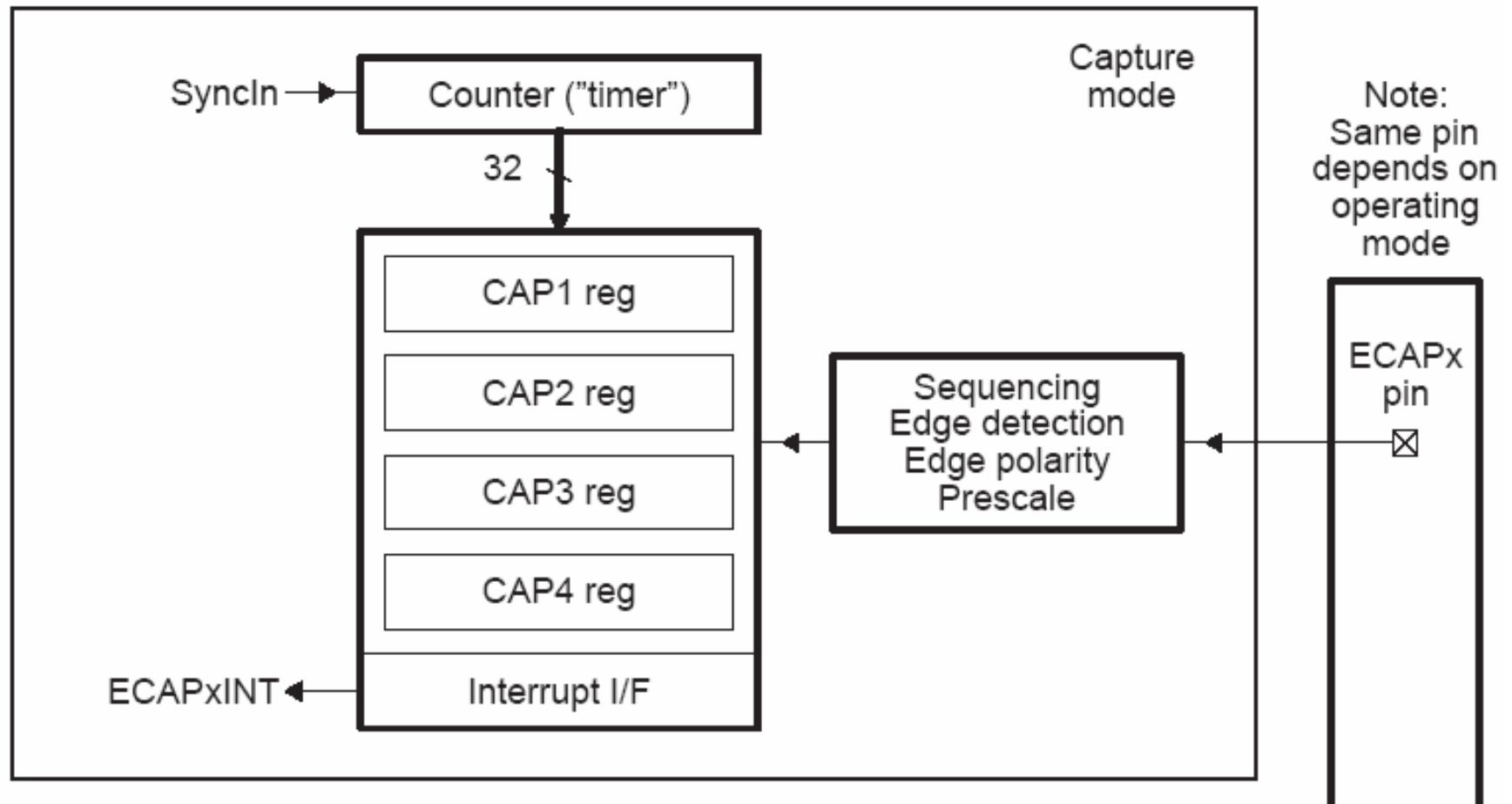


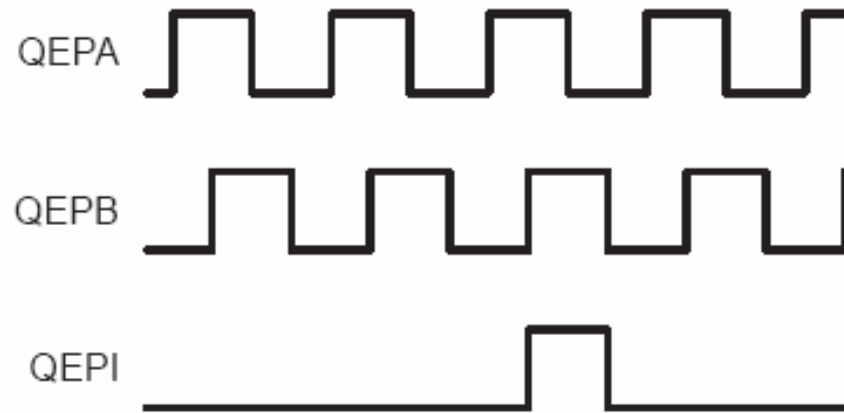
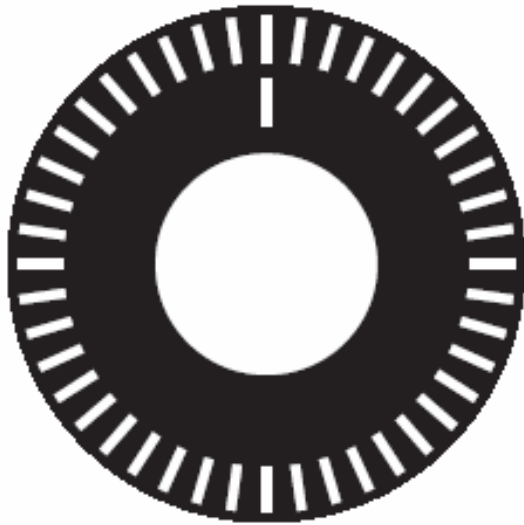
Figure 2. Capture and APWM Modes of Operation



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Optical Encoder Disk



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Enhanced QEP

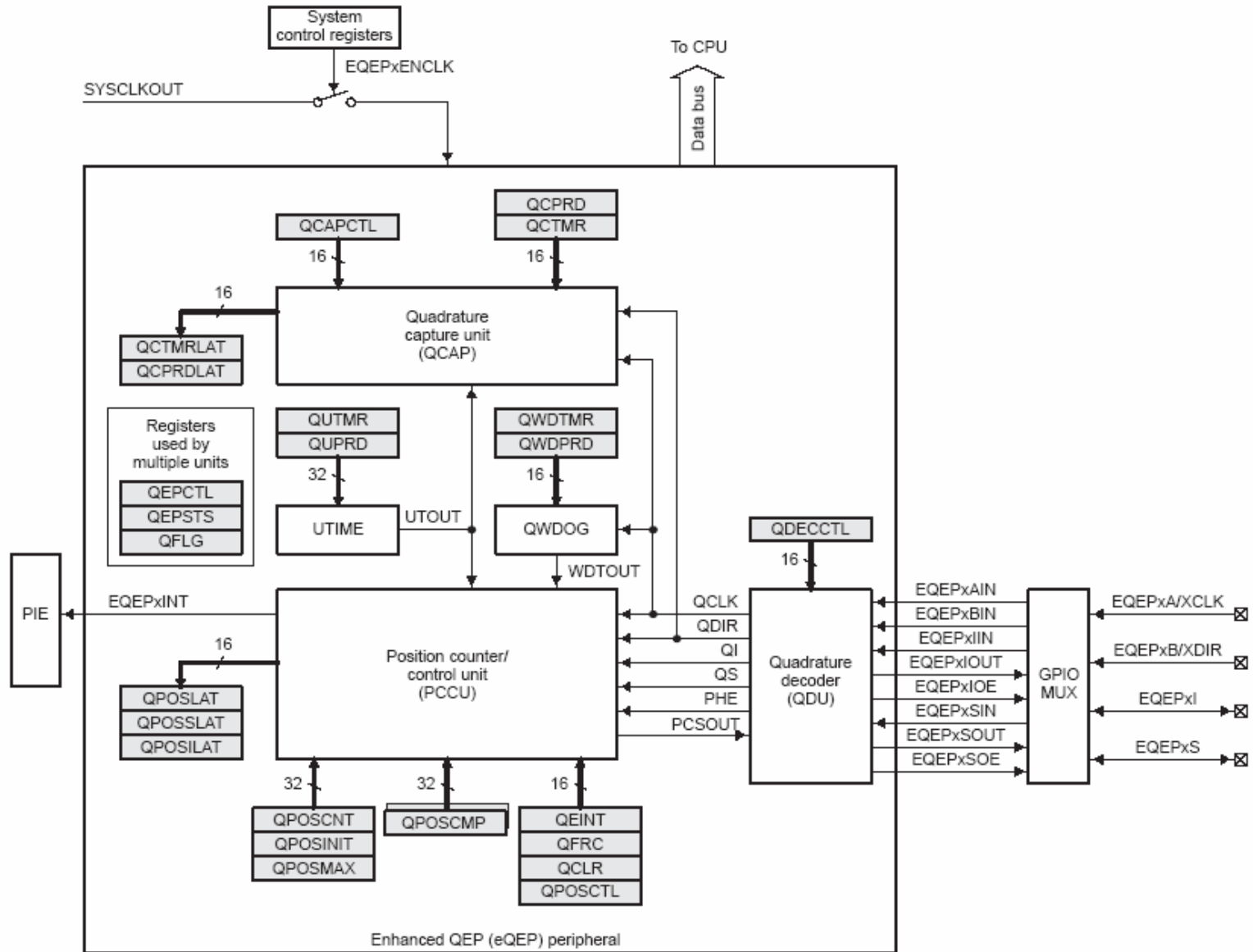
The eQEP peripheral contains the following major functional units (as shown in Figure 4):

- Programmable input qualification for each pin (part of the GPIO MUX)
- Quadrature decoder unit (QDU)
- Position counter and control unit for position measurement (PCCU)
- Quadrature edge-capture unit for low-speed measurement (QCAP)
- Unit time base for speed/frequency measurement (UTIME)
- Watchdog timer for detecting stalls (QWDOG)

Minds in Motion



Enhanced QEP



C28xx DSP 廣泛的應用領域



Digital Power Supply

Provides control, sensing, PFC, and other functions

Optical Networking

Control of laser diode



Printer

Print head control
Paper path motor control

Evaluating Other Segments

eg. Musical Instruments



Non-traditional Motor Control

Many new cool applications to come



C28xx DSP 廣泛的應用領域

Motor Control

Active suspension
 Air conditioners
 Aircraft A/C
 Bonding machines
 Building automation
 Cameras
 Car A/C
 CD and DVD drives
 Check readers
 CNC control
 Compressors
 Copiers
 Door openers
 Elevator motor control
 Encoders
 Fan control
 Food mixers
 Fork lifts
 Fuel pumps
 Golf trainers
 Hair removers

Heart/lung machines
 Human transporters
 Industrial drives
 Inverters
 Lawn mowers
 Magnetic bearings
 Mass flow control
 Medical pumps
 Missile control
 Plotters
 Postal sorters
 Power assisted steering
 Power drills
 Power generators
 Printers
 Refrigerators
 Robot control
 Sewing machines
 Ship propulsion control
 Stepper motor control
 Textile machines
 Toy trains
 Treadmills

Vacuum cleaners
 Vibration control
 Wafer testers
 Washing machines
 Windmill control

Digital Power

Battery charging
 Frequency converters
 Fuel cell control
 Server power control
 Solar energy control
 Uninterr. power supplies

Optical Networking

TEC control
 Optical switch control
 Tunable laser control

Others

Adaptive cruise control
 Airbag control
 Antitheft systems

Blood analyzers
 Data encryption systems
 E-meters
 Gas sensors
 GPS systems
 Ignition control
 Induction ovens
 Park assist systems
 Power line modems
 Radar control
 Reactor monitoring
 RF ID systems
 Spectrum analyzers
 Telecom switches
 Tire pressure sensing
 Ultrasound scanners
 Welding equipment
 Wireless modems
 Material test
 Biophotonics system
 AFM
 MRI
 MEMS

... and many more



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Thanks!



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