Spínané zdroje a jejich digitální řízení

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Tato prezentace je spolufinancována Evropským sociálním fondem a státním rozpočtem České republiky.

Agenda

- Linear Regulator
- Non-Isolated SMPS
- Isolated SMPS
- Resonant SMPS
- Digital Control of SMPS
- Hands on (Step down Converter)

Switch Mode Power Supply Introduction

- We can distinguish SMPS according many parameters:
  - Type of source
    - Voltage Source Converters, Current source Converters
  - Type of conversion
    - DC/DC, AC/DC, AC/AC or DC/AC
  - Ratio V_{OUT}/V_{IN}
    - Step Up, Step Down or Both
  - Galvanic Isolation
    - Isolated/non-isolated
  - Type of operation
    - Linear, Pulse with modulated, Frequency Controlled (Resonant)

How to select right SMPS?

- When we select the power supply for our application we should consider:
  - Cost
  - Weight and space
  - Required efficiency
  - The input power source(s)
  - The number of output voltages required and their particular characteristics
  - The noise tolerance of the load circuits
  - Battery life (if the product is to be portable)

Principles of Power Suplies Operation

- Linear Regulators
- Pulse Width Modulated Switched Mode Power Supplies
- Frequency Controlled (resonant) Switched Mode Power Supplies

Agenda

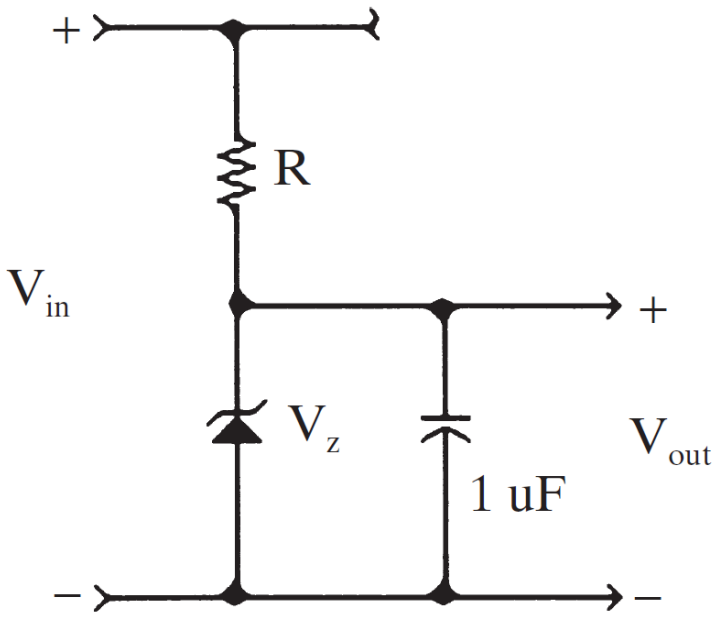
- Linear Regulator
  - Zener shunt regulator
  - Transistor “series pass” regulator
  - How to select right linear regulator
- Non-Isolated SMPS
- Isolated SMPS
- Resonant SMPS
- Digital Control of SMPS
- Hands on

Linear Power Supply

- The control element changes the impedance to drop input voltage to desired output level
- Advantages
  - Very simple to implement
  - Low cost
  - Very low noise generation
- Disadvantages
  - Very low efficiency (35 – 50%)
  - Low output power (<10W)
  - Output voltage always lower than input
  - Cannot provide galvanic isolation

Examples of Linear Power Supply

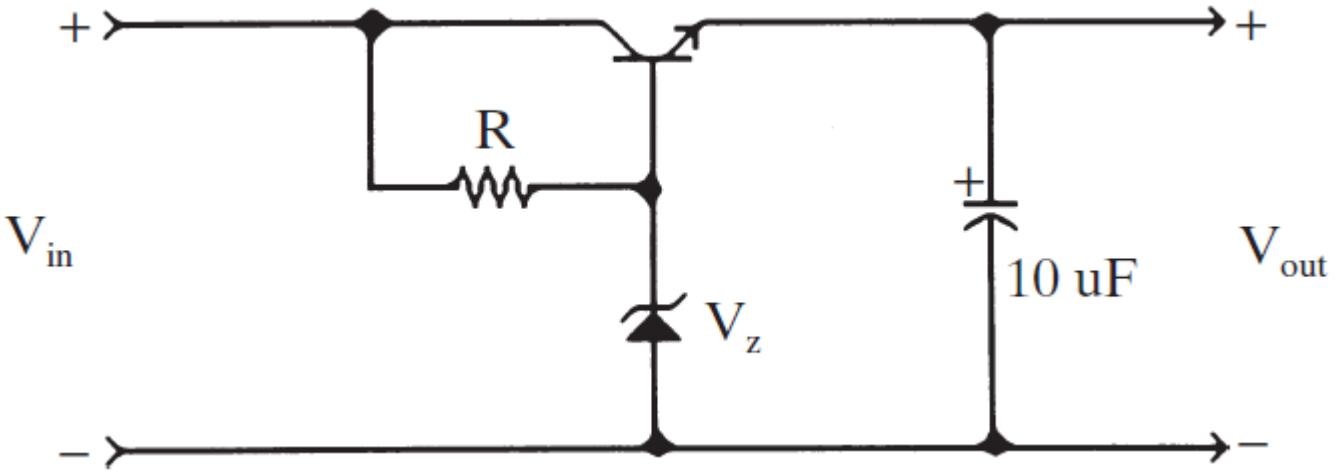
- Zener “shunt” Regulator



- Regulating element in parallel with load
- Very low output power
- Zener voltage changes with the temperature
- Very high losses

Examples of Linear Power Supply

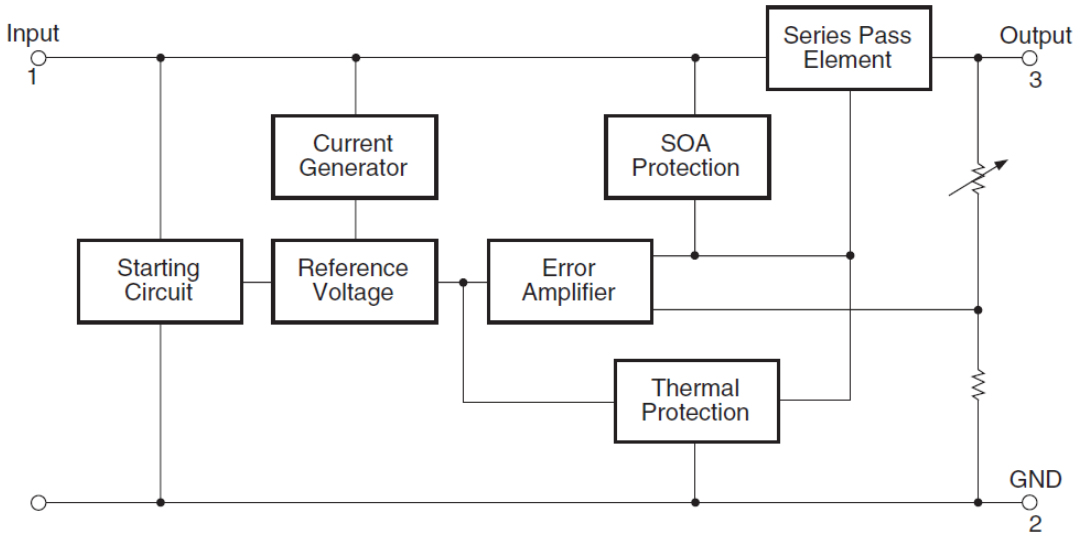
- Bipolar Transistor “series-pass” Regulator



- Regulating element in series with load
- Output power depends on used transistor
- Zener voltage changes with the temperature
- Lower losses at low load

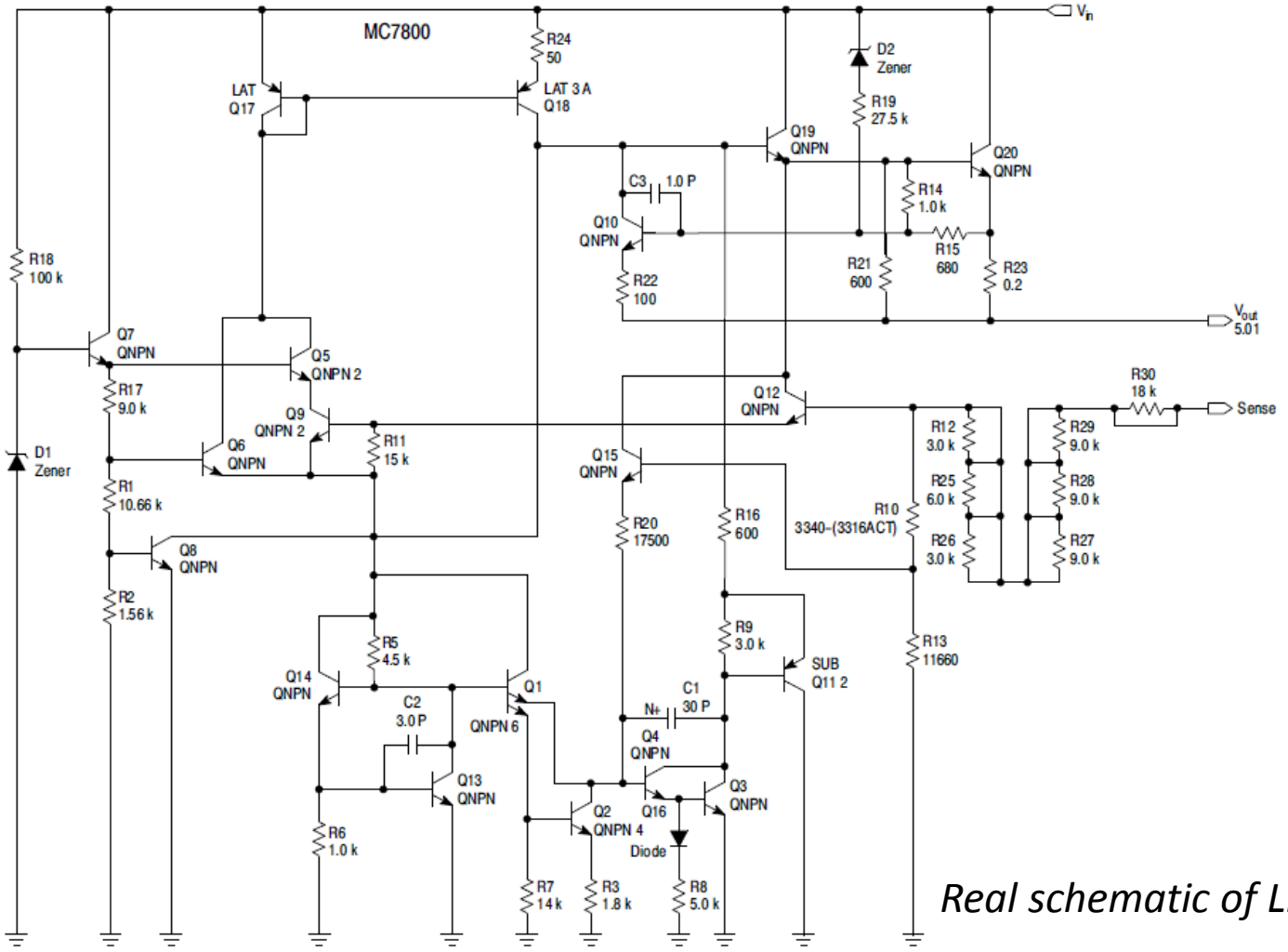
Examples of Linear Power Supply

- There are plenty of integrated circuits providing linear voltage regulator
- These circuits provides more features such as current limit, thermal protection



Block Diagram of LM7805

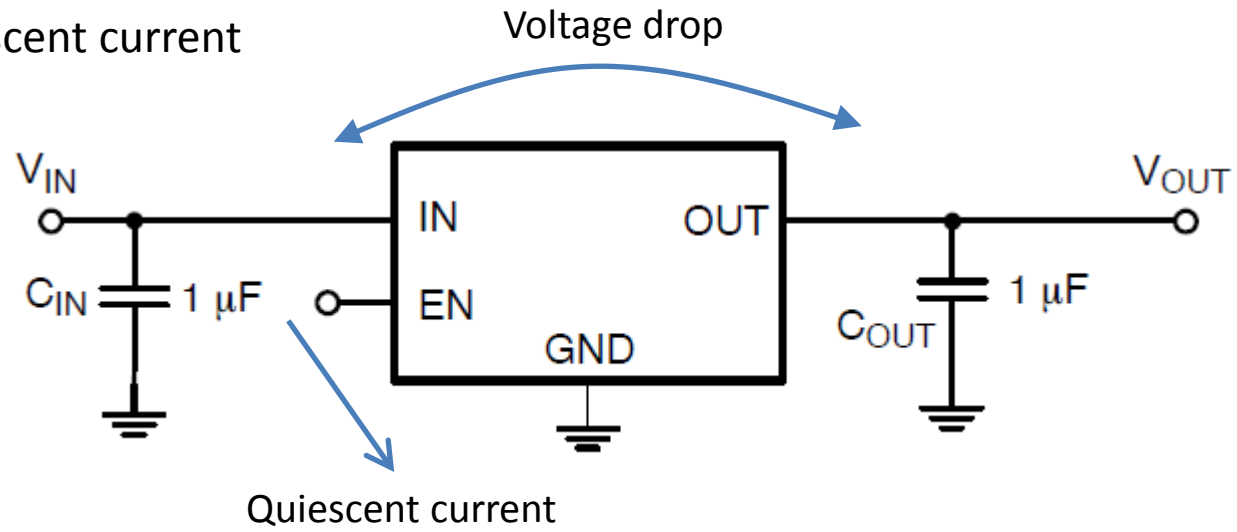
Examples of Linear Power Supply



Real schematic of LM7805

Linear Power Supply

- The most important parameters for voltage regulator selection
  - Input voltage range (V_{IN})
  - Output voltage/current
  - Voltage drop
  - Quiescent current

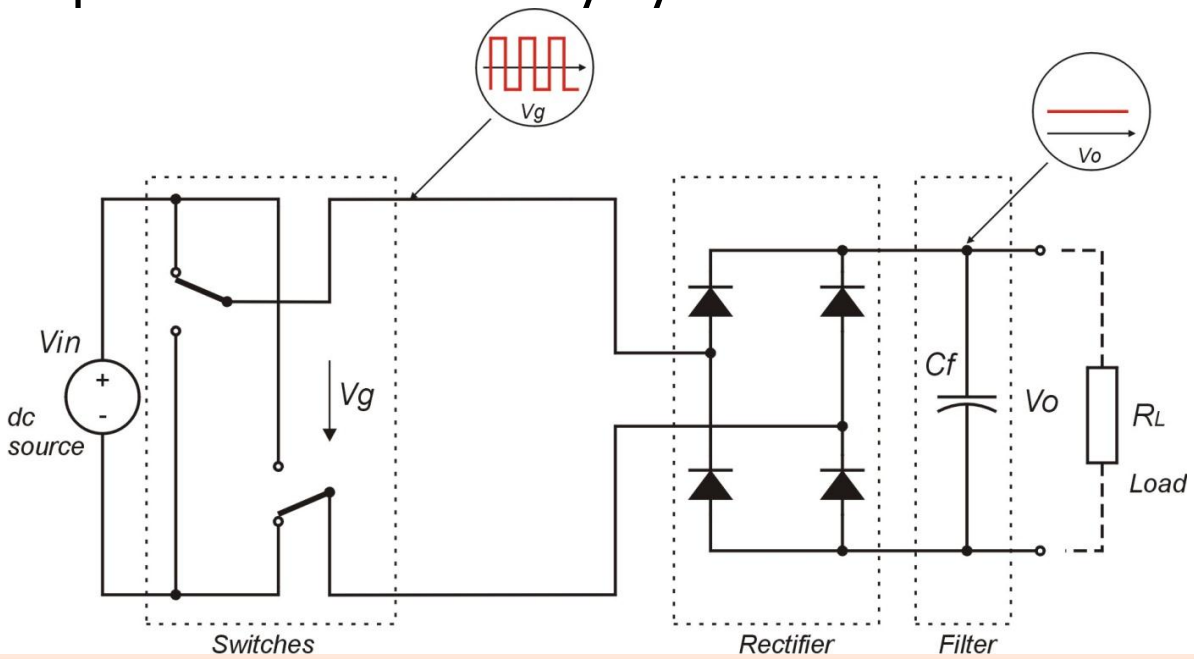


Agenda

- Linear Regulator
- Non-Isolated SMPS
  - Buck (Step down) Converter
  - Boost (Step up) Converter
  - Buck – Boost (Inverting/Non-inverting) Converter
  - CÚK Converter
  - SEPIC Converter
- Isolated SMPS
- Resonant SMPS
- Digital Control of SMPS
- Hands on (Step down Converter)

Switched Mode Power Supply

- The semiconductor switches generate square wave voltage output using PWM modulation - Vg
- The Vg is rectified by output rectifier and filtered by a low pass filter
- The Vo corresponds to actual duty cycle

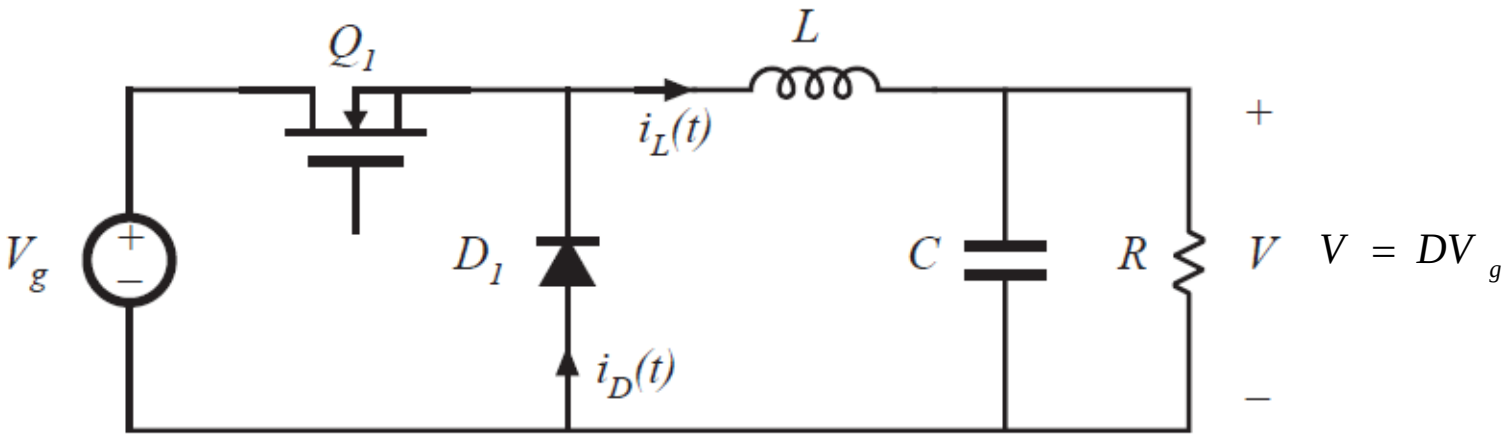


Switched Mode Power Supply

- The semiconductor switches work in ON and OFF state only
- Advantages
  - Very high efficiency
  - Lower/higher output voltage that input
  - Isolated/non isolated solution
  - Can handle very high output power
- Disadvantages
  - More complex design
  - More expensive
  - More noisy due to switching

Buck Converter

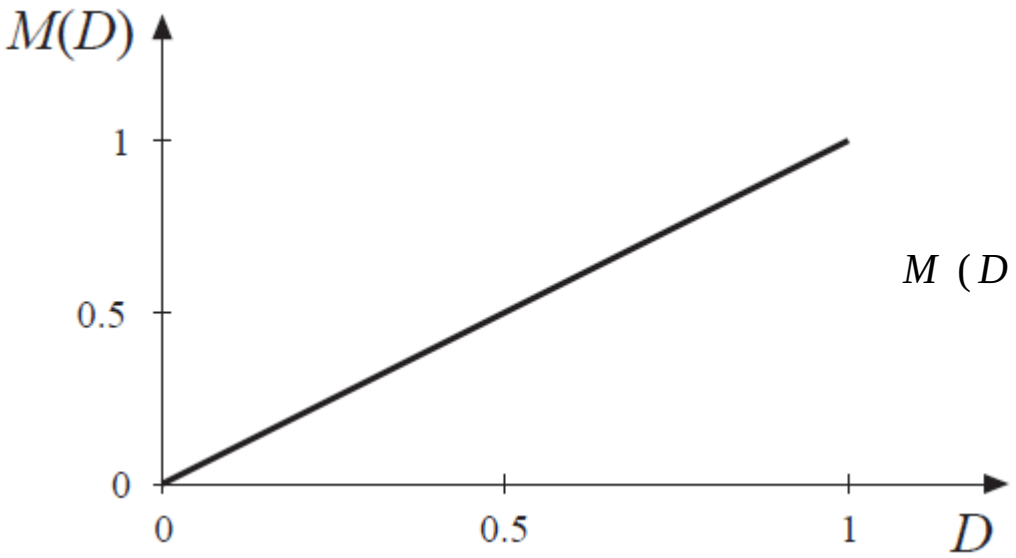
- Step down non isolated converter



Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Buck Converter

- Output transfer function of buck converter



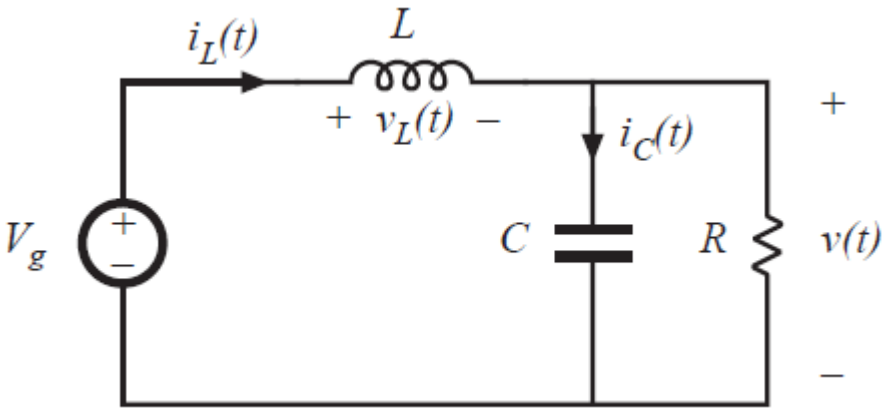
$$M(D) = D$$

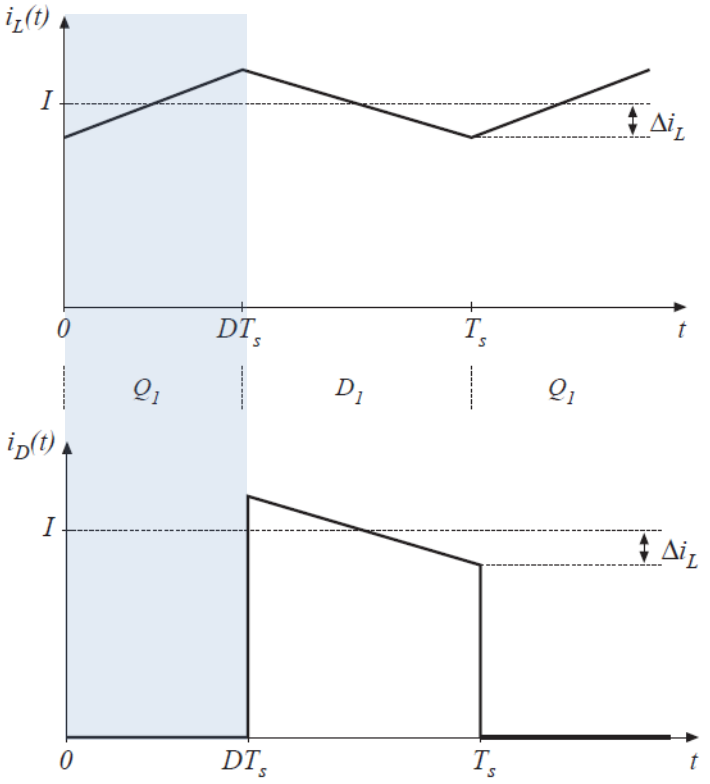
Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Buck Converter

- Continuous conduction operation of Buck Converter

First sub-interval



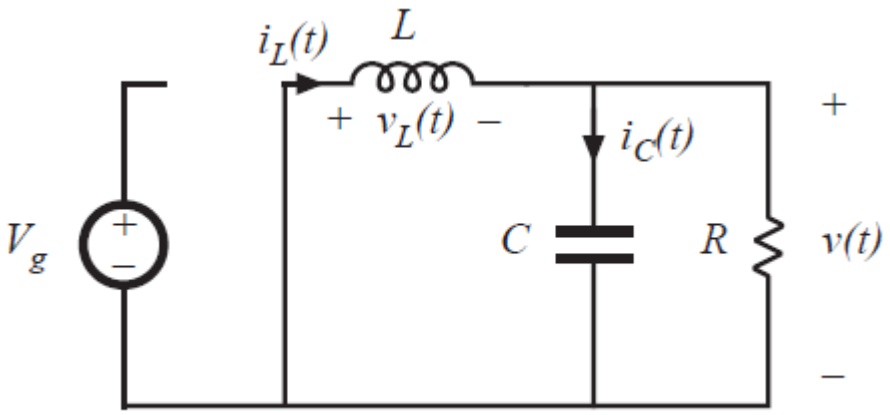


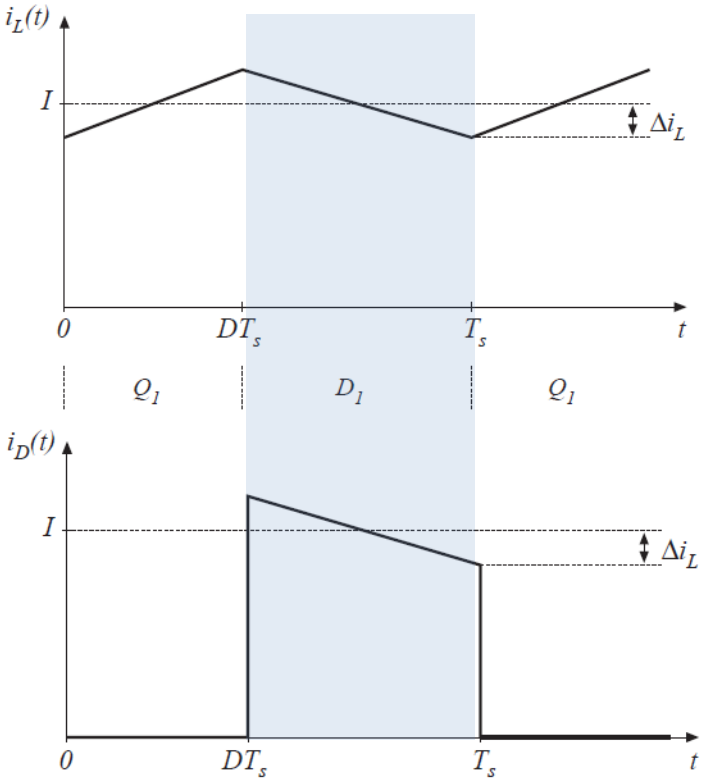
Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Buck Converter

- Continuous conduction operation of Buck Converter

Second sub-interval





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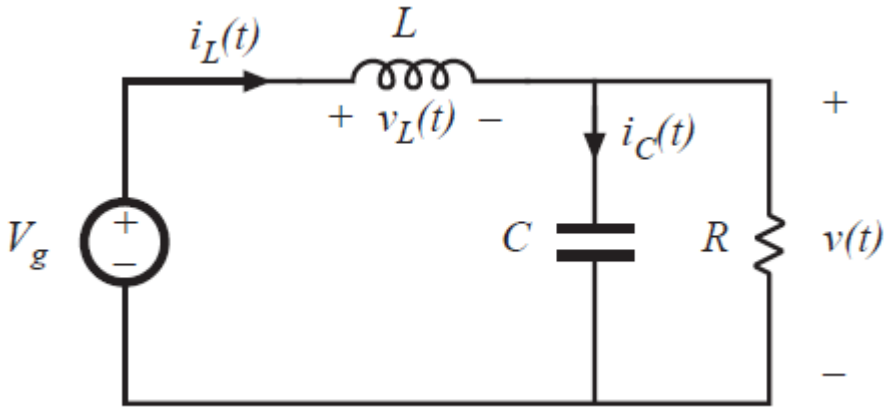
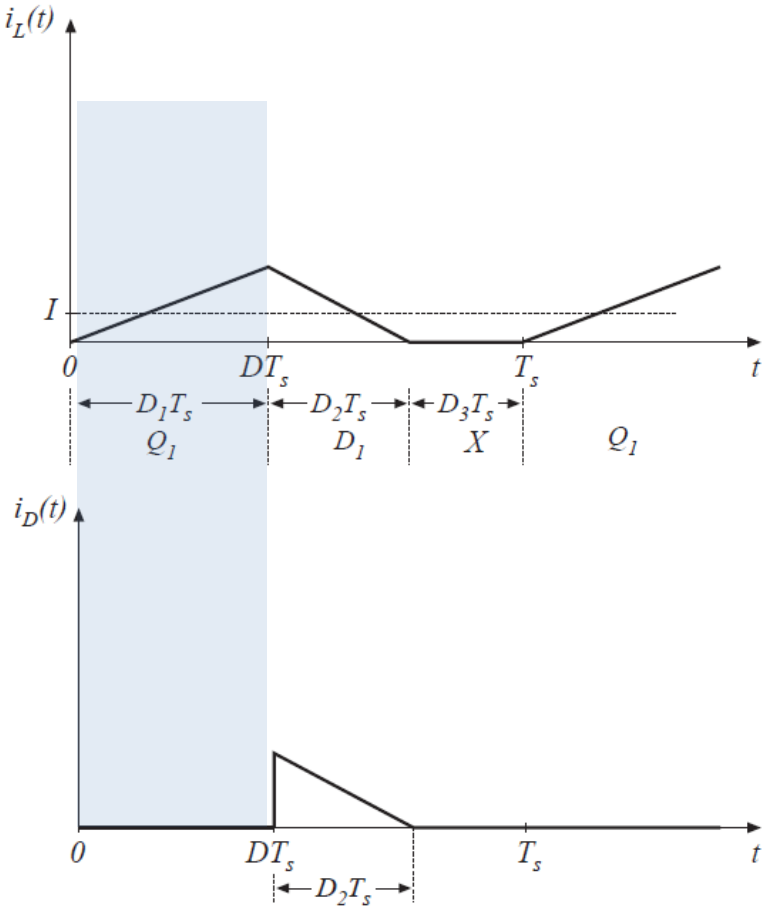
Buck Converter

- Discontinuous conduction operation of Buck Converter

First sub-interval



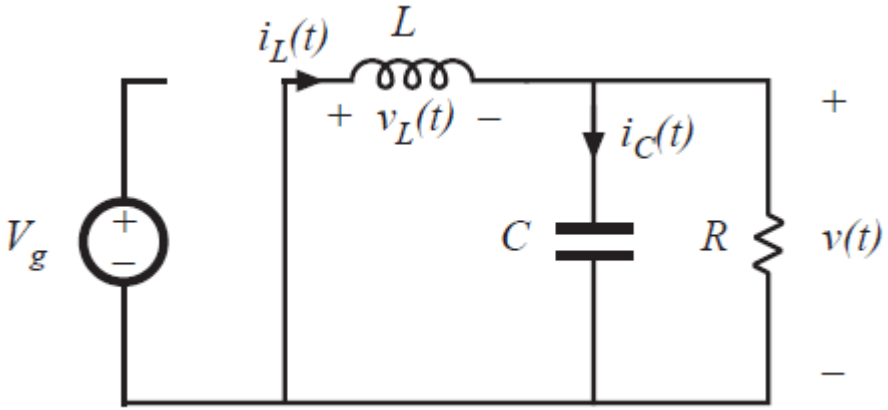


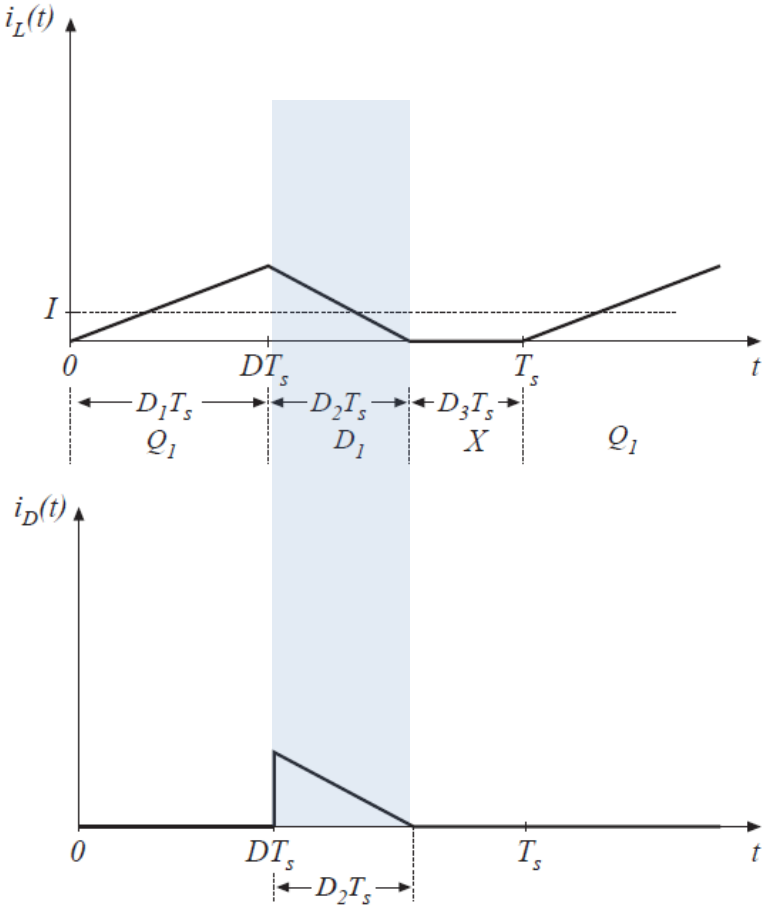
Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Buck Converter

- Discontinuous conduction operation of Buck Converter

Second sub-interval



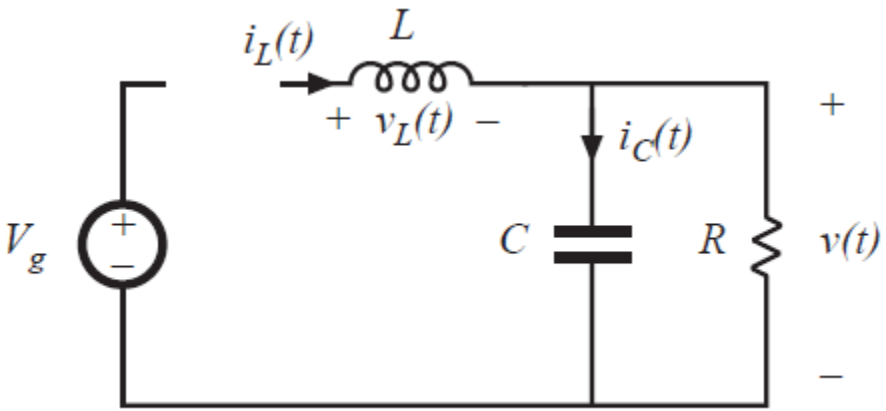


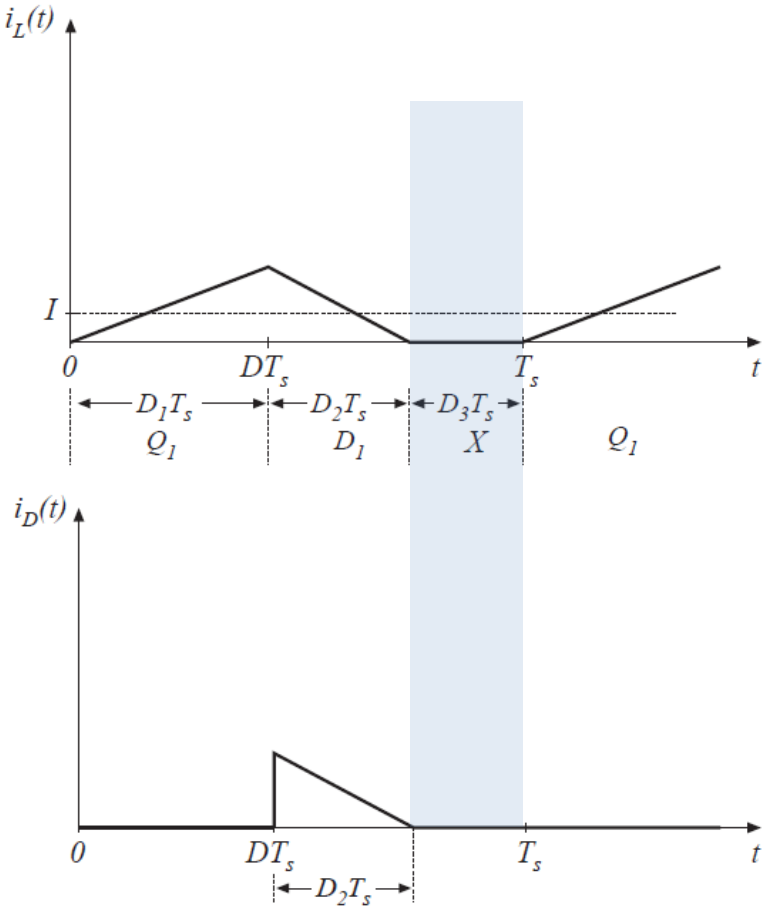
Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Buck Converter

- Discontinuous conduction operation of Buck Converter

Third sub-interval

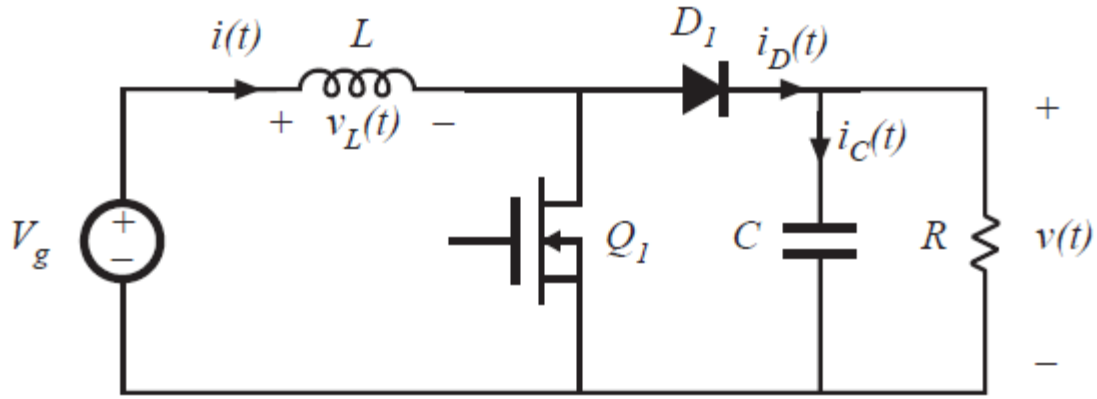




Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Boost Converter

- Step up non isolated converter

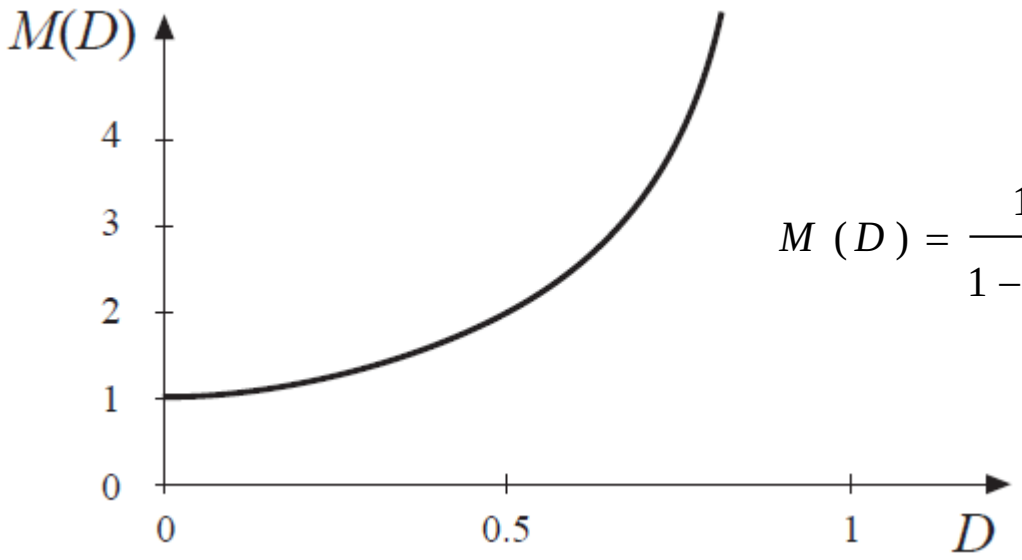


$$V = \frac{V_g}{1 - D}$$

Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Boost Converter

- Output transfer function of boost converter



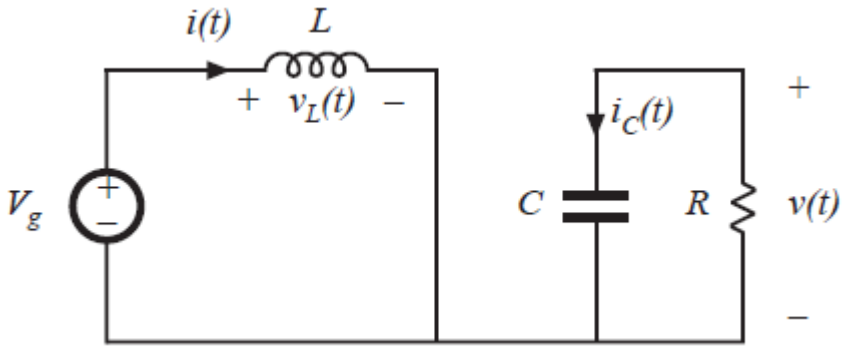
$$M(D) = \frac{1}{1 - D}$$

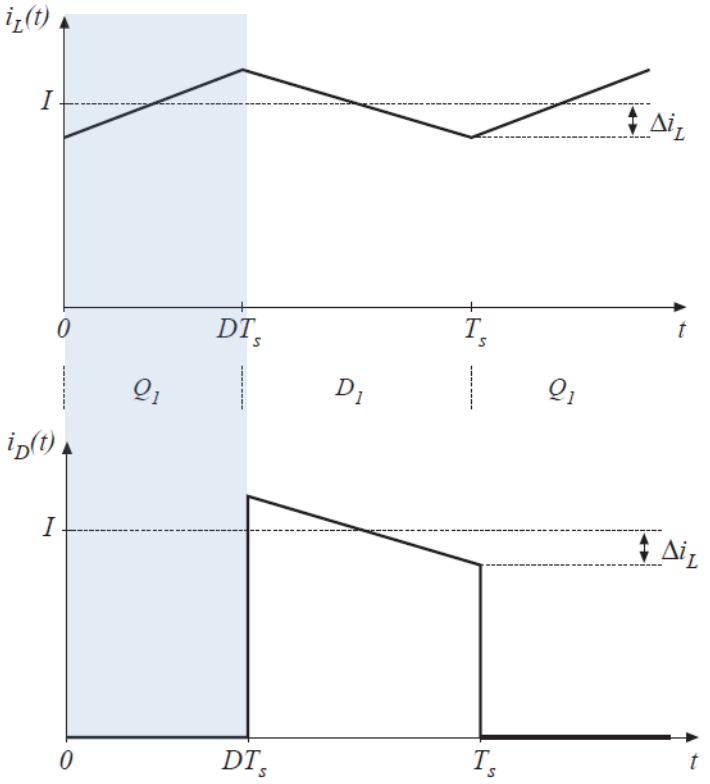
Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Boost Converter

- Continuous conduction operation of Boost Converter

First sub-interval





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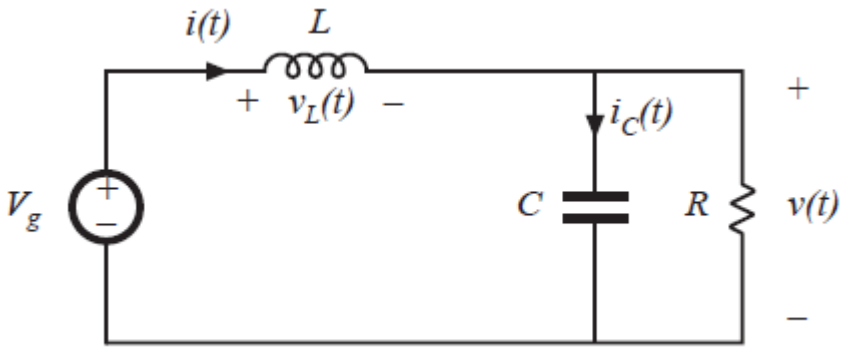
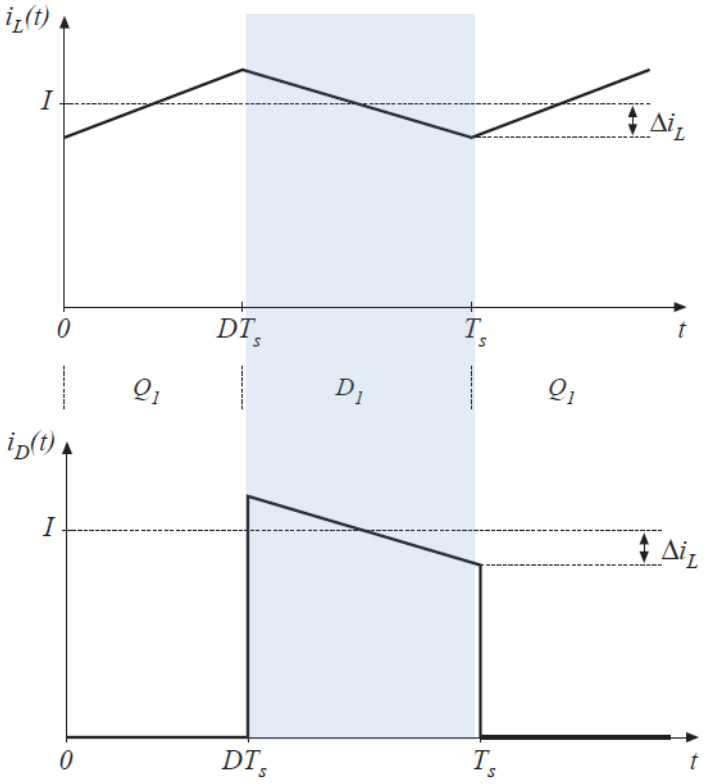
Boost Converter

- Continuous conduction operation of Boost Converter

Second sub-interval





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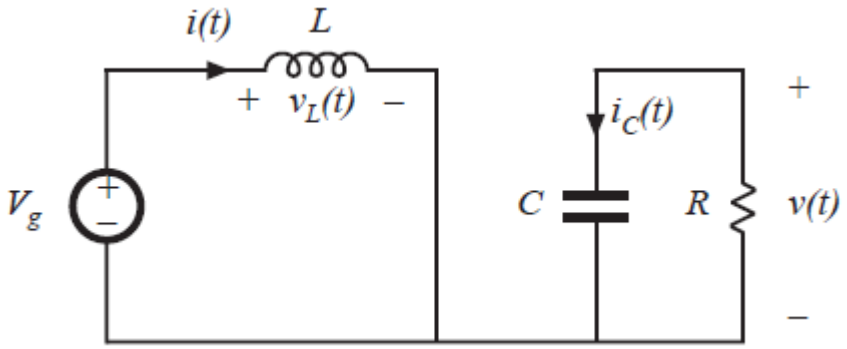
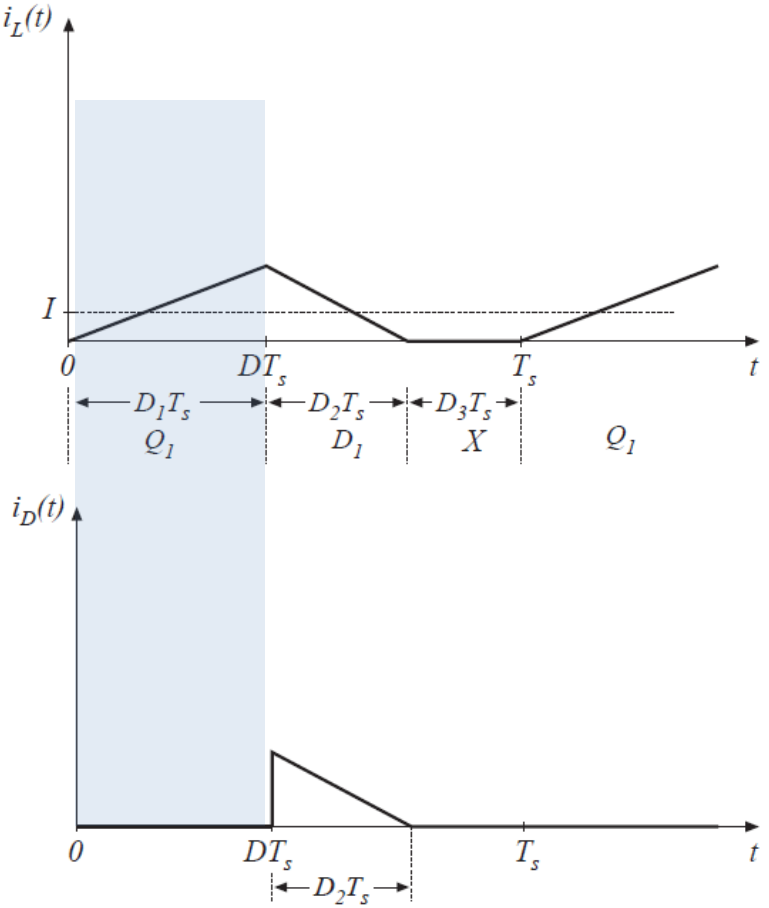
Boost Converter

- Discontinuous conduction operation of Boost Converter

First sub-interval





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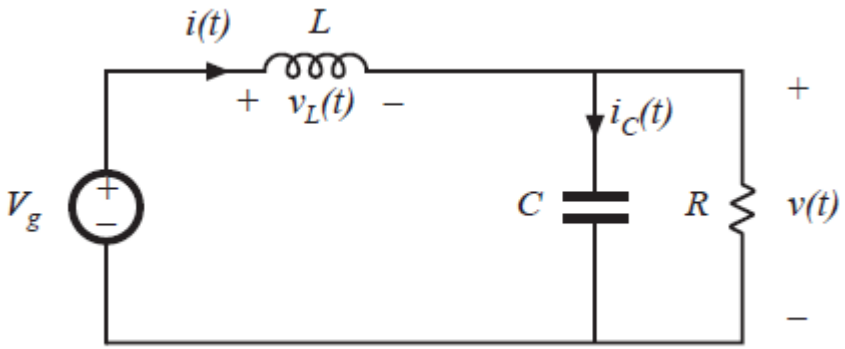
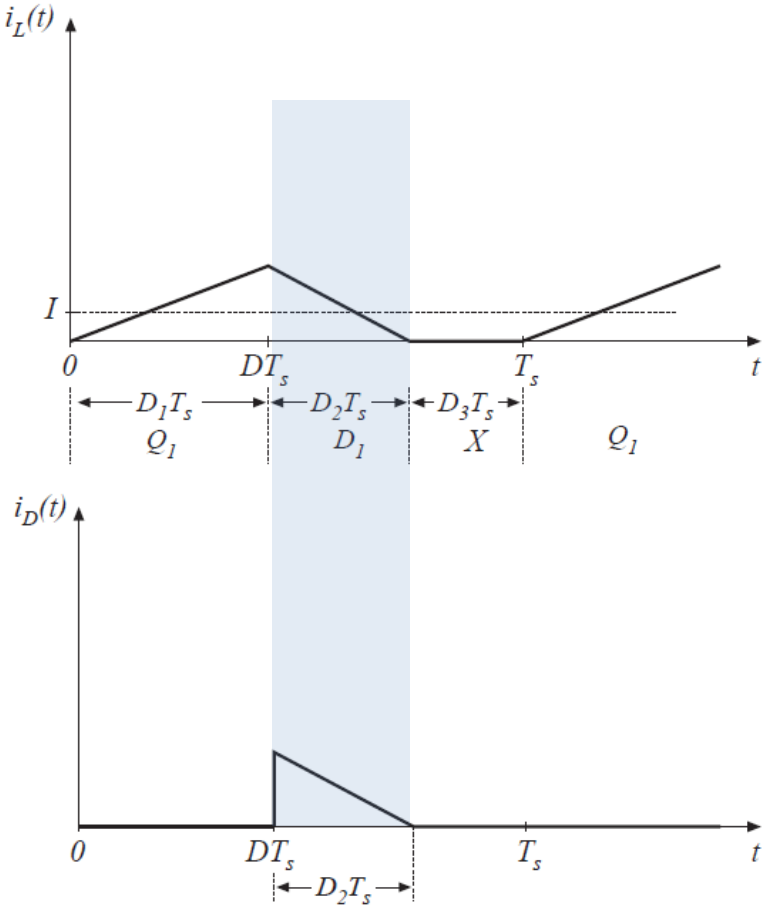
Boost Converter

- Discontinuous conduction operation of Boost Converter

Second sub-interval





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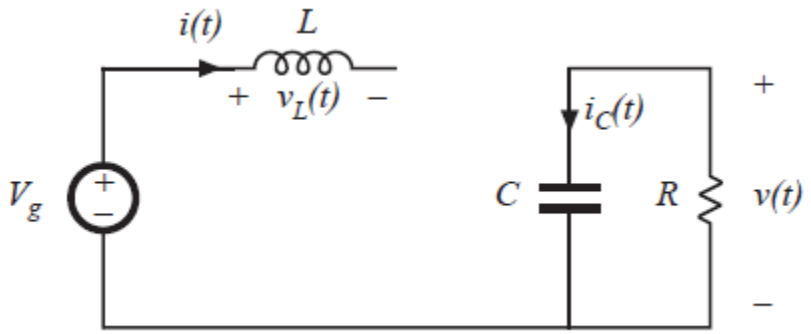
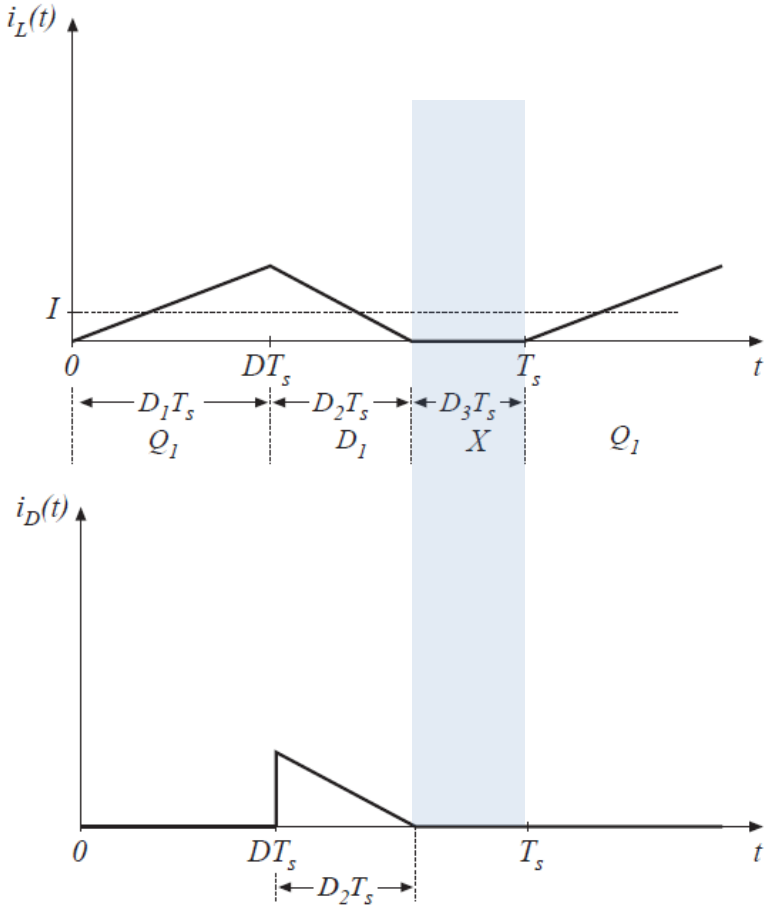
Boost Converter

- Discontinuous conduction operation of Boost Converter

Third sub-interval





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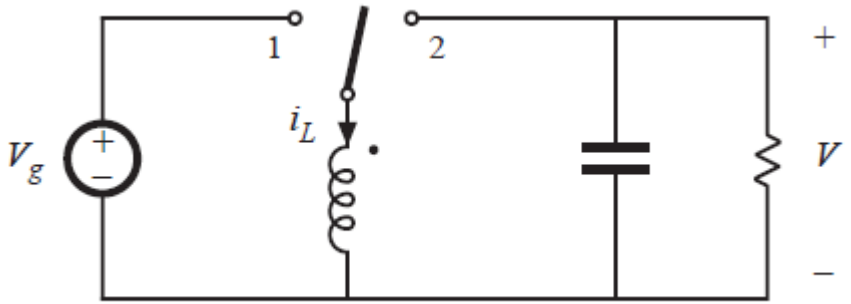
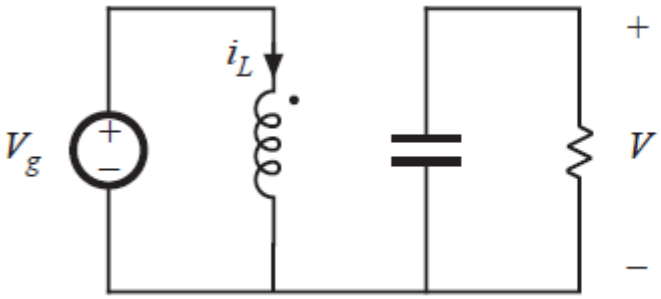
Buck-Boost Converter (inverting)

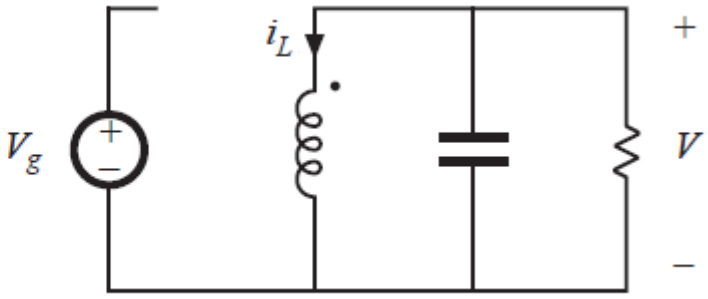


$$V = -V_g \frac{D}{1 - D}$$

First sub-interval



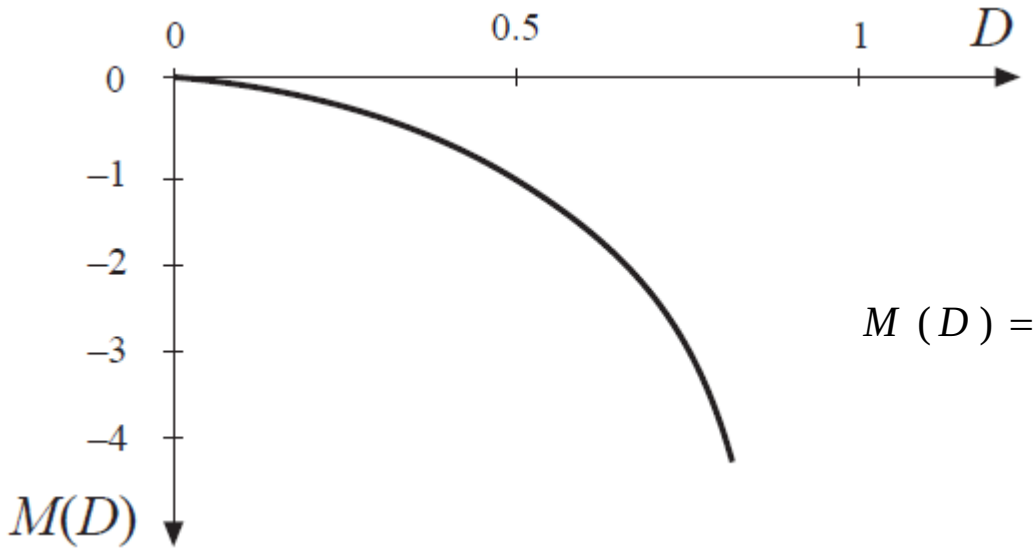
Second sub-interval



Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Buck-Boost Converter (inverting)

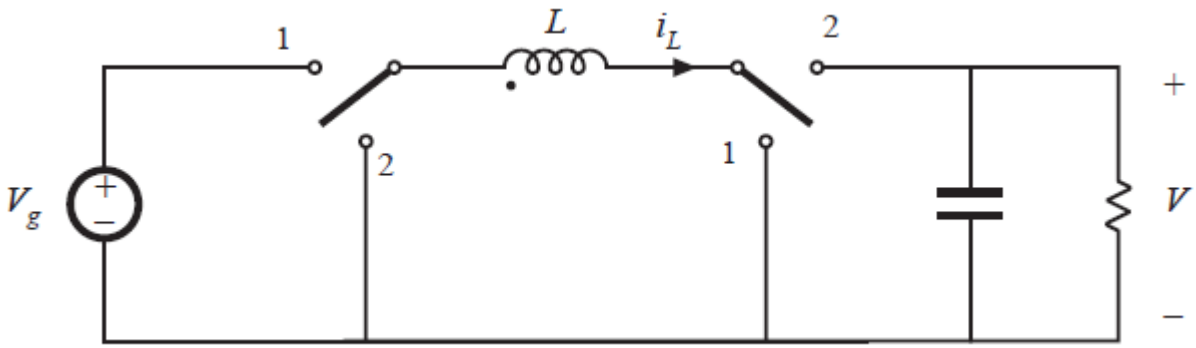
- Output transfer function of buck-boost Converter



$$M(D) = -\frac{D}{1-D}$$

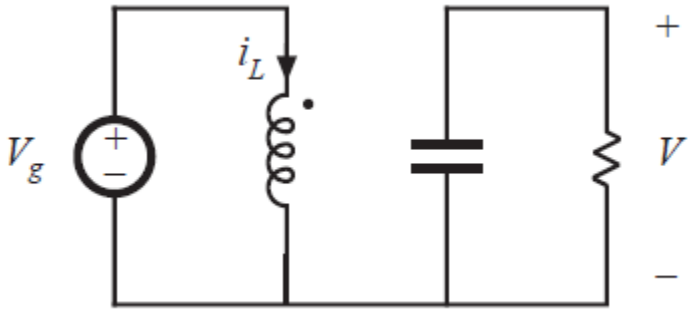
Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Buck-Boost Converter (non inverting)

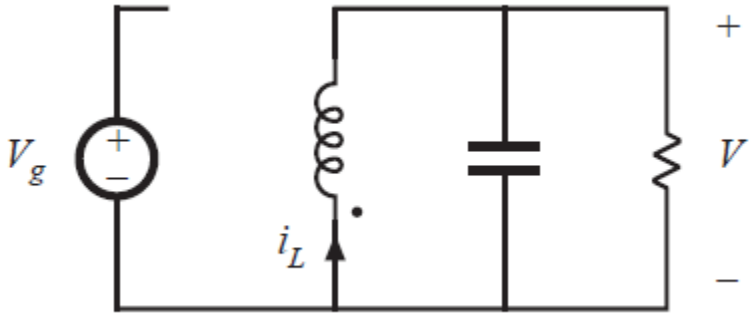


$$V = V_g \frac{D}{1 - D}$$

First sub-interval



Second sub-interval



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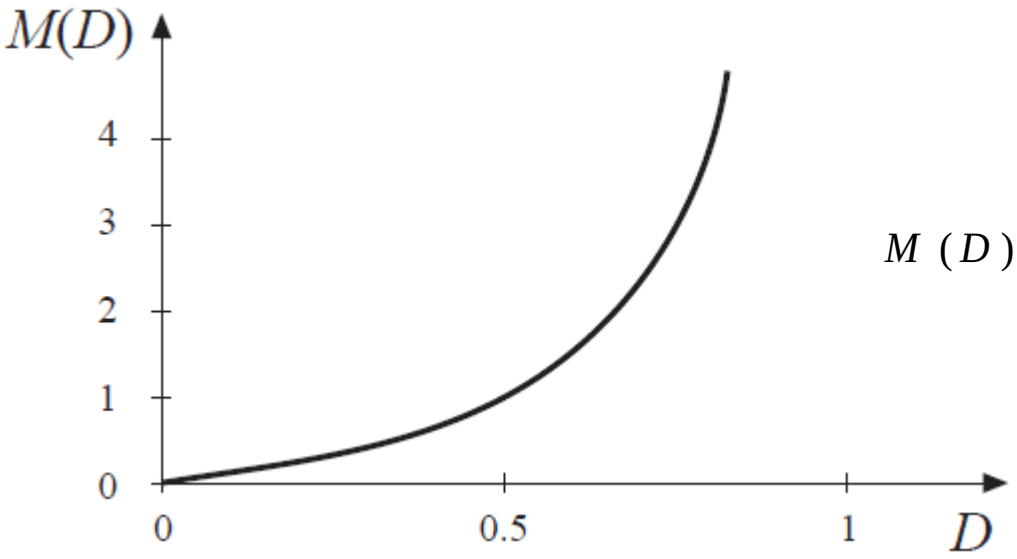
Buck-Boost Converter (non inverting)

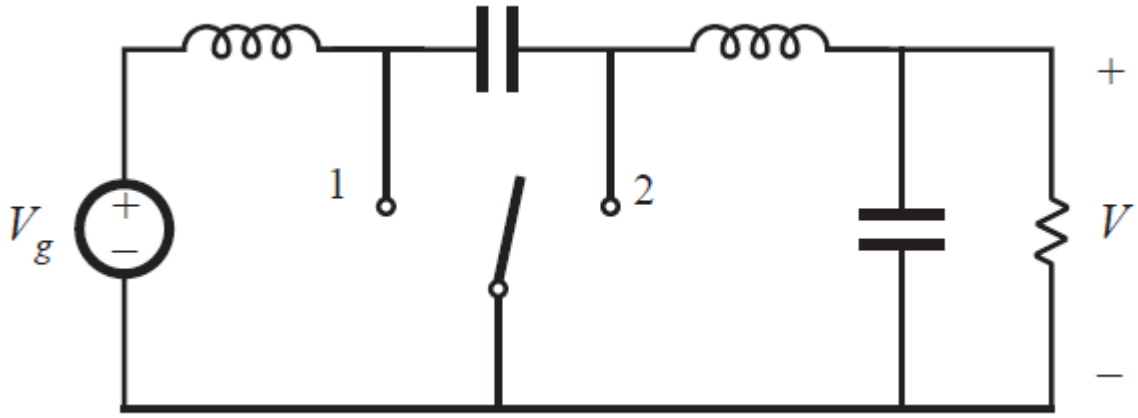
- Output transfer function of buck-boost Converter



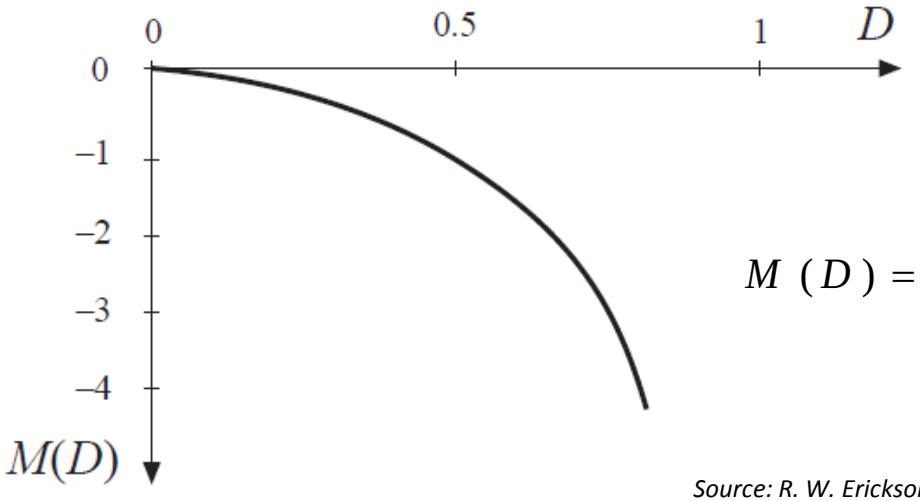
$$M(D) = \frac{D}{1 - D}$$

Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

CÚK Converter



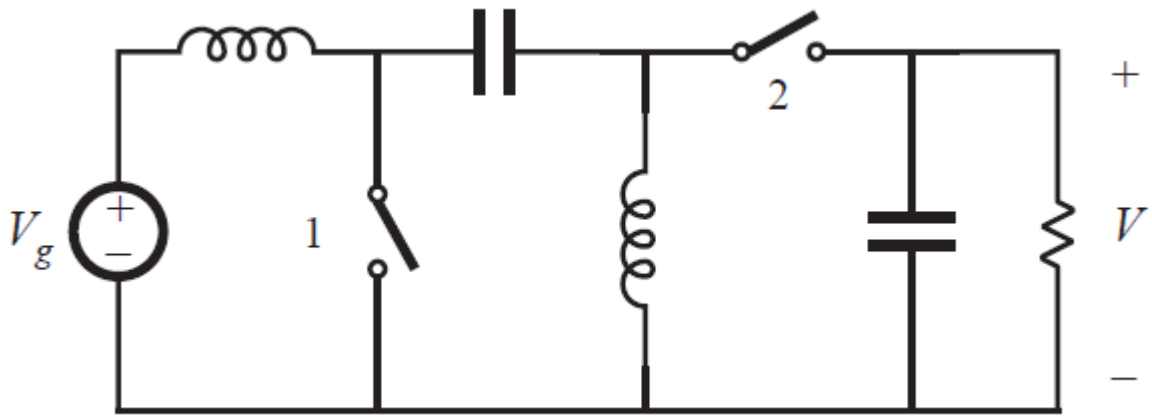
$$V = -V_g \frac{D}{1 - D}$$



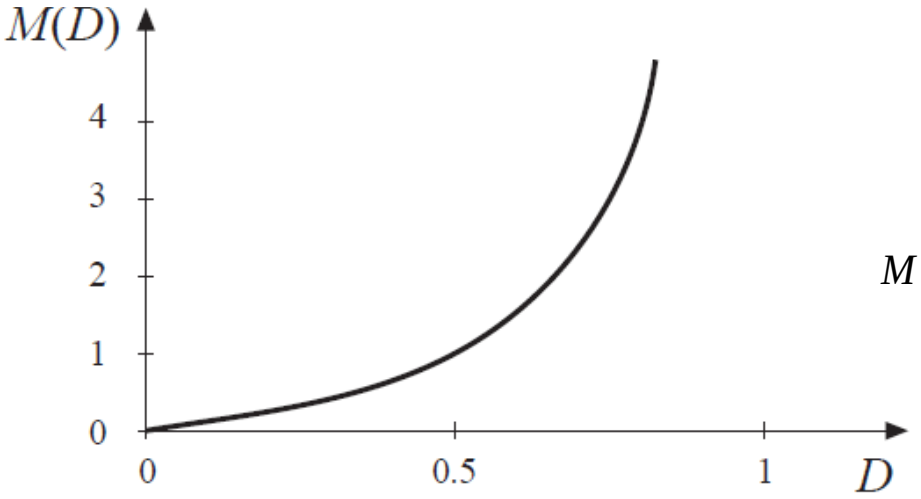
$$M(D) = -\frac{D}{1 - D}$$

Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

SEPIC Converter



$$V = V_g \frac{D}{1 - D}$$



$$M(D) = \frac{D}{1 - D}$$

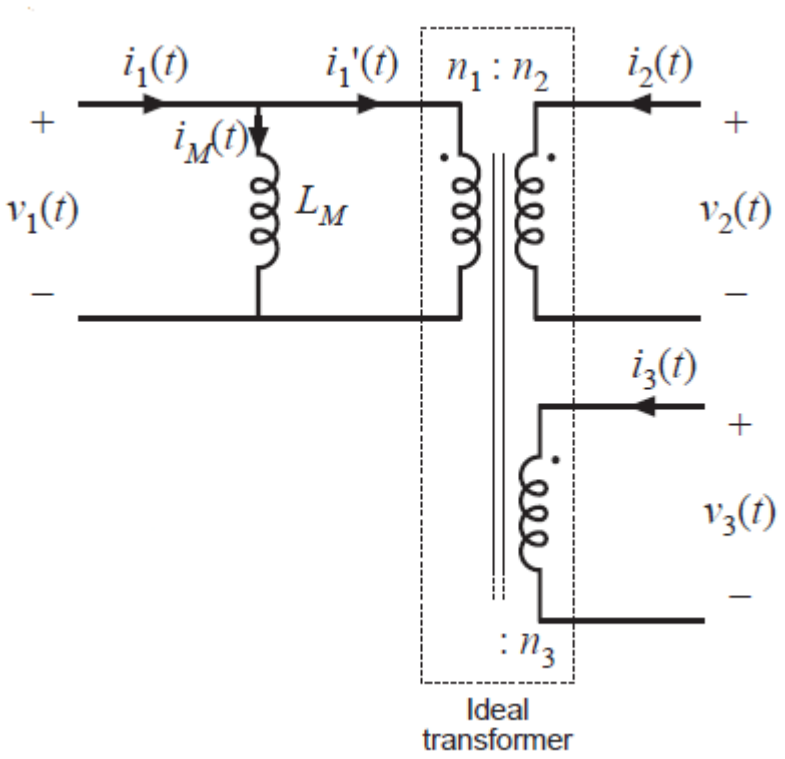
Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Agenda

- Linear Regulator
- Non-Isolated SMPS
- Isolated SMPS
  - Flyback Converter
  - Forward Converter
  - Push Pull Converter
  - Half Bridge
  - Full Bridge
- Resonant SMPS
- Digital Control of SMPS
- Hands on (Step down Converter)

Transformer in SMPS

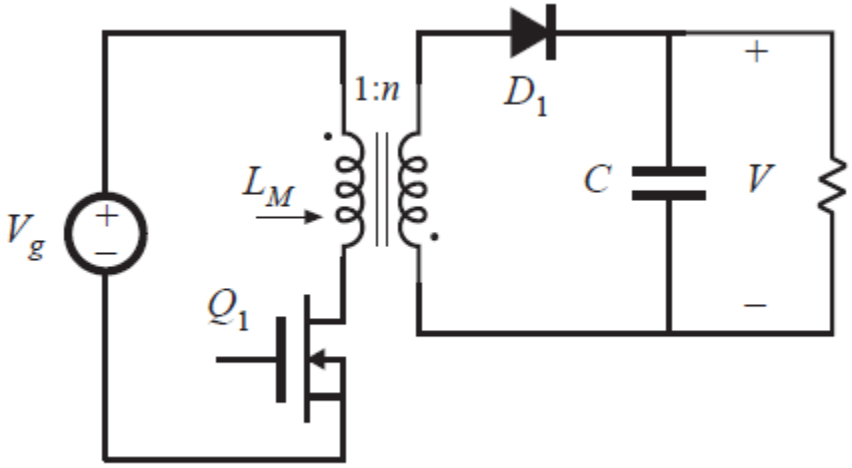
- When use the transformer?
  - Isolated SMPS
  - To high ratio between input/output voltage (optimize operation conditions)
  - Multiple output SMPS



Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

FlyBack Converter

- The primary and secondary windings have opposite polarity
- The energy is stored in the magnetic core gap
- The least number of the components
- Suitable for output power <150W

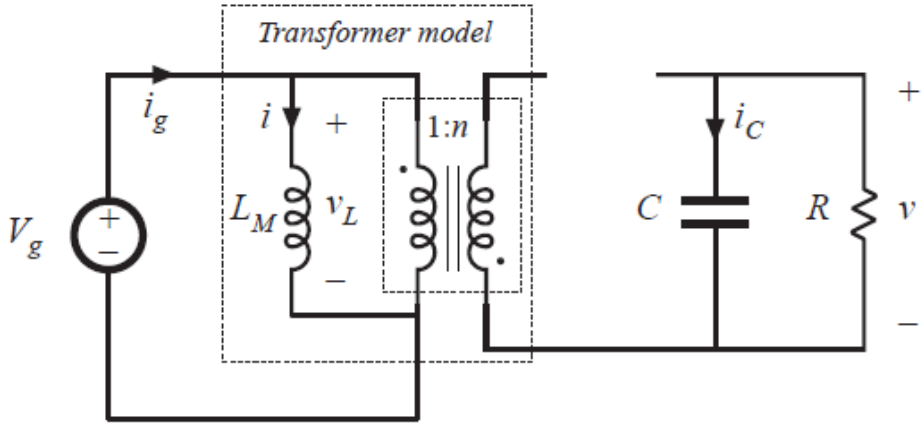


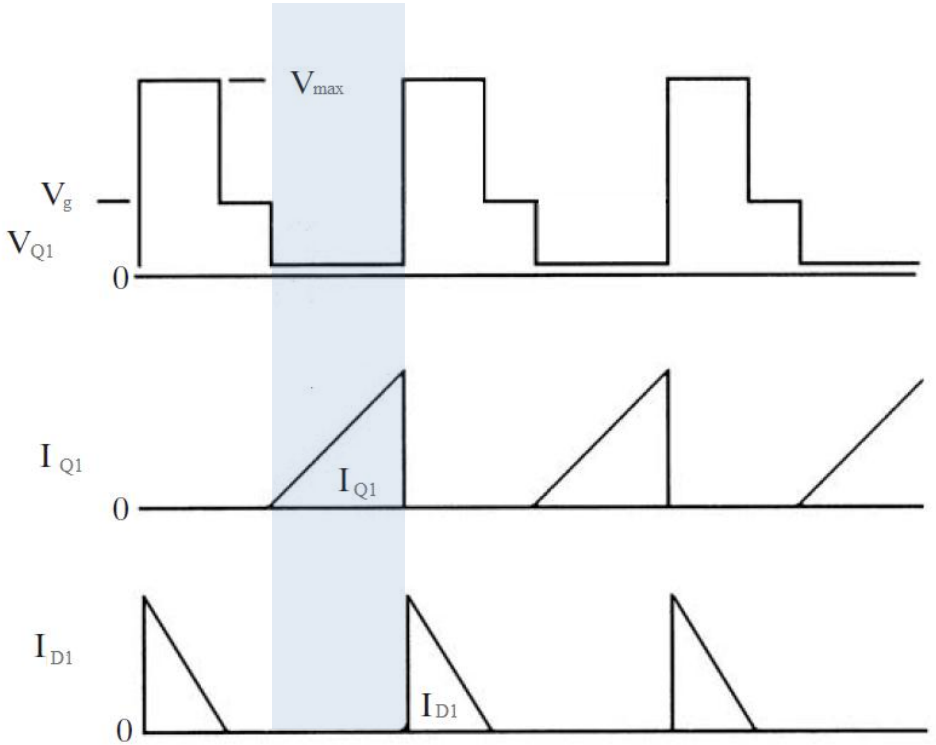
$$M(D) = D\sqrt{\frac{T_P V_{OUT}}{2 I_{OUT} L_P}}$$

Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

FlyBack Converter

- Sub-interval 1

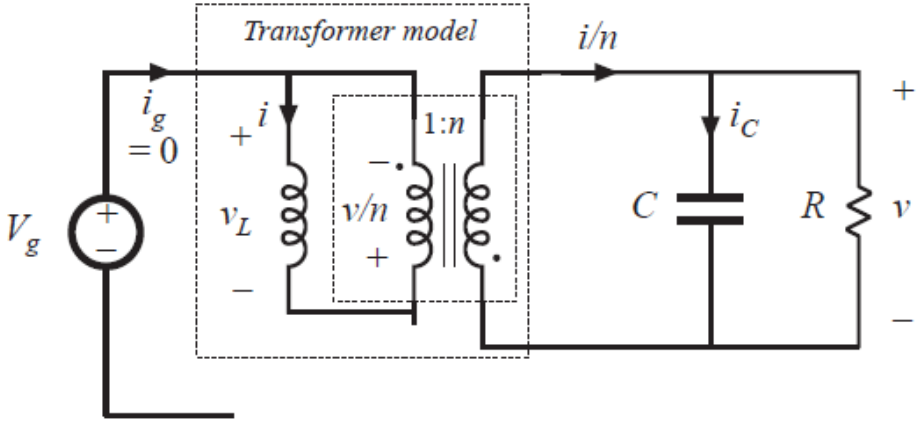


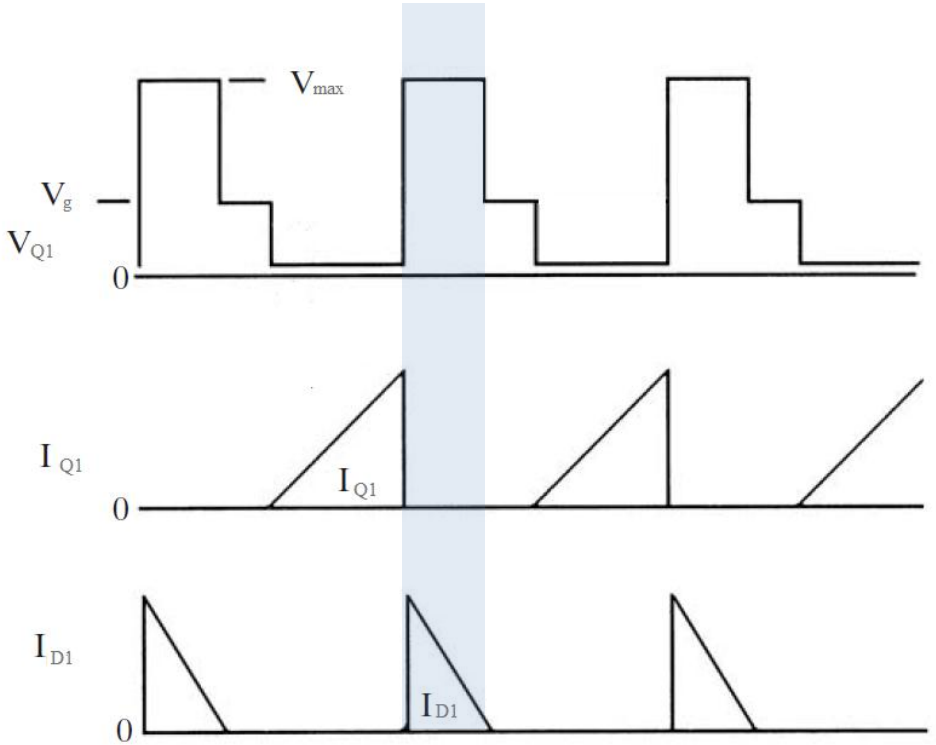


Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

FlyBack Converter

- Sub-interval 2

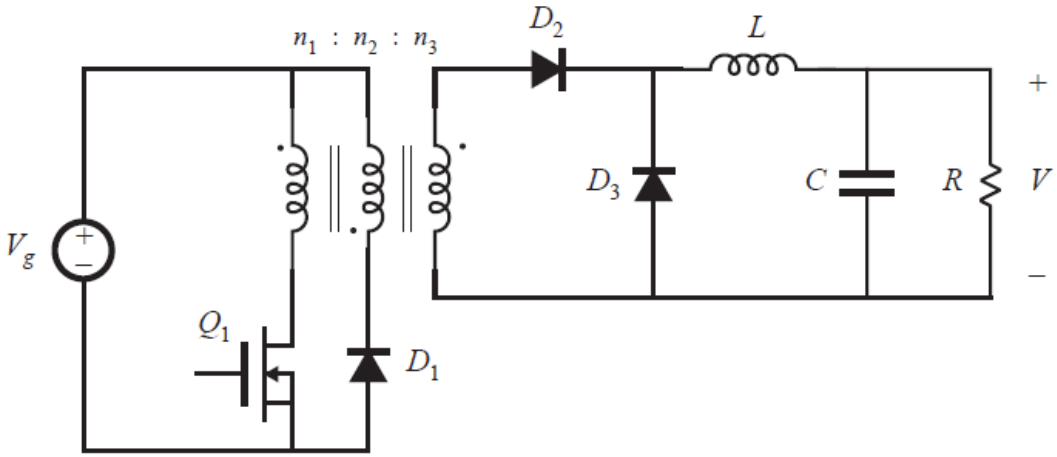




Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Forward Converter

- Sub-interval 2

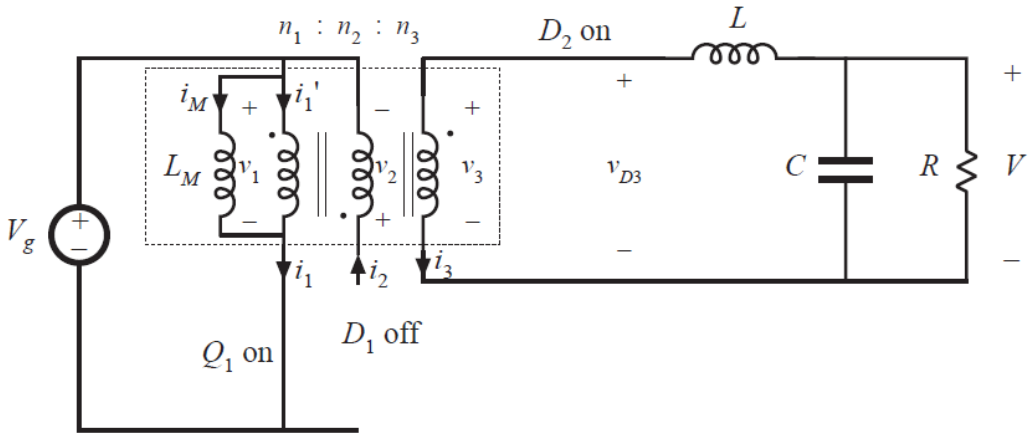


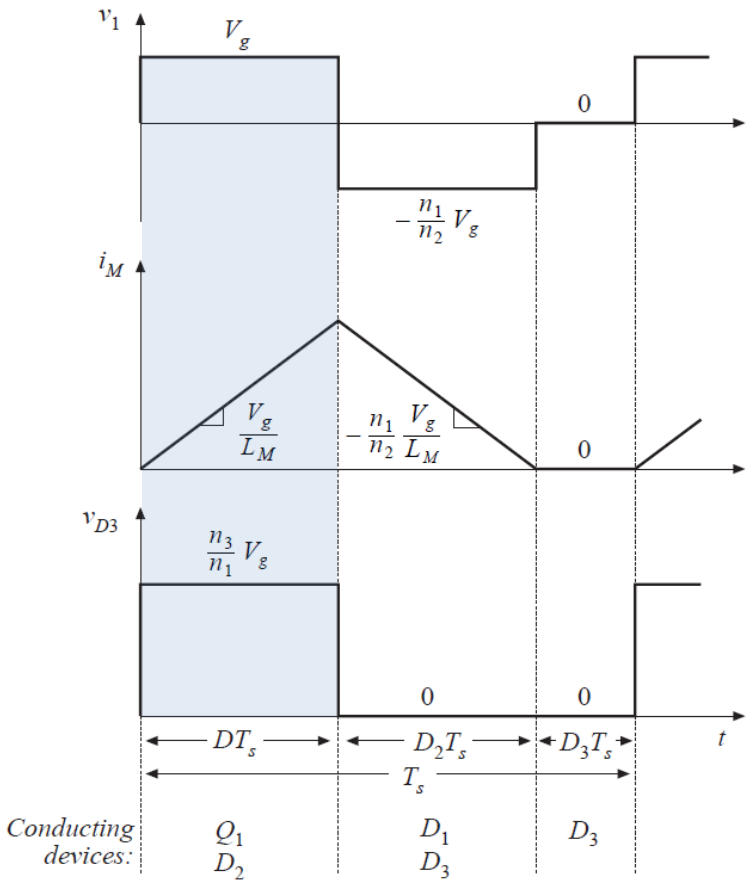
$$M(D) = D\frac{n_3}{n_1}$$

Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Forward Converter

- Sub-interval 1

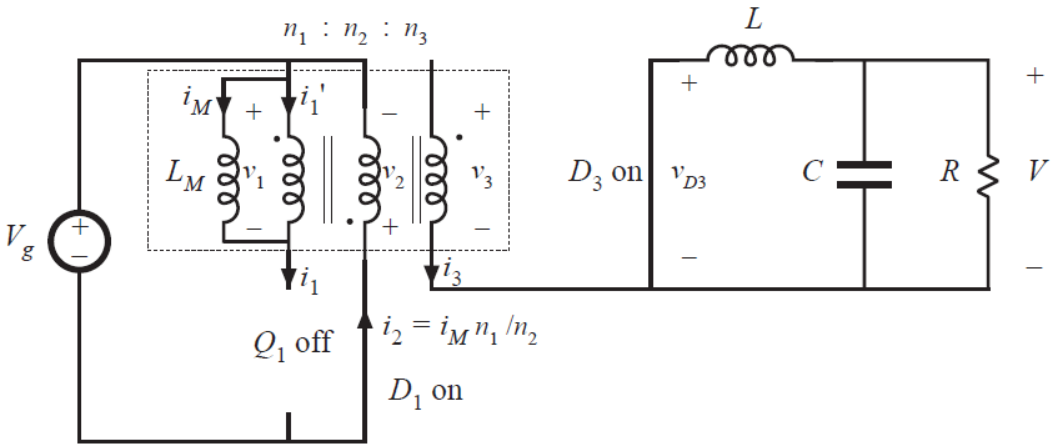


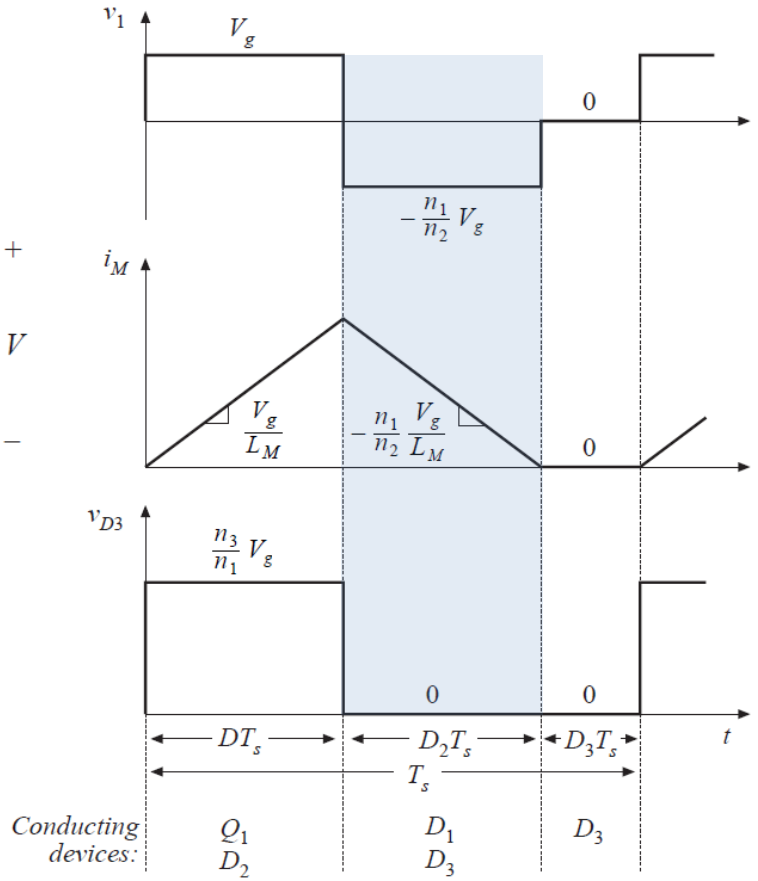


Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Forward Converter

- Sub-interval 2

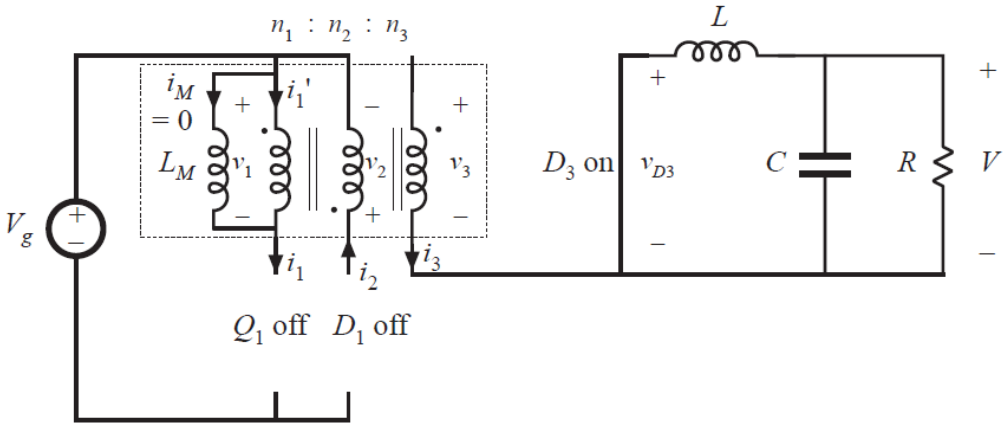


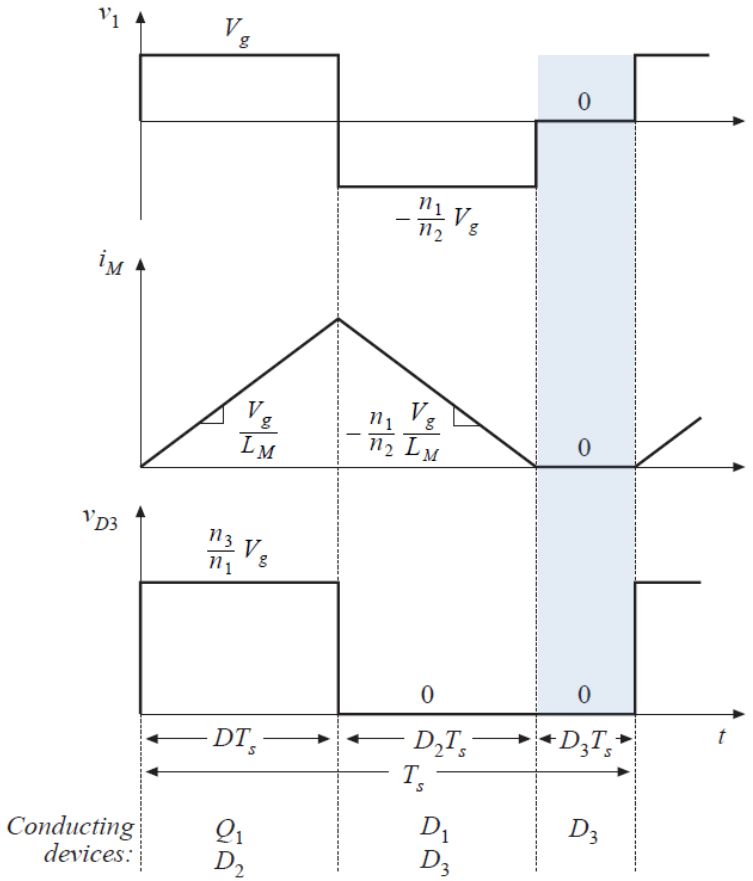


Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Forward Converter

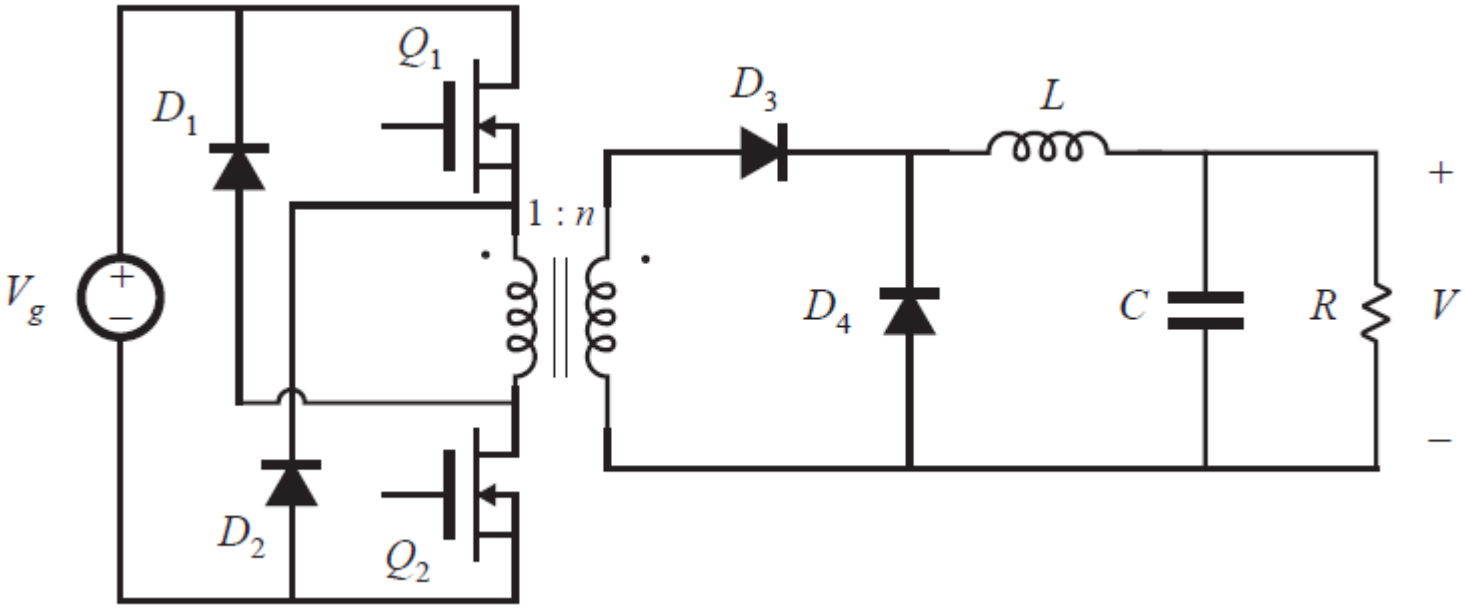
- Sub-interval 3





Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

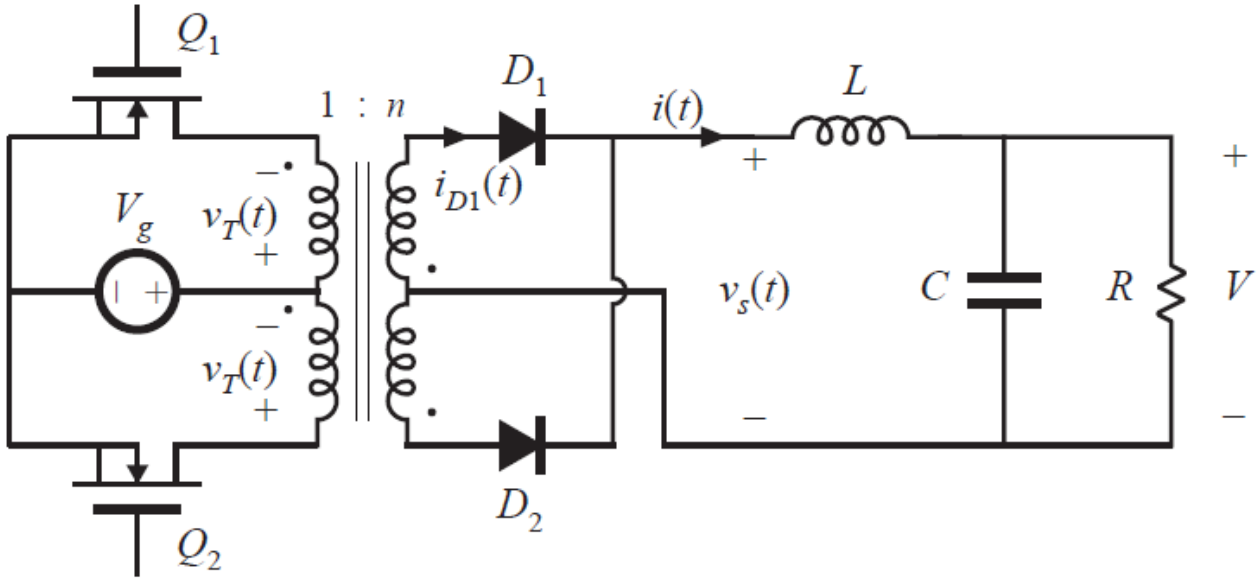
2-Switch Forward Converter



Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Push Pull Converter

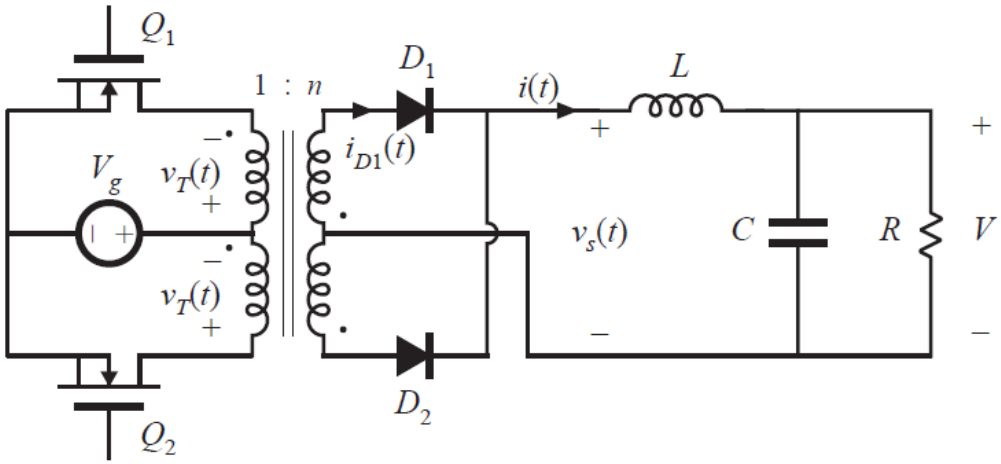
- Usually used as step up converter ($V>V_g$) or with low input voltage
- The transistors have to withstand $2V_g$

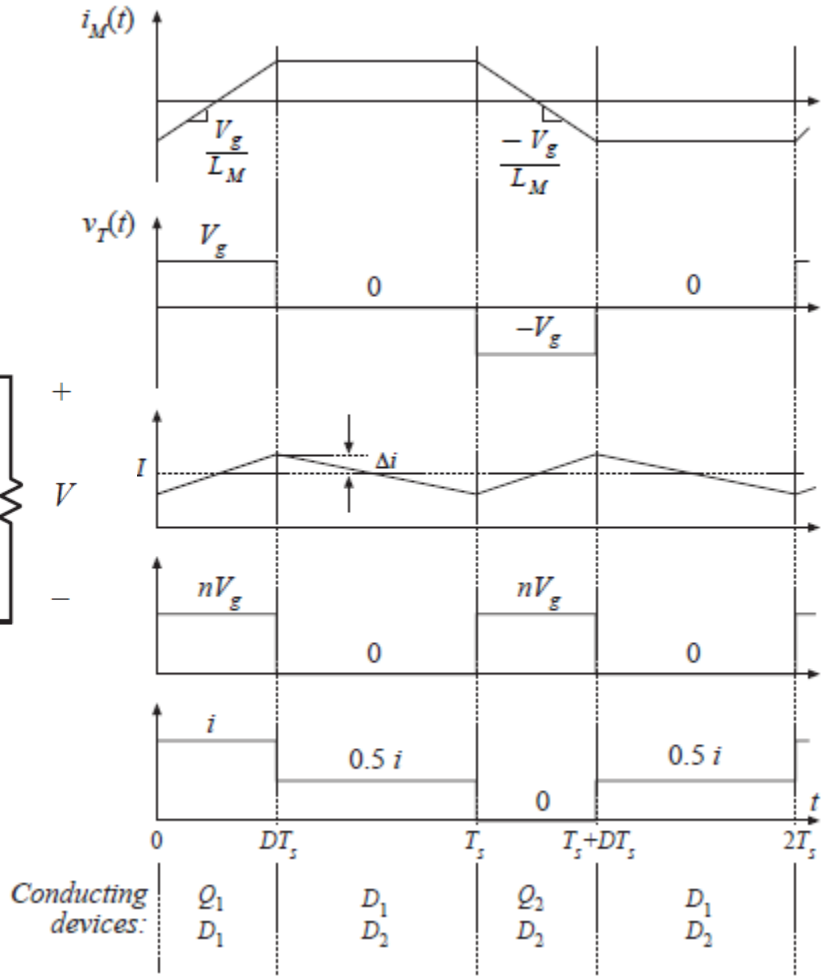


$$M(D) = 2Dn$$

Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Push Pull Converter

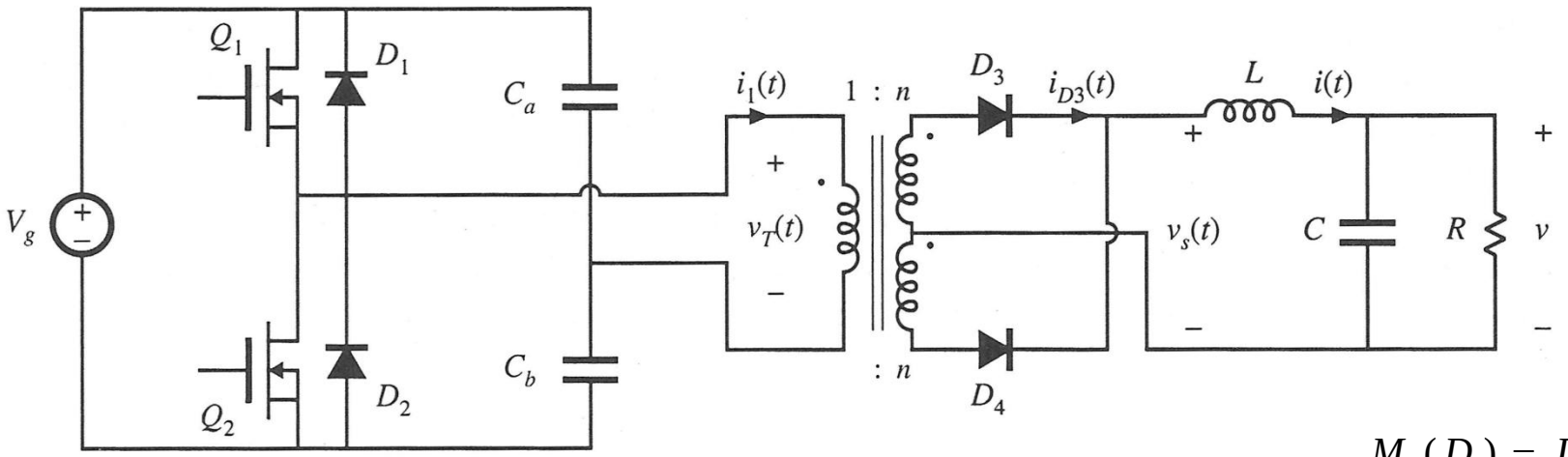




Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Half Bridge Converter

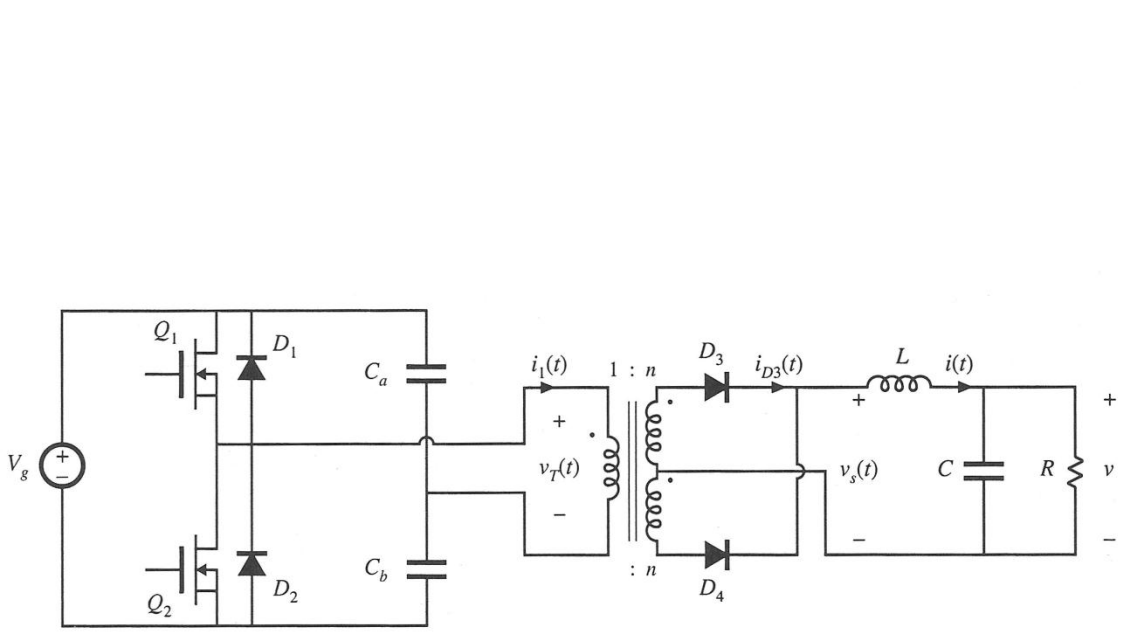
- Advantage: Transistors have to withstand Vg only
- Disadvantage: floating gate driver

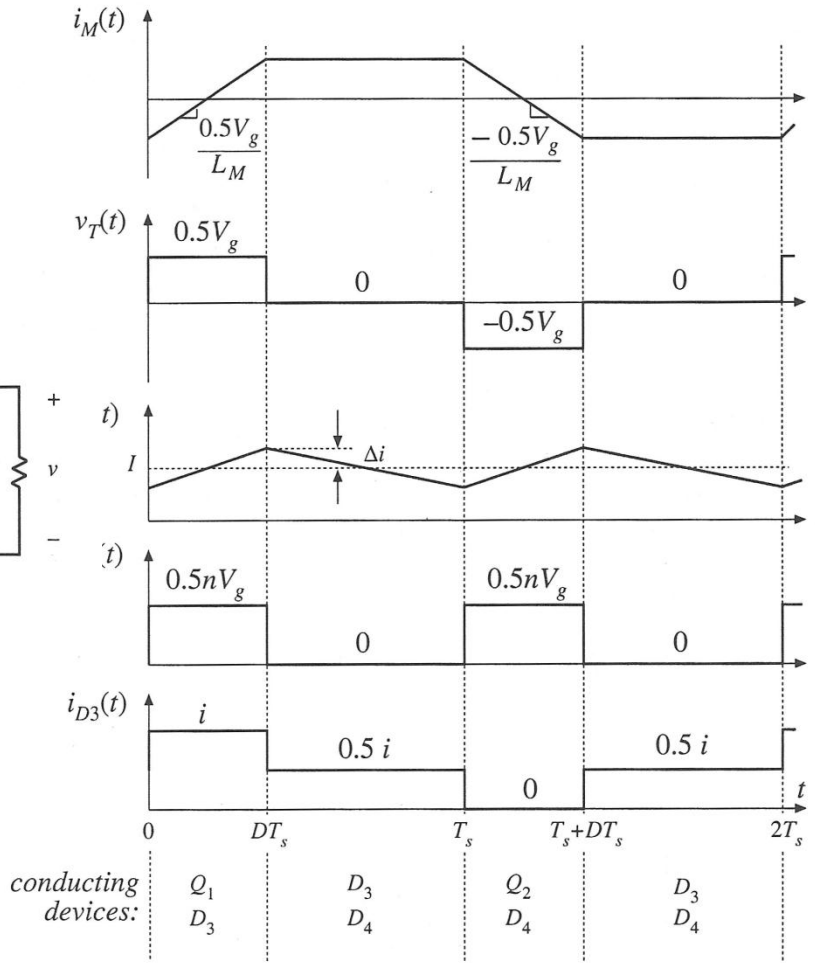


$$M(D) = Dn$$

Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Half Bridge Converter

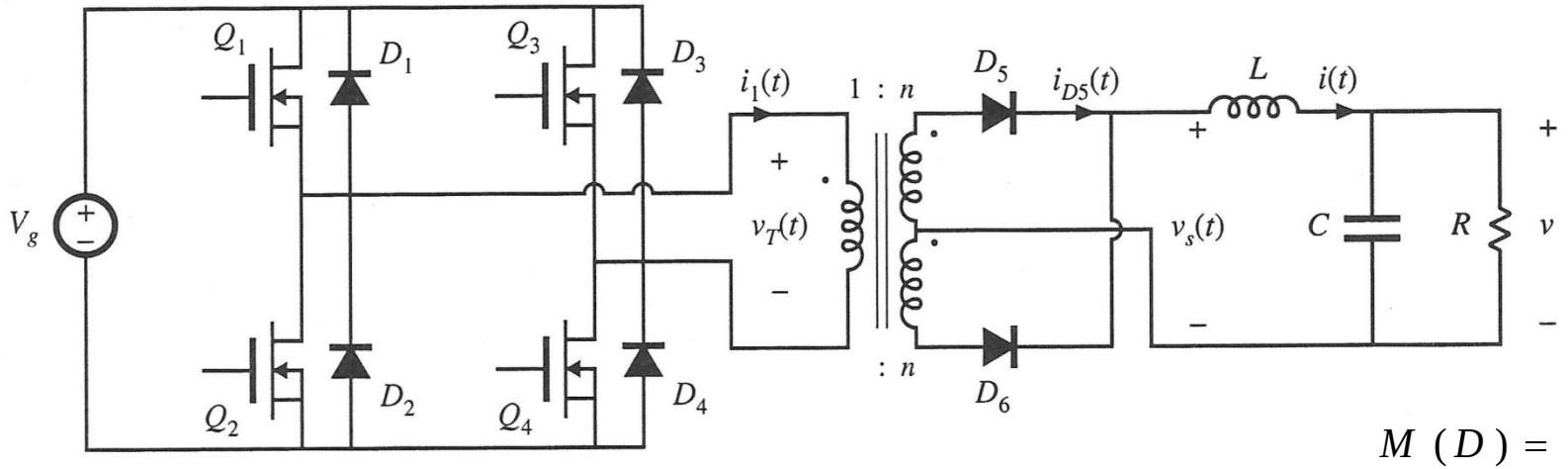




Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Full Bridge Converter

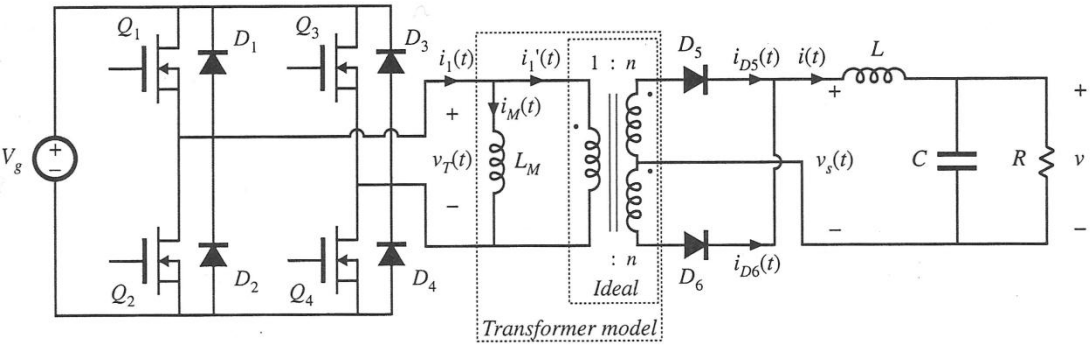
- Advantage: More output power than half bridge

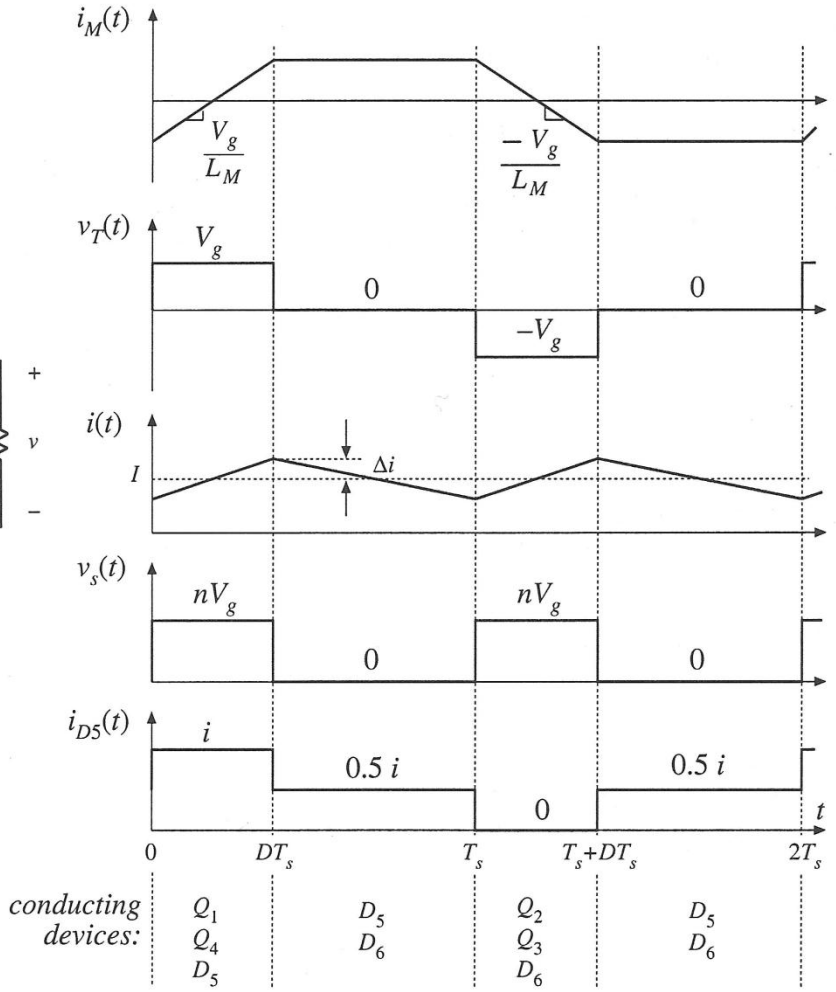


$$M(D) = Dn$$

Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

Full Bridge Converter





Source: R. W. Erickson, D. Maksimović: Fundamentals of Power Electronics

How to select right topology?

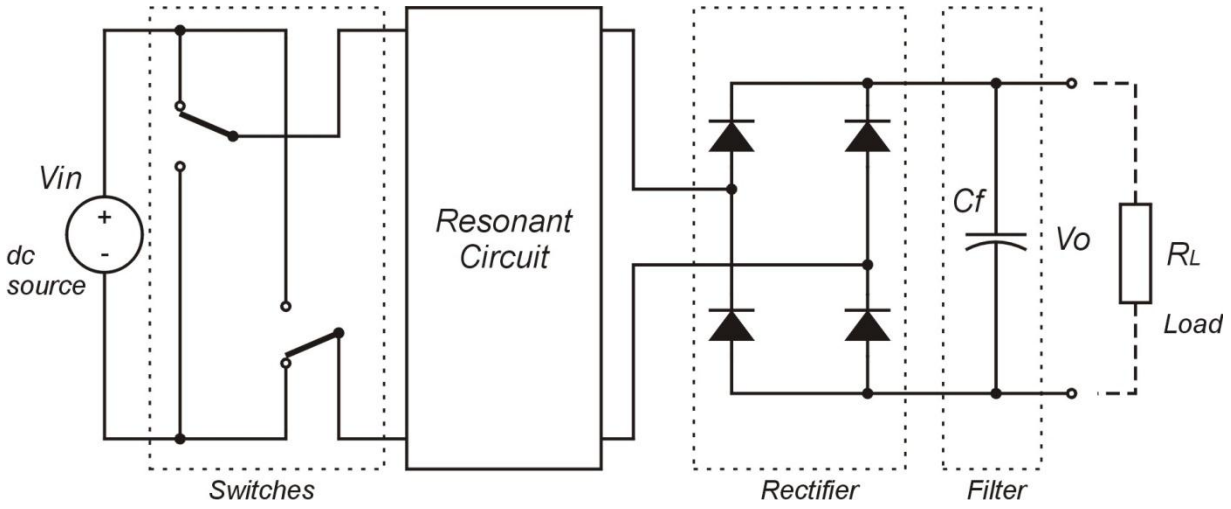
- To select right topology we need to consider:
  - Do we need isolation?
  - Input voltage / output voltage ration
  - Output power
  - Cost

Agenda

- Linear Regulator
- Non-Isolated SMPS
- Isolated SMPS
- Resonant SMPS
  - Series Converter
  - Parallel Converter
  - LLC Converter
- Digital Control of SMPS
- Hands on (Step down Converter)

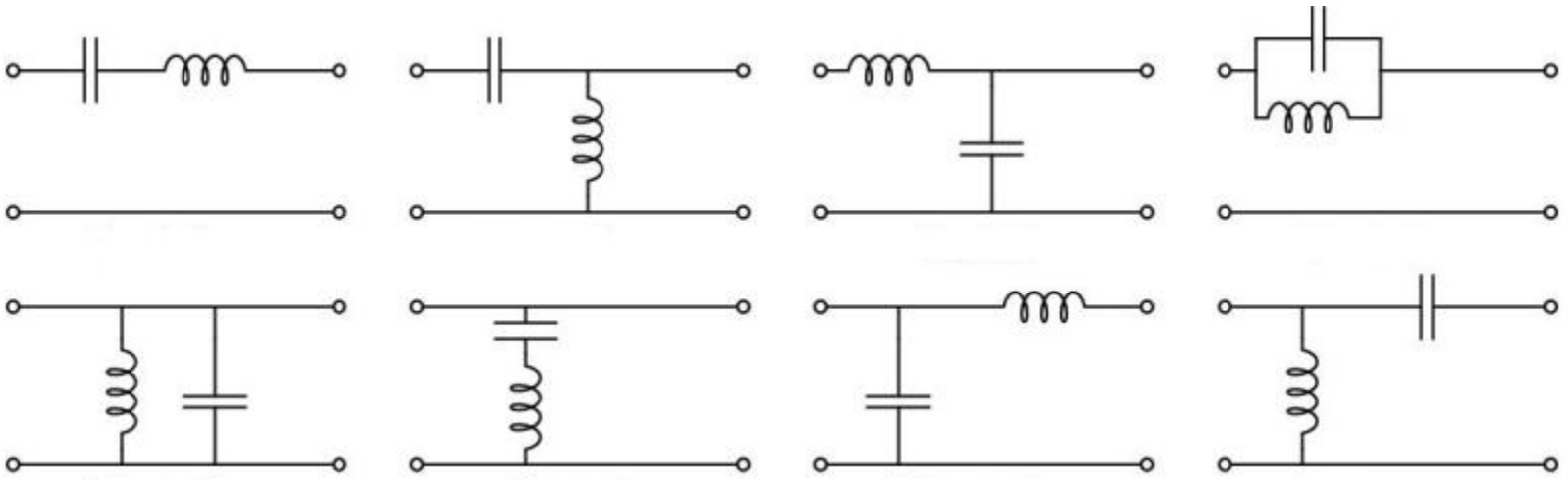
Resonant Converter Introduction

- The resonant converter employs **resonant circuit** between semiconductor switches and rectifier
- The **resonant circuit** consist of at least one capacitor and inductor



Resonant Converters

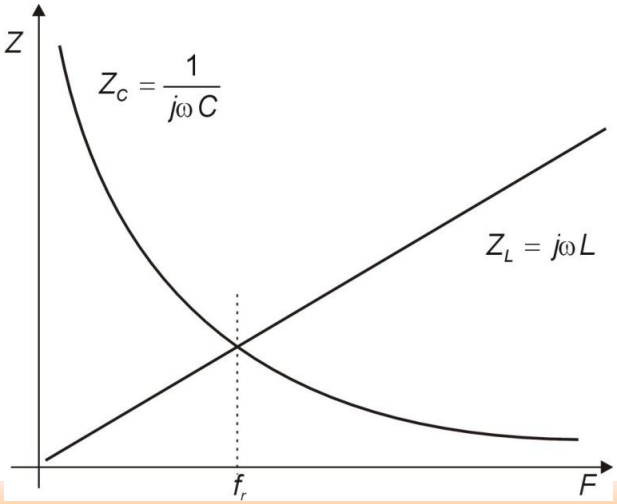
- There are many variants, how to implement resonant circuit (two and three components)
- This presentation focuses on widely used combinations:
  - Series resonant converter
  - Parallel resonant converter
  - LLC Resonant converter

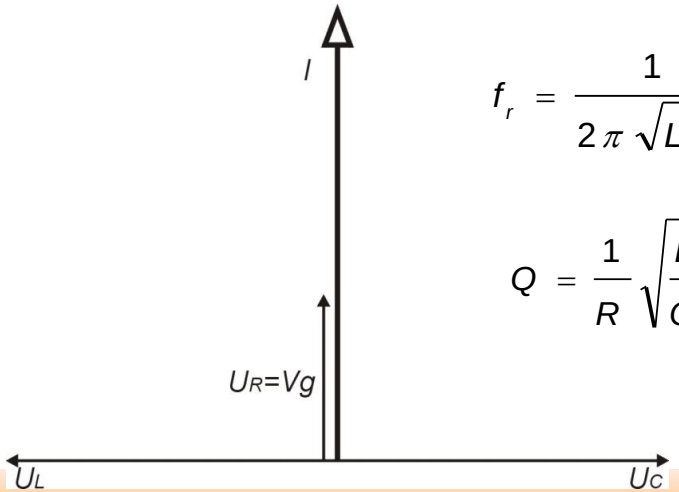


All possibilities for two components resonant circuit

Resonant Converter Introduction

- Series LC (RLC) circuit features at resonant frequency f_r
  - The resonant tank **impedance is frequency dependent**
  - The resonant tank has minimal impedance
  - There is zero voltage drop on resonant tank (ideally)
  - **The voltage drop on L and C components is Q – times (Q - quality factor) higher than voltage on resonant tank**



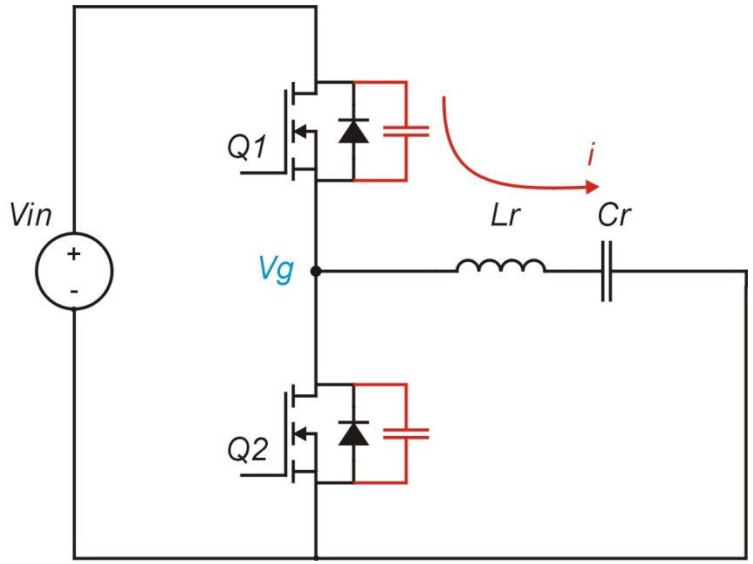


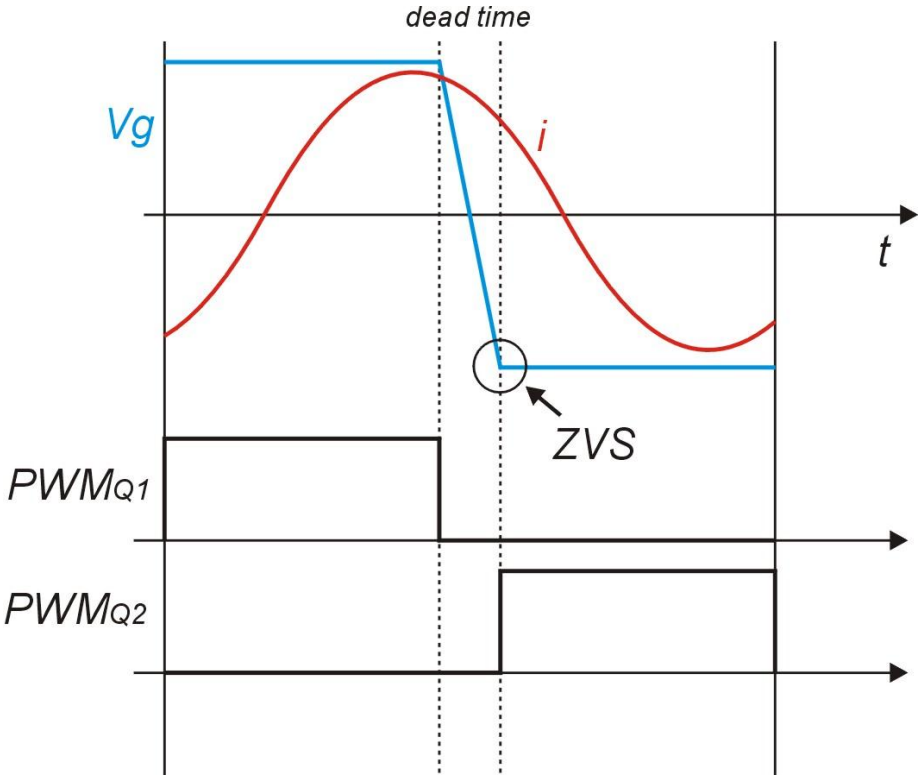
$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

Resonant Converter Introduction

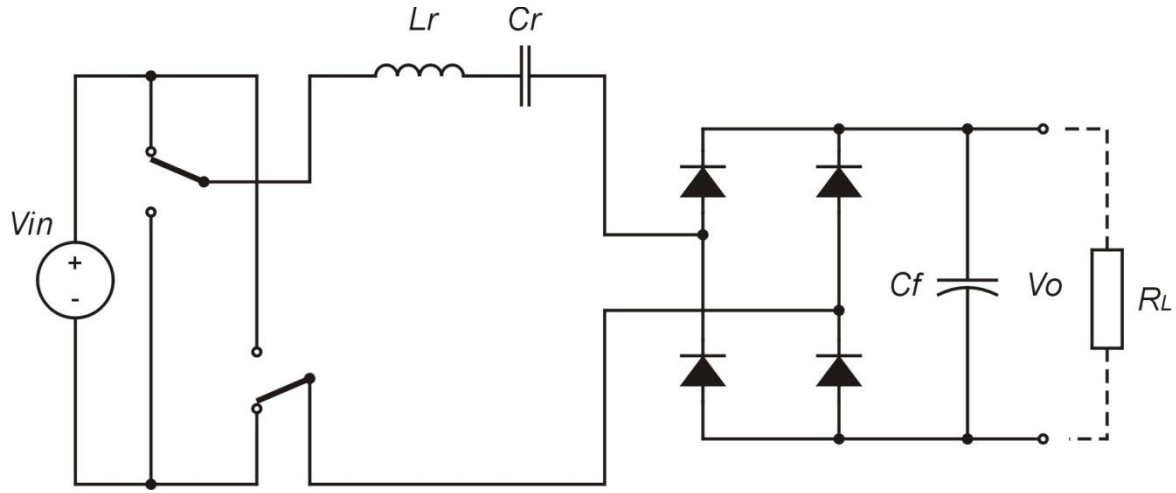
- Zero Voltage Switching (ZVS) of MOSFET transistor
  - The MOSFET transistor is switch on at zero drain-source voltage
  - There are no turn on losses





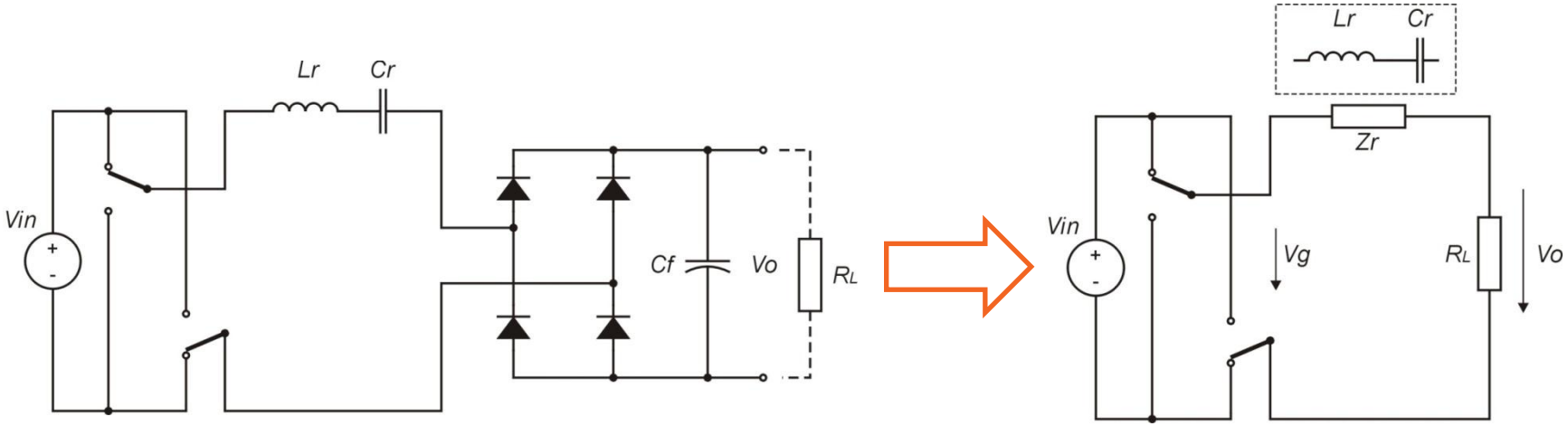
Resonant Converter Introduction

- Series Resonant Converter
  - The resonant tank is connected in series with the load RL



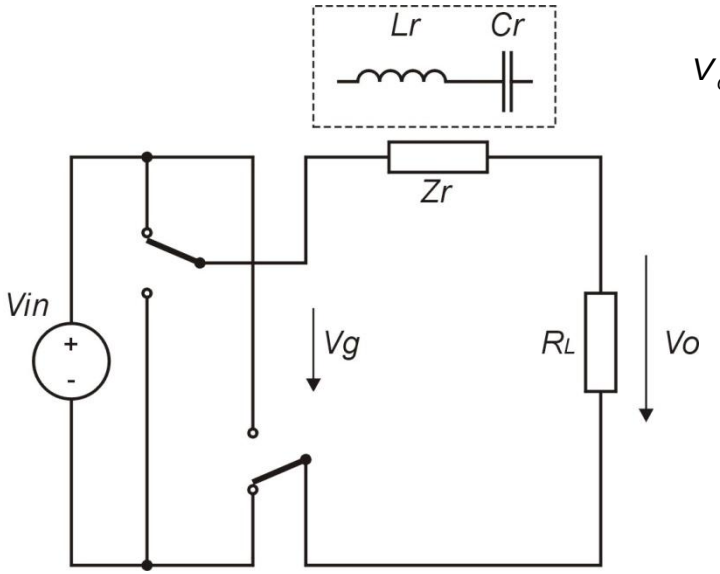
Resonant Converter Introduction

- Series Resonant Converter
  - The resonant tank is connected in series with the load RL
  - The resonant tank creates voltage divider together with the load

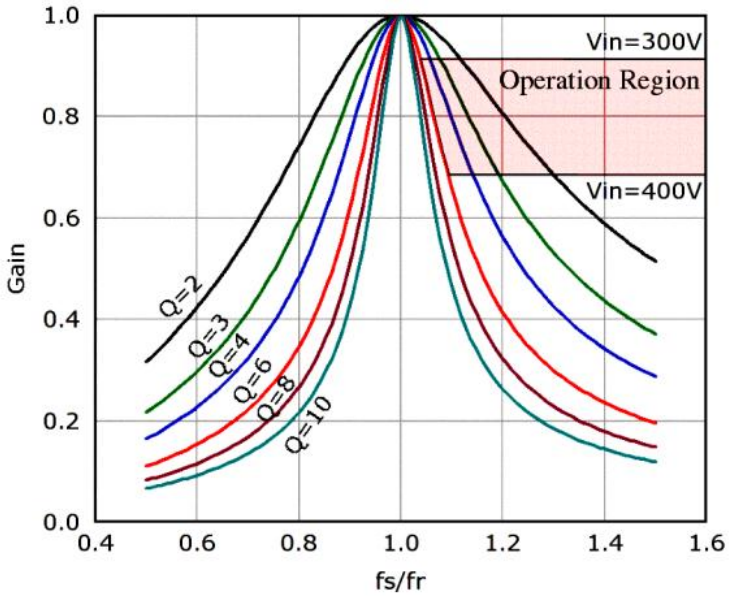


Resonant Converter Introduction

- Series Resonant Converter
  - The resonant tank creates voltage divider together with the load
  - The resonant tank impedance is frequency dependent



$$V_O = Gain \times V_G$$

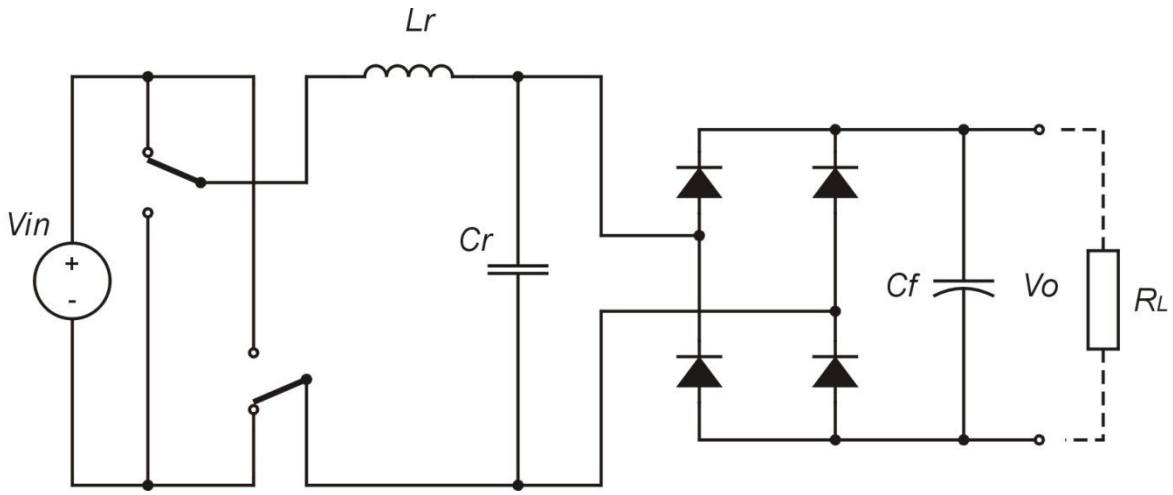


Resonant Converter Introduction

- Series Resonant Converter (SRC) - Summary
  - The SRC can run at ZVS over the resonant frequency
  - At light loads it is difficult to control output voltage
  - High conduction losses at high input voltage and light loads

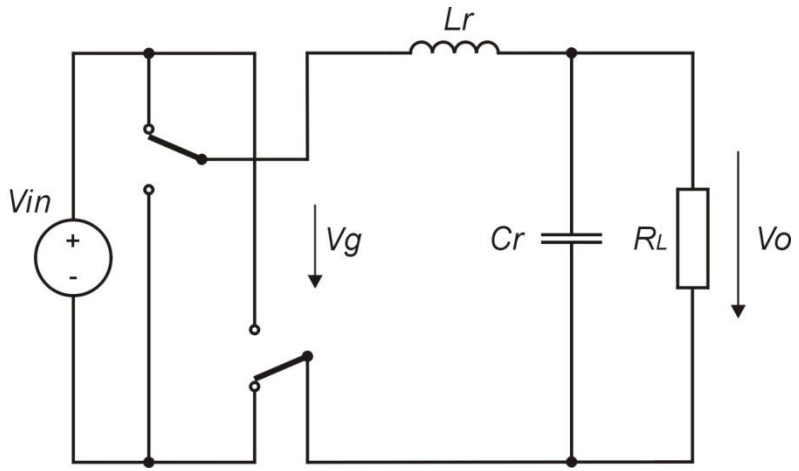
Resonant Converter Introduction

- Parallel Resonant Converter
  - The load RL is connected in parallel to resonant circuit

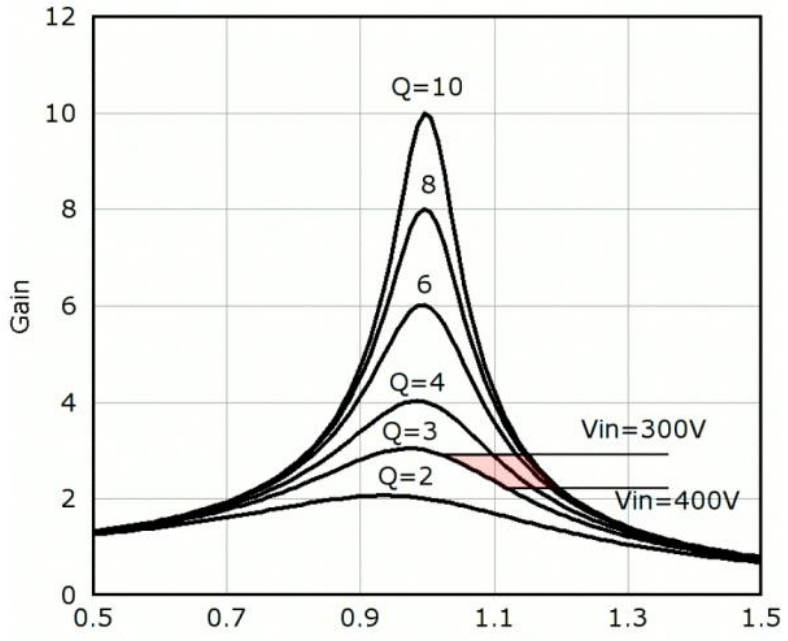


Resonant Converter Introduction

- Parallel Resonant Converter



$$V_O = Gain \times V_G$$

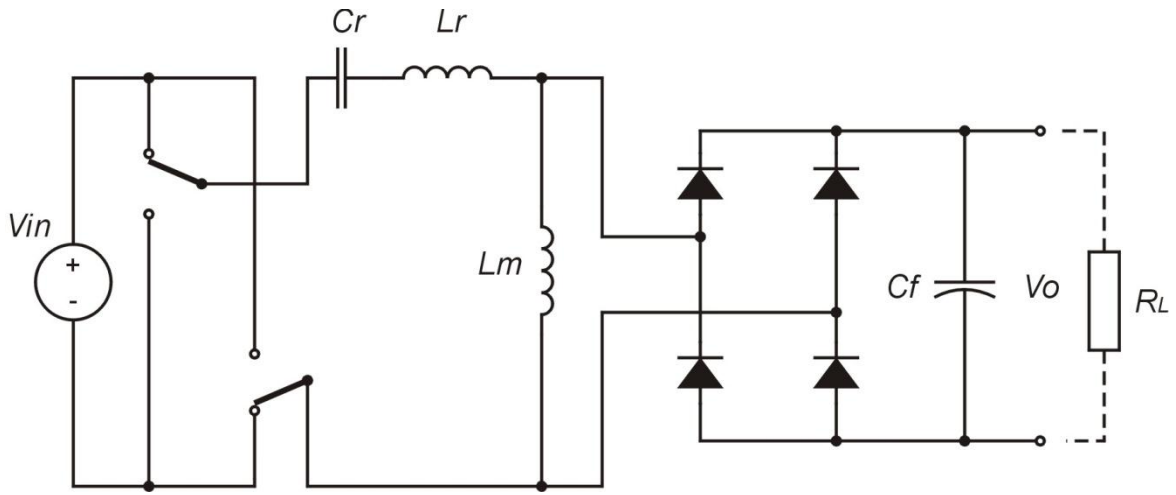


Resonant Converter Introduction

- Parallel Resonant Converter (PRC) - Summary
  - The PRC can also run at ZVS over the resonant frequency
  - The PRC can work at no load condition
  - High conduction losses at high input voltage and light loads

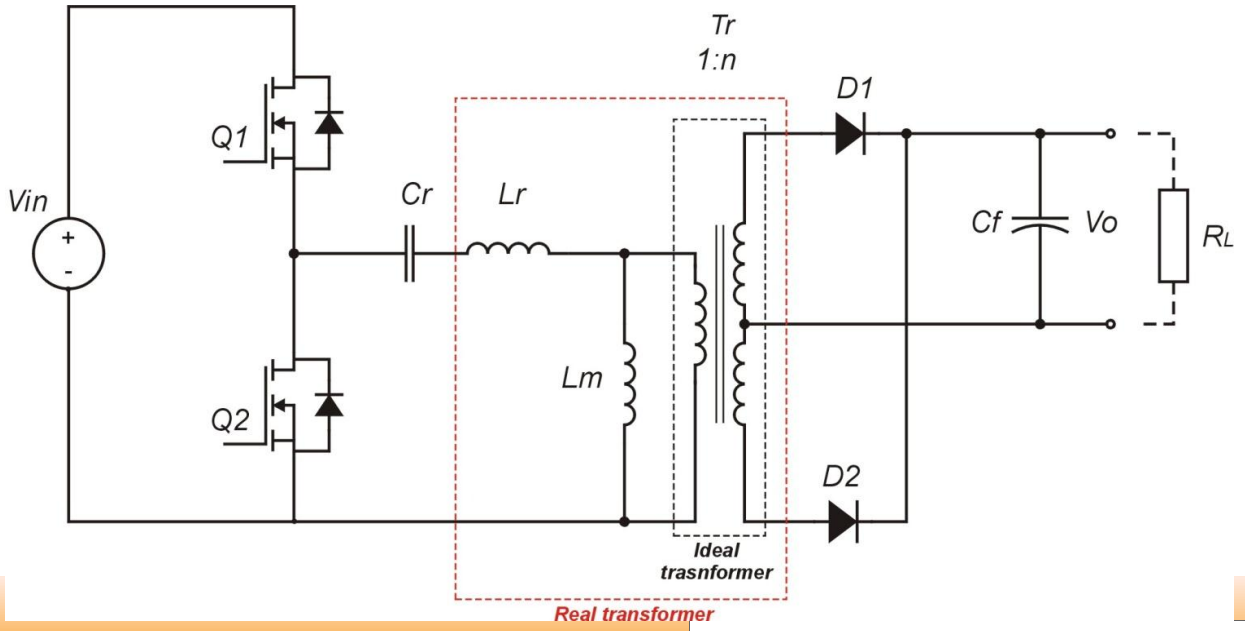
Resonant Converter Introduction

- LLC resonant Converter
  - Additional inductance is employed in resonant circuit
  - The load RL is connected in parallel to this inductance



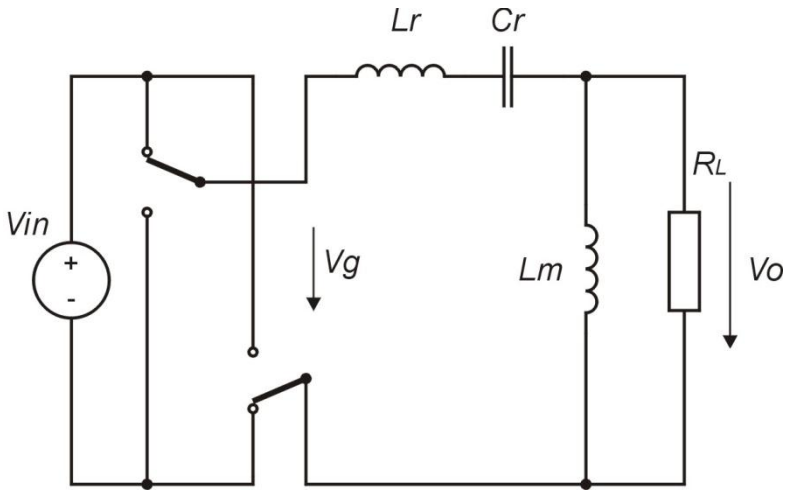
Resonant Converter Introduction

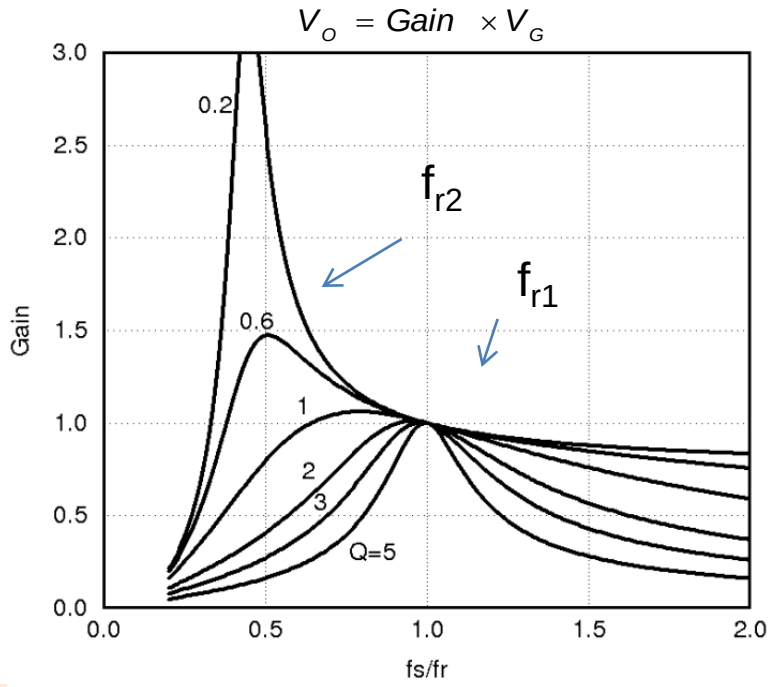
- LLC resonant Converter
  - When transformer used in LLC converter, the magnetizing inductance and leakage inductance can be used in resonant circuit instead of external separate inductances
  - This is one of the advantages of LLC resonant converter



Resonant Converter Introduction

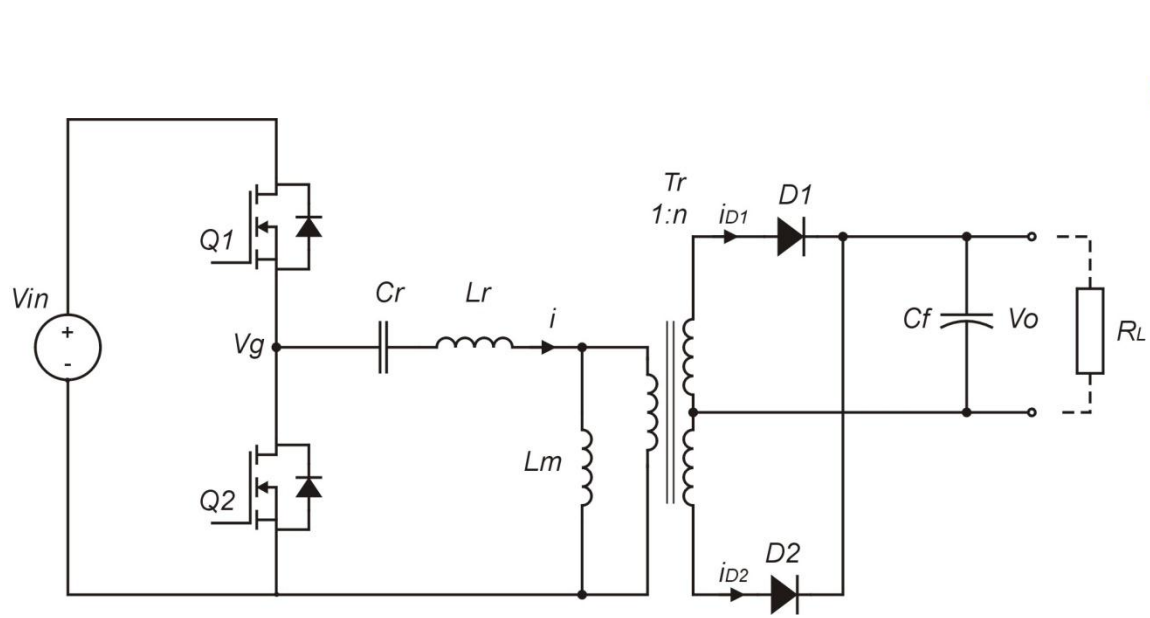
- LLC Resonant Converter
  - There are two resonant frequencies: first one for Lr and Cr and second one for (Lr + Lm) and Cr

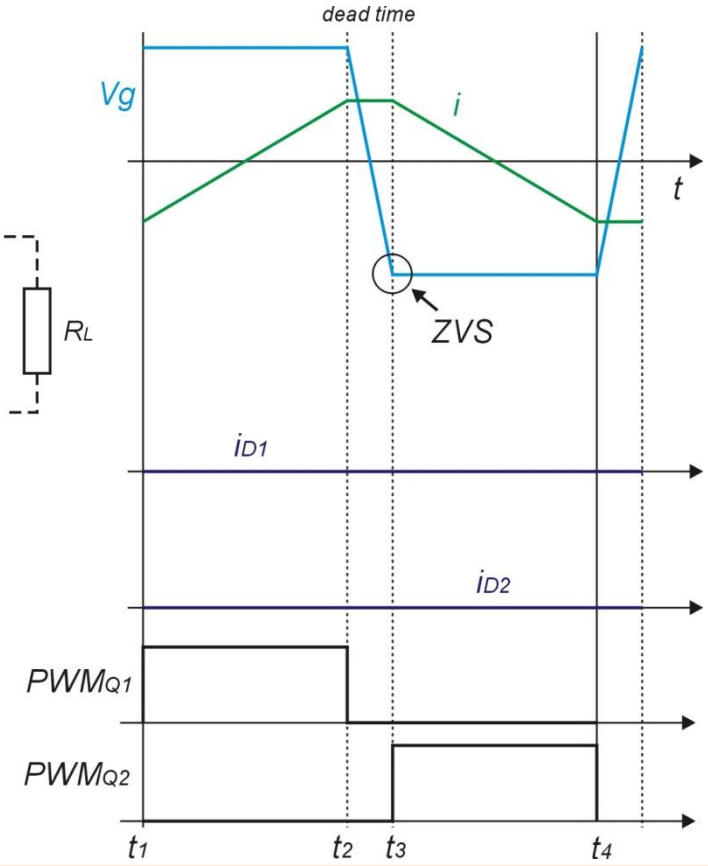




Resonant Converter Introduction

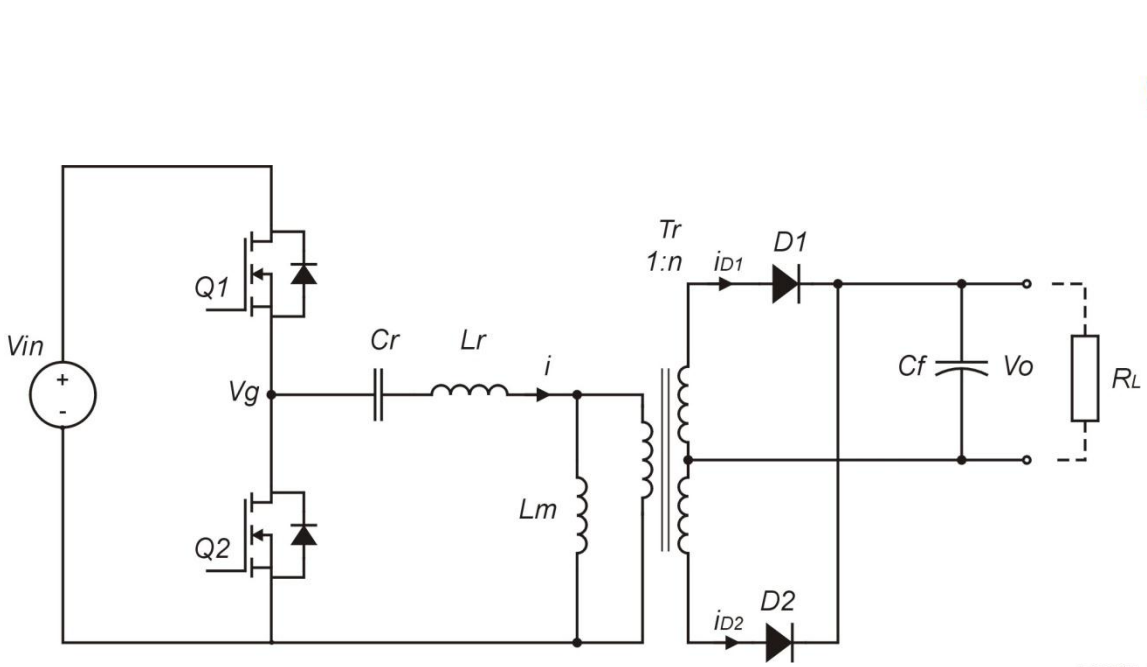
- LLC Resonant Converter – Operation at no Load

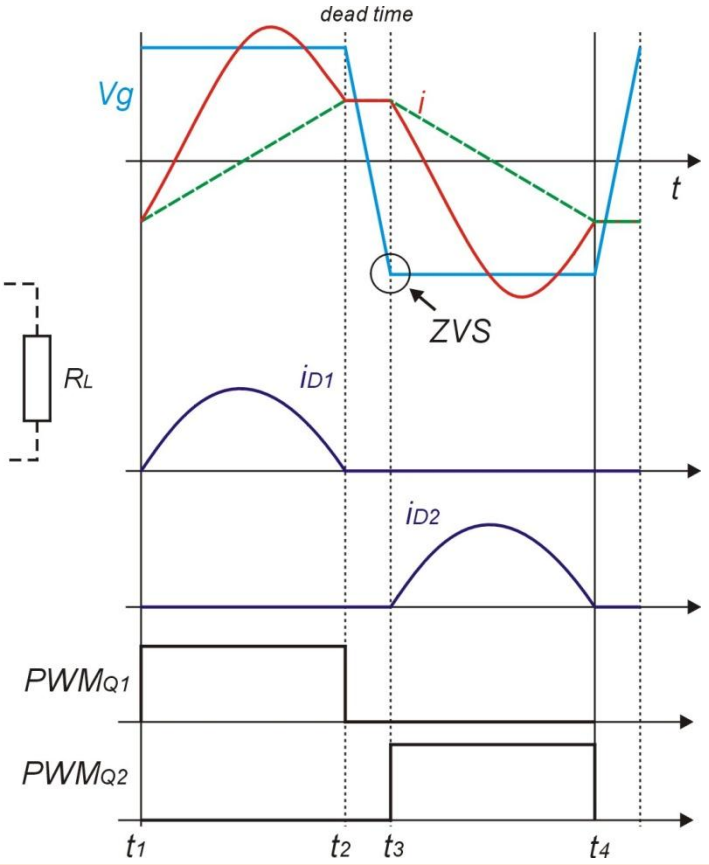




Resonant Converter Introduction

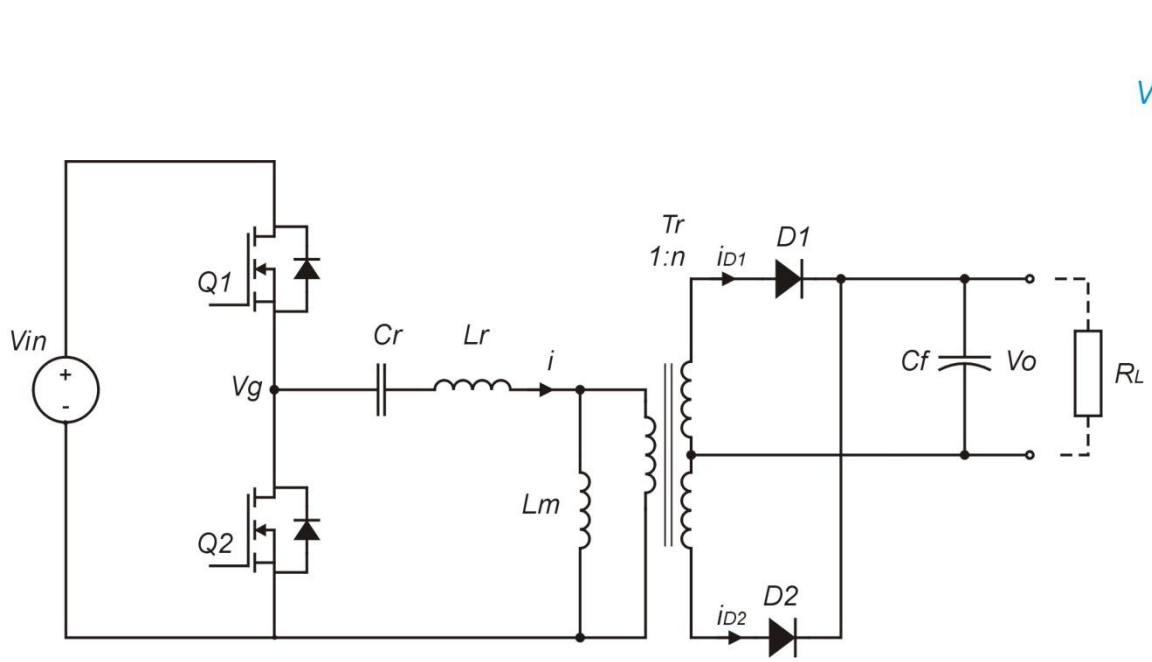
- LLC Resonant Converter – Operation at Resonance

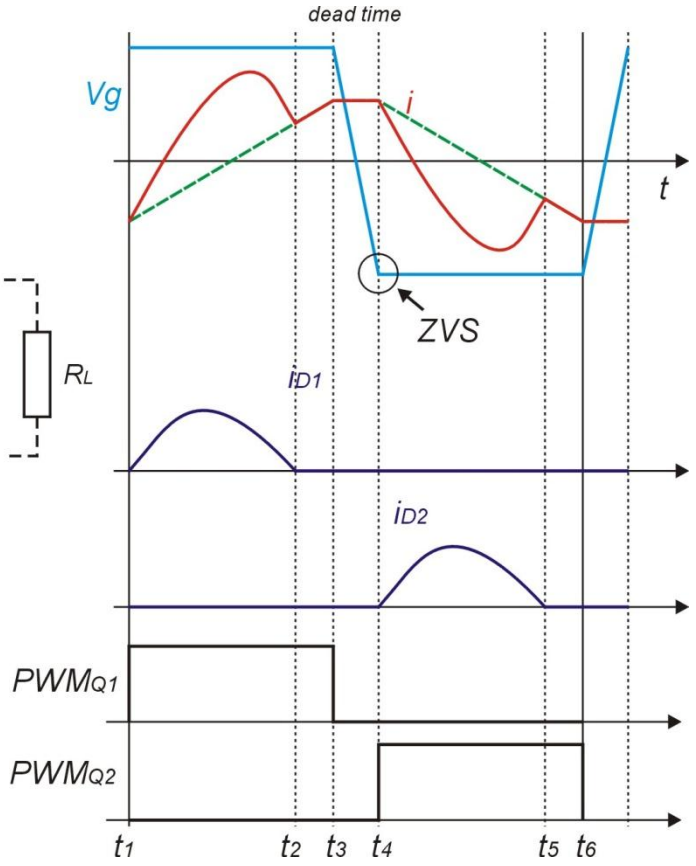




Resonant Converter Introduction

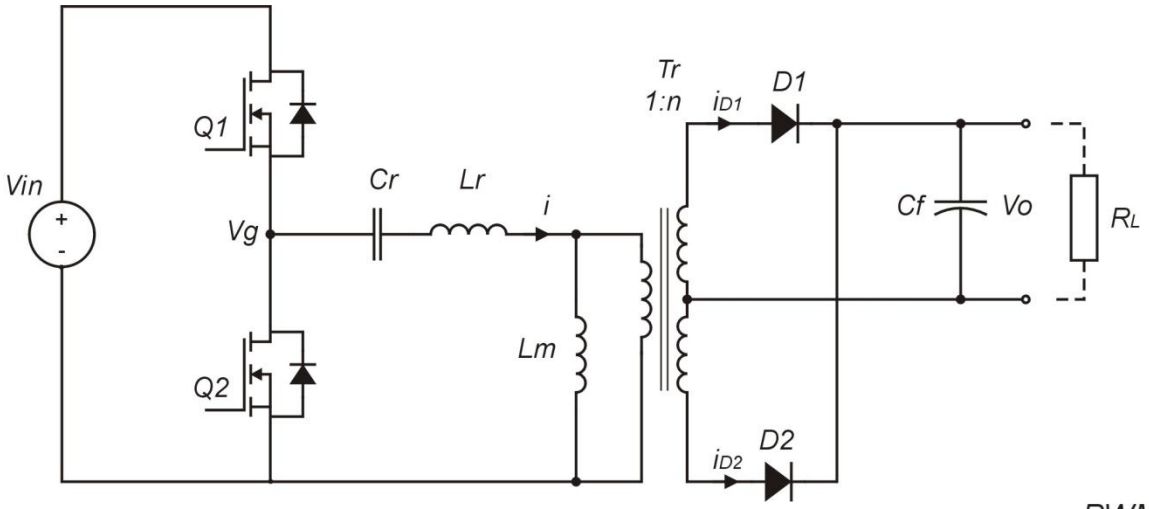
- LLC Resonant Converter – Operation below Resonance

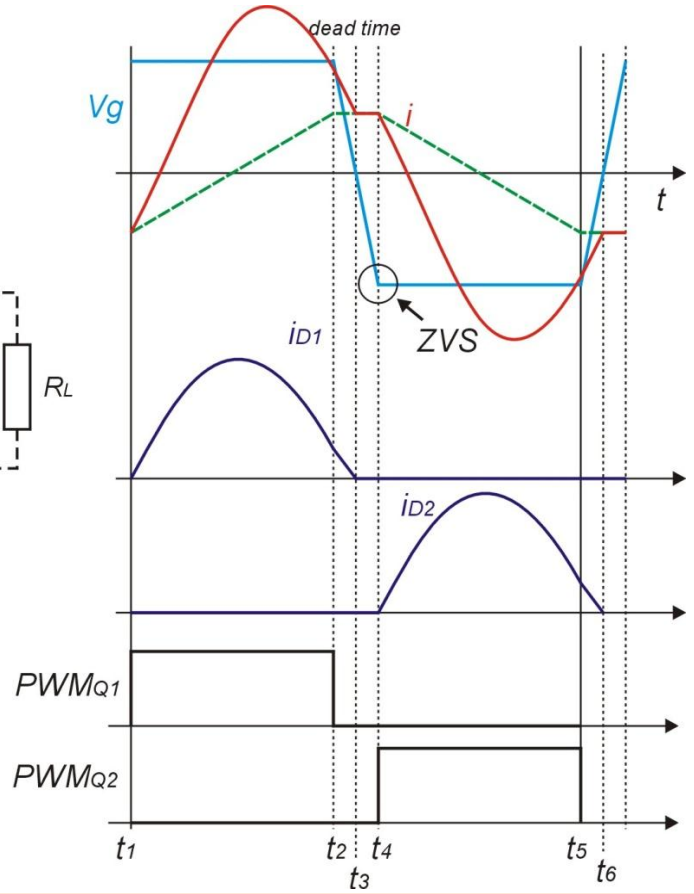




Resonant Converter Introduction

- LLC Resonant Converter – Operation above Resonance



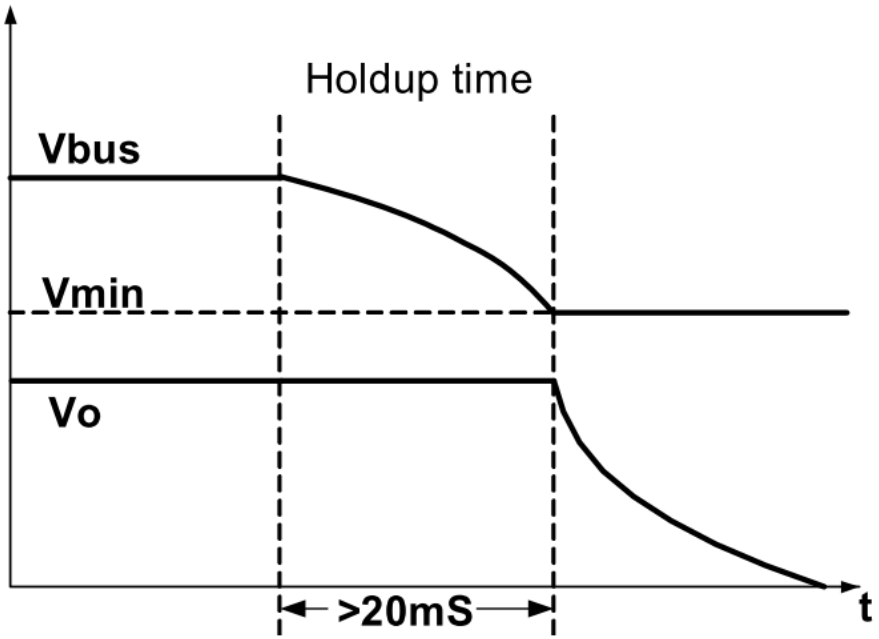


Resonant Converter Introduction

- LLC Resonant Converter - Summary
  - The LLC resonant converter can run at ZVS in whole range of the operating frequency (above even below resonant frequency)
  - The LLC resonant converter can work at no load condition. The turn of current can be controlled by Lm inductor
  - The LLC resonant converter works at resonant frequency at nominal input voltage
  - The LLC resonant converter can operate over wide range of operating input voltage

Resonant Converter Introduction

- Operation at wide input range
  - There is a requirement, that power supply must delivery output power during one whole period, if there is mains line drop out2



Resonant Converter Introduction

- Operation at wide input range – PWM modulated Converters
  - The PWM modulated converters are not able to increase gain by changing duty cycle. Therefore the $V_{BUS} - V_{min}$ has to small (20-30V).
  - The whole energy has to by stored in DC bus capacitor
  - Example of DC bus capacitor calculation

P_{out} = 500W
V_{BUS} = 400V
V_{min} =370V
f_{min} = 45Hz

$$C \geq \frac{2P}{f_{min}\,(V_{BUS} - V_{min})} = 962\ \mu F$$

Resonant Converter Introduction

- Operation at wide input range – Resonant Converters
  - Some resonant converters can increase gain over 1 by changing switching frequency. Therefore the $V_{BUS} - V_{min}$ can be much higher than for PWM modulated converters.

  - Example of DC bus capacitor calculation

    P_{out} = 500W
    V_{BUS} = 400V
    V_{min} =200V
    f_{min} = 45Hz

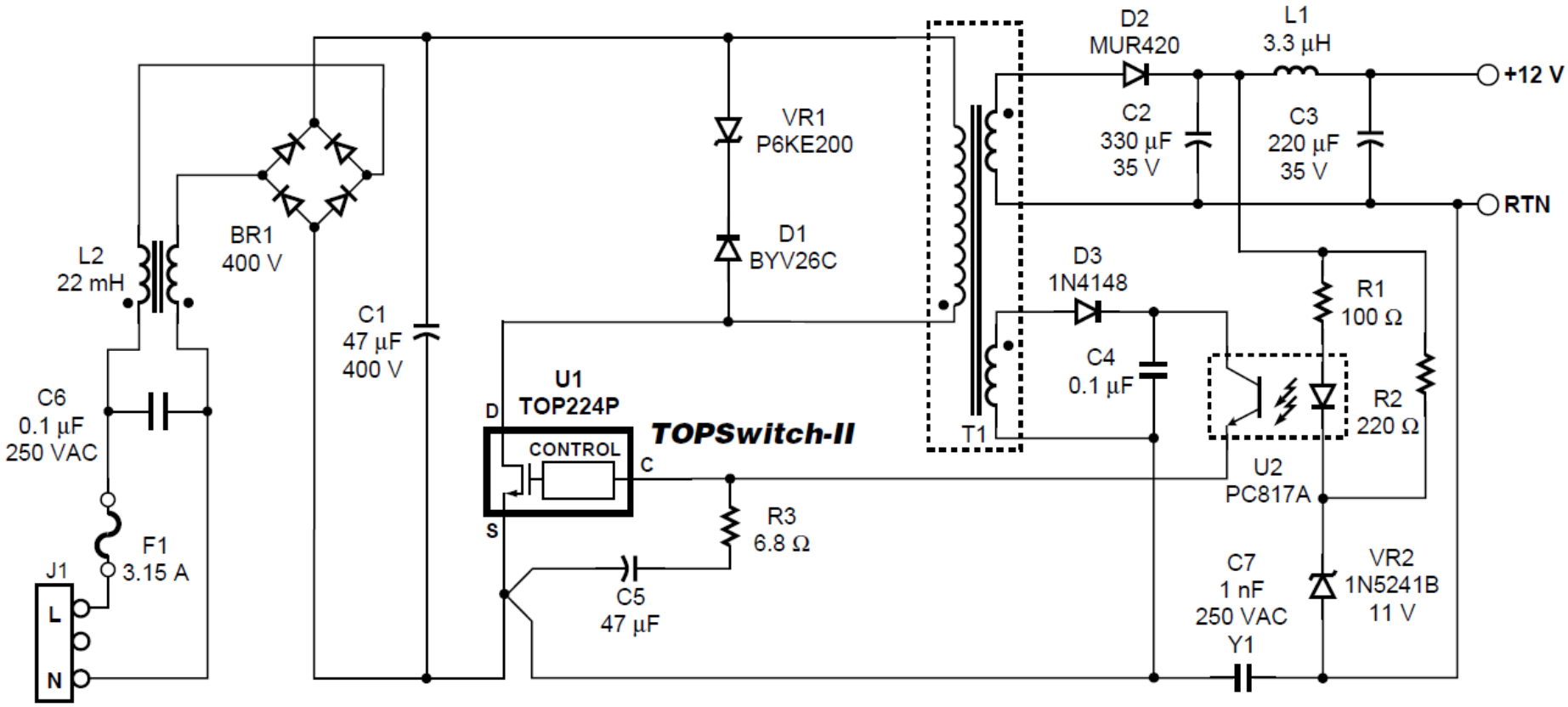
$$C \geq \frac{2P}{f_{min}\,(V_{BUS} - V_{min})} = 185\ \mu F$$

  - The DC Bus capacitor can be significantly smaller **185 µF versus 962 µF**!!!

Agenda

- Linear Regulator
- Non-Isolated SMPS
- Isolated SMPS
- Resonant SMPS
- Digital Control of SMPS
  - Advantages of Digital Control
  - MCU Requirements/Example of suitable MCU's
  - Key MCU Peripherals
  - Example of SMPS Application
- Hands on (Step down Converter)

Analog Control of SMPS



Analog Control of Flyback Converter (Power Integration)

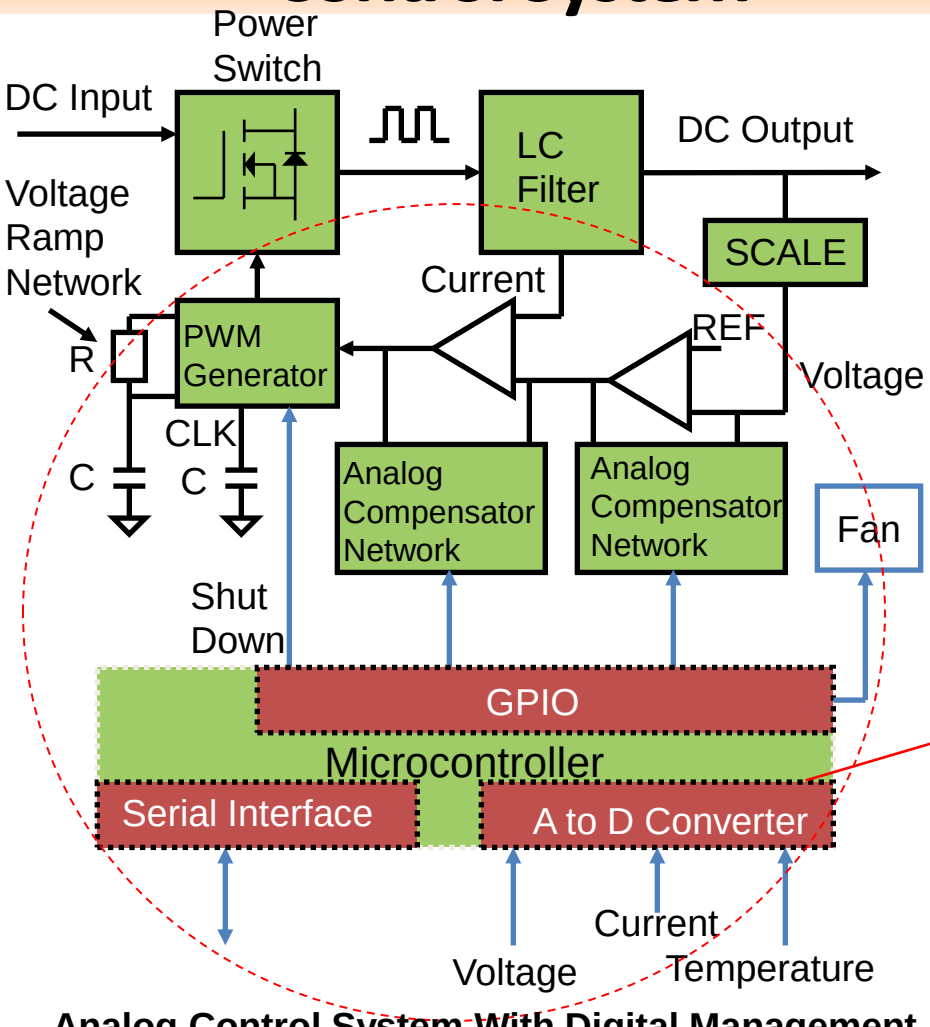
Where Is Digital Power Conversion Applied?

- "Digital power Conversion" is a power system that is controlled by digital circuits, in much the same way as would be with analog circuits, to monitor, supervise, communicate and control looping. A fully digitally controlled power system includes both digital control and digital power management.

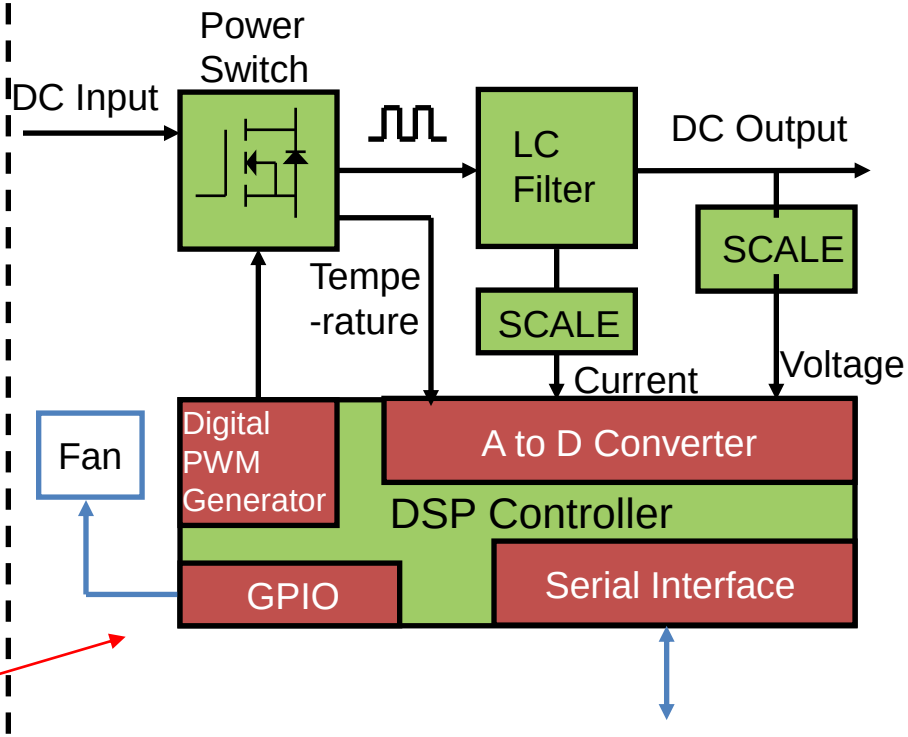
- Digital Control
  - The control feedback or feed-forward loop, which is controlled by the digital circuit or programmable controller, regulates the output of the power system by driving the power switch duty cycle using pulse width modulation techniques.
  - The control circuits combine A/D conversion, Pulse Width Modulation, and Communication interfaces, operating entirely or mostly in digital mode.

- Digital Power Management
  - A Digital circuit or **programmable controller** provides the functions of configuration, tracking, monitoring , protection, supply sequencing, and communication with the environment.

Comparison of Analog and Digital Power Control System



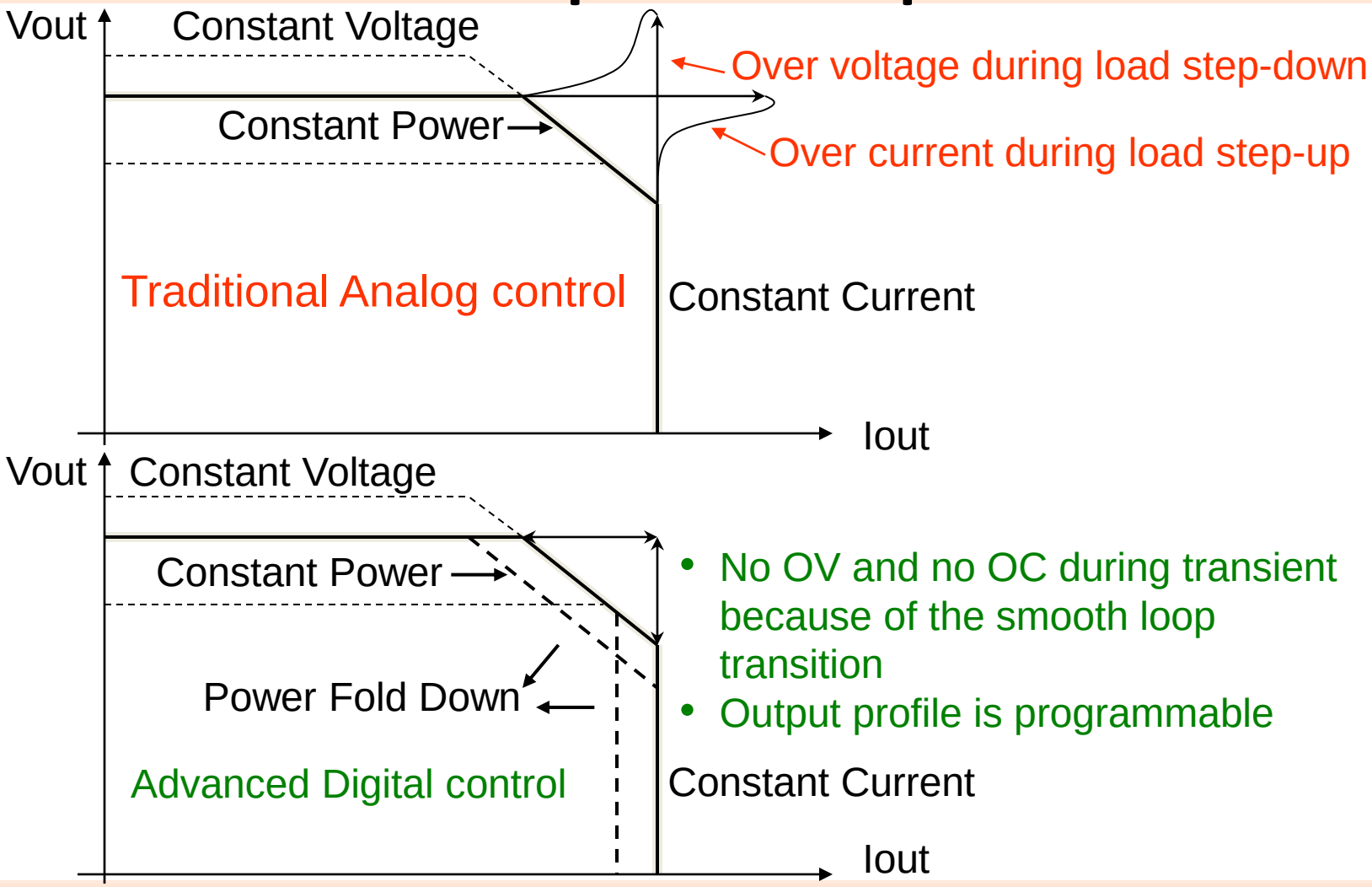
Analog Control System With Digital Management



Both MCU and Analog PWM controller are replaced by one DSC

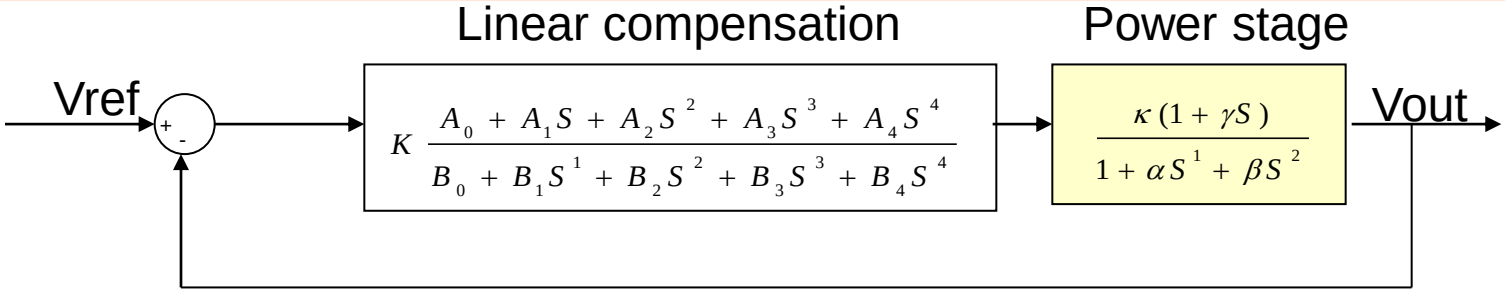
Full Digital Control System

Analog Control vs. Digital Control - Transient Response Comparison

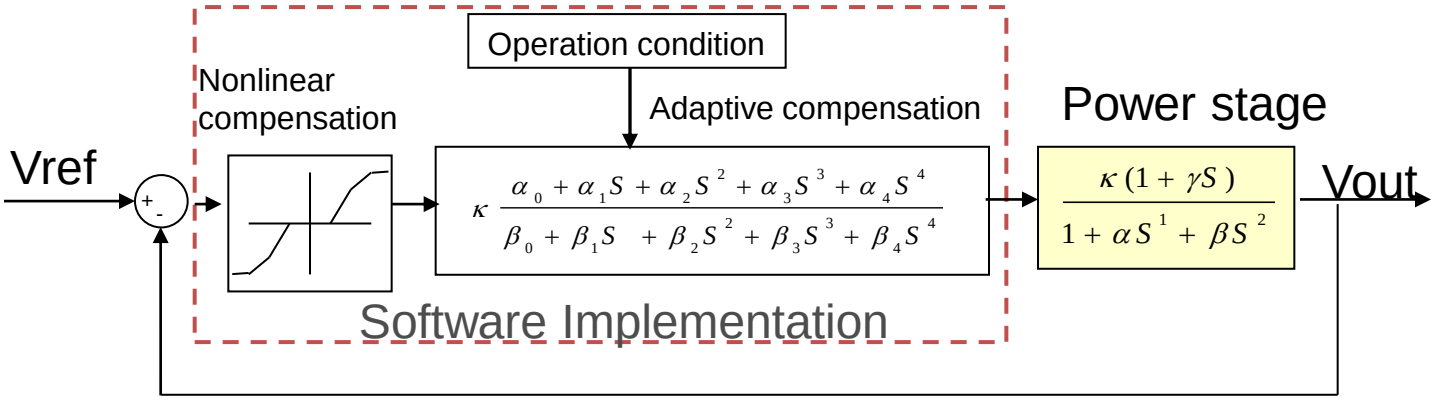


- No OV and no OC during transient because of the smooth loop transition
- Output profile is programmable

Digital vs. Analog Control Loop



A typical control loop implemented by an analog circuit



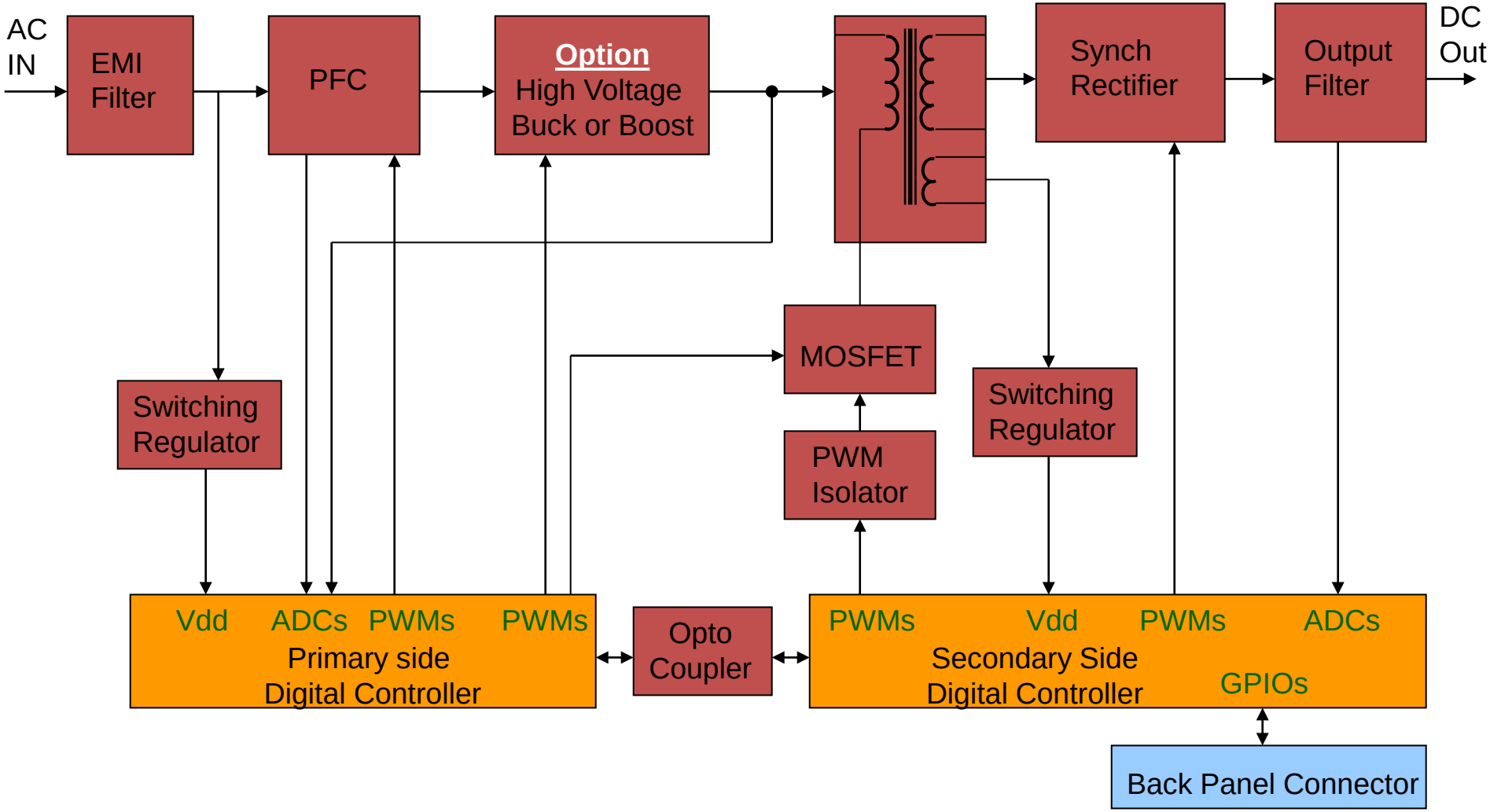
A digital control loop implemented by Digital Signal Controller (DSC)

Benefit of digital control:
1) Optimize feedback loop to meet application requirements
2) Runtime changes to compensation parameters according to operating conditions

Compare Digital Control To Analog Control

	Analog Control	Digital Control
Control Circuit	Complex, Bulky	Simple, Programmable, Integrated
Flexibility	Bad	Good
Design Continuity	Bad	Good
Sample Mode	Continuous	Digitialization Error
Processing	Continuous	Control Delay

Digital Controlled Power Supply



Benefits of Digital Power

- **Free from** the effects of **component tolerance**, parametric drift, aging, etc.
- **Configurable** feedback loop **structure** for specific application requirements
- **Adaptive control** to meet changing operating conditions
- **Flexible** Pulse Width **Waveform-generation** module
- **Programmable relationships** among **PWM** outputs
- **Upgradeable** with new features **without hardware** changes
- **Retainable** operational **data** for diagnostic and record keeping
- **Diverse communications** capabilities
- **Reduced** component count and **cost**
- **Higher** power density due to over all **integration**
- **Shorter R&D cycle**, fewer turns of board prototyping
- **Portable Projects** for faster reuse
- **Defendable firmware**–protects IP and differentiating technology

Agenda

- Linear Regulator
- Non-Isolated SMPS
- Isolated SMPS
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- Digital Control of SMPS
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  - Key MCU Peripherals
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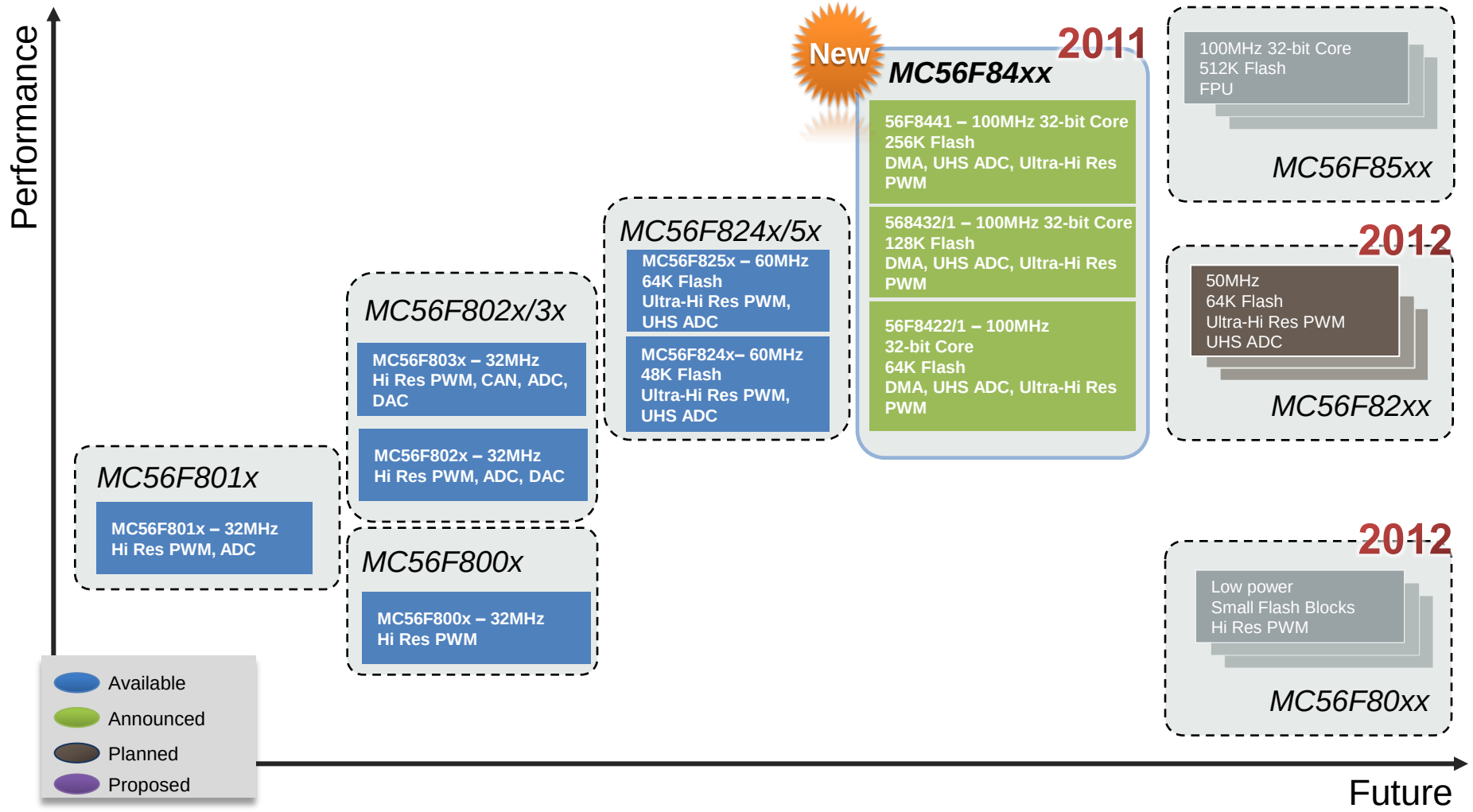
Digital Control of Power Conversion Applications

- General requirements
  - **Powerful Core**
    - The control loop is calculated every 5-20 μs (motor control application 50 – 200 μs)
  - Very **fast A/D Converter** (better than 1μs conversion, capable of parallel conversion)
  - **PWM module** capable of **high resolution frequency** and **duty cycle** generation
    - The resolution should be comparable to resolution of ADC measurement
    - It means more than 10 bits for frequencies 100 – 400kHz

DSC Roadmap


Performance
New
2011
MC56F84xx
56F8441 – 100MHz 32-bit Core
256K Flash
DMA, UHS ADC, Ultra-Hi Res PWM
568432/1 – 100MHz 32-bit Core
128K Flash
DMA, UHS ADC, Ultra-Hi Res PWM
56F8422/1 – 100MHz
32-bit Core
64K Flash
DMA, UHS ADC, Ultra-Hi Res PWM
100MHz 32-bit Core
512K Flash
FPU
MC56F85xx
2012
50MHz
64K Flash
Ultra-Hi Res PWM
UHS ADC
MC56F82xx
MC56F824x/5x
MC56F825x – 60MHz
64K Flash
Ultra-Hi Res PWM, UHS ADC
MC56F824x– 60MHz
48K Flash
Ultra-Hi Res PWM, UHS ADC
MC56F802x/3x
MC56F803x – 32MHz
Hi Res PWM, CAN, ADC, DAC
MC56F802x – 32MHz
Hi Res PWM, ADC, DAC
MC56F801x
MC56F801x – 32MHz
Hi Res PWM, ADC
MC56F800x
MC56F800x – 32MHz
Hi Res PWM
2012
Low power
Small Flash Blocks
Hi Res PWM
MC56F80xx
Available
Announced
Planned
Proposed
Future

DSP56800E Version 3 Core Improvement

(the differences between V2 core and V3 core)

New Instructions

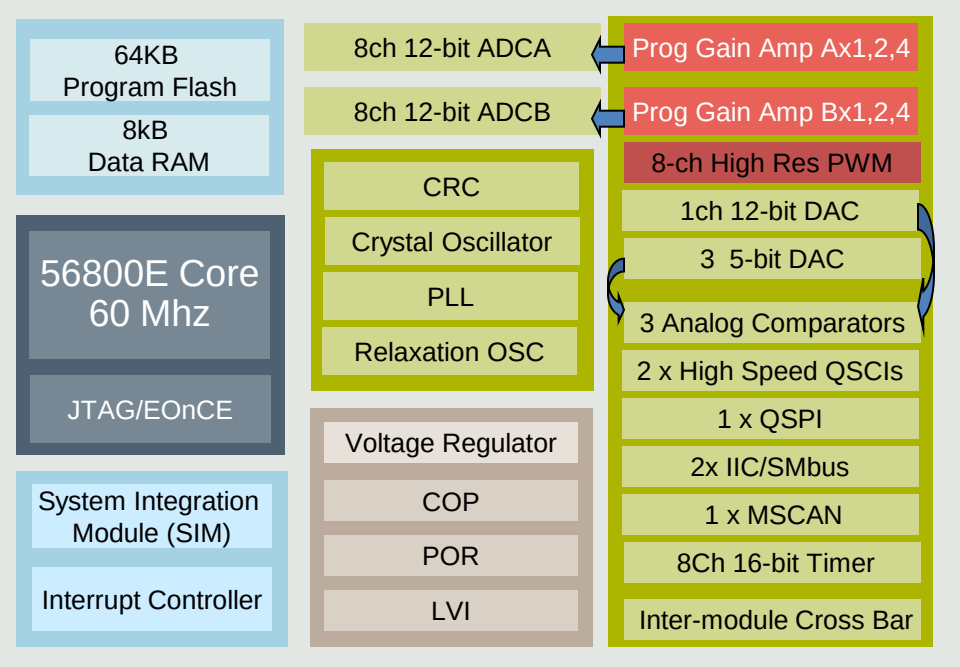
- 32 x 32 -> 32/64 Multiply and MAC Instructions
  - ✓ IMAC32 - Integer Multiply-Accumulate 32 bits x 32 bits -> 32 bits
  - ✓ IMPY32 - Integer Multiply 32 bits x 32 bits -> 32 bits
  - ✓ IMPY64 - Integer Multiply 32 bits x 32 bits -> 64 bits
  - ✓ IMPY64UU - Unsigned Integer Multiply 32 bits x 32 bits -> 64 bits
  - ✓ MAC32 - Fractional Multiply-Accumulate 32 bits x 32 bits -> 32 bits
  - ✓ MPY32 - Fractional Multiply 32 bits x 32 bits -> 32 bits
  - ✓ MPY64 - Fractional Multiply 32 bits x 32 bits -> 64 bits
- Multi-Bit Clear-Set instruction to improve flexibility of peripheral register handling.

Other Features

- Bit Reversed Address Mode For FFT algorithms.
- Swap all address generation Unit Registers with Shadowed registers to reduce Interrupt context switch latency.

MC56F824x/MC56F825x Features

- *60 MHz/60 MIPS from 56800E core*
- 2.7-3.6V operation
- *64K Bytes program FLASH*
- *8K Bytes program/data RAM*
- Flash security
- 8Mhz/100Khz tunable internal relaxation oscillator
- Software programmable phase locked loop
- *Up to 60 MHz peripherals – timers and PWMs*
  - ***8 output PWM module***
  - ***520ps PWM and PFM resolution***
- 2-12-bit ADCs with total 16 inputs
  - **600ns conversion rate**
  - **built-in PGA with 1x, 2x, 4x, gains**
- *1 12-bit digital to analog converter*
- *3 5-bit digital to analog converters*
- *3 analog comparators*
- 8 16-bit enhanced GP multifunction programmable timers
- Cyclic redundancy check generator (CRC)
- Computer operating properly timer
- 2 high speed serial communications interface (SCI)
- 1 queued serial peripheral interface (QSPI)
- 1 MS-CAN bus
- 2 I^2C/SMbus communications interface
- Up to 54 GPIOs
- Inter module cross-bar
- JTAG/EOnCE™ debug port
- Industrial temperature range: -40°C to 105°C with 60 Mhz



44LQFP, 48LQFP 64 LQFP, Samples Available

56F82xx Series Feature Summary

	56F8245	56F8246	56F8247	56F8255	56F8256	56F8257
Performance	60 MHz / MIP					
High Speed Peripheral Clock	120 MHz					
Program / Data Flash	48KB			64KB		
Program / Data RAM	6KB	6KB	8KB	8KB	8KB	8KB
Program Security	Yes					
eFlexPWM Channels	1 x 6ch	1 x 6ch	1 x 9ch	1 x 6ch	1 x 6ch	1 x 9ch
HiRes PWM Channels	6ch					
Enhanced FlexPWM w/ Input Capture	0	0	3	0	0	3
PWM Fault Inputs	4					
12-bit ADCs w/ PGA	2 x 4ch	2 x 5ch	2 x 8ch	2 x 4ch	2 x 5ch	2 x 8ch
12-bit DACs	1					
Analog Comparator w/ 5bit DAC Ref	3					
Cross Bar Module	Yes					
High Speed 16-bit Timer (TMR)	8					
GPIO (max 8mA)	35	39	54	35	39	54
IIC /SMBus	2					
QSCI (UART) / LIN Slave	2					
QSPI Synchronous	1					
CAN	0			1		
COP, POR, LVD, PLL CRC	Yes					
JTAG / EOnCE	Yes					
Operating Temperature Range	-40 °C to 105 °C					
Package	44 LQFP	48 LQFP	64 LQFP	44 LQFP	48 LQFP	64 LQFP

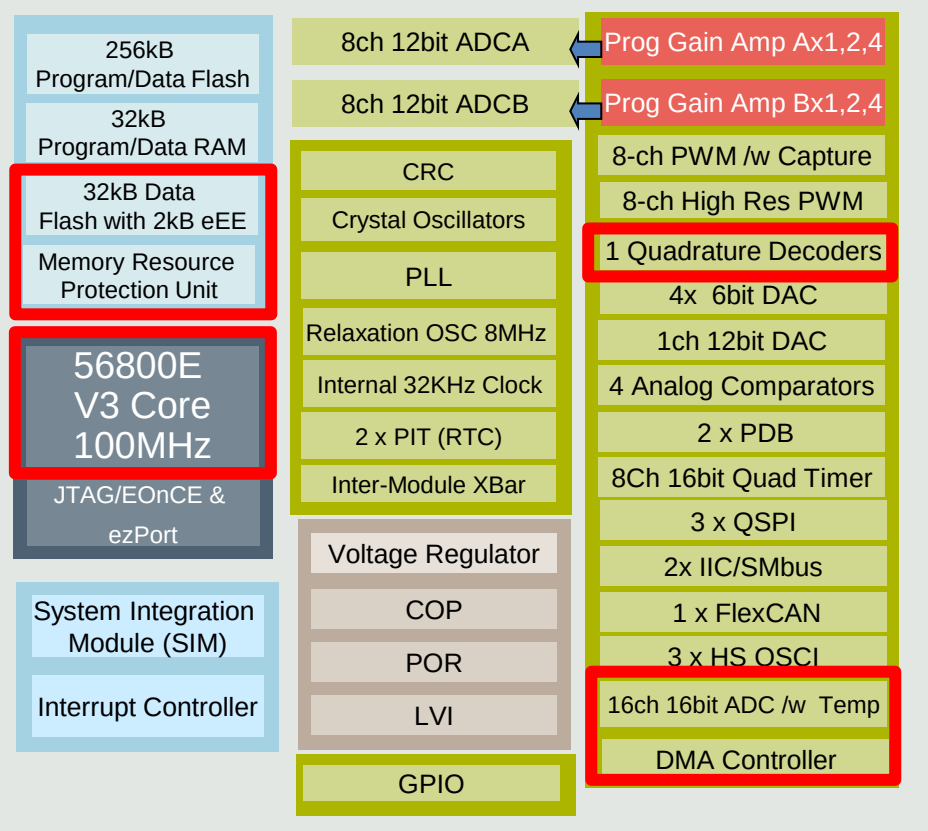
MC56F84xx Features

100 MHz/100MIPS 56800 V3 Core
- Harvard architecture
- **32 x 32bit MAC and 32bit arithmetic operation**

- 2.7-3.6V Operation

- 256kB Program/Data FLASH
- 32kB Data Flash with up to 2kB of eEE
- 32kB Data/Program RAM
- Resource Protection Unit

- 3 HS-QSCI (8MBS) , 3xQSPI, 2xIIC/SMBus, 1xFlexCAN
- Multi-purpose timers
  - 2 Periodic Timers with Real Time Interrupt Generation
  - 2 Programmable Delay Blocks
  - 8Ch multifunction timers
- 8ch High Resolution PWM Channels
  - **312ps PWM and PFM resolution**
- 8ch PWM Channels with Input Capture
- 8ch x 2 12-bit ADC converter with built-in PGA
  - **300ns/3.33Msps conversion time with 12bit resolution**
- 8ch 16bit SAR ADC with built-in temperature sensor and band gap.
  - 2us conversion time.
- 4 Analog Comparators
- 1 Quadrature Decoder
- 1ch 12bit DAC with external outputs + 4ch 6bit DAC
- DMA controller
- Inter-Module Crossbar
- On-chip voltage regulator (Single 3.3V Power Supply)
- System Integration : Internal relaxation oscillator, PLL, COP, 32kHz , EWM, auxiliary Internal clock, low voltage detect, EZPort
- 5V tolerant I/O
- Temperature Range: -40°C to +105°C



48 LQFP, 64 LQFP, 80LQFP, 100LQFP

56F8400 Series Feature Summary

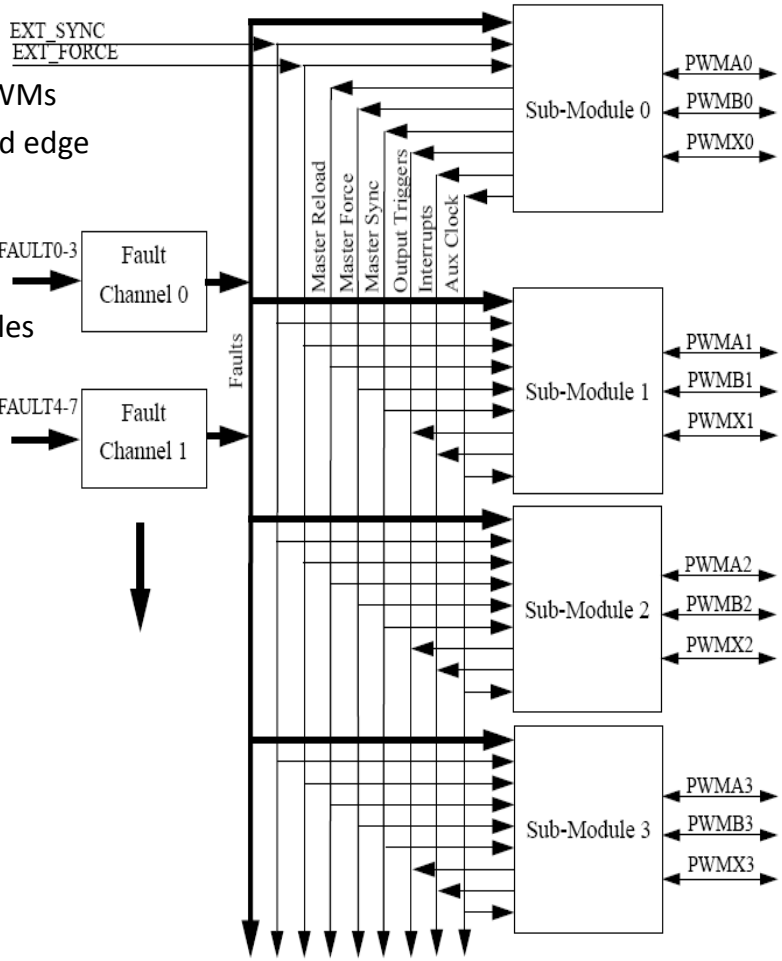
	Fully Featured Digital Control				Digital Control						Dual Motor				Single Motor			
Part Number																		
Core MHz	100	100	100	100	100	100	100	100	100	100	80	80	80	80	60	60	60	60
Flash Mem (kB)	256	256	128	128	128	128	64	64	128	128	256	256	128	128	128	128	64	64
SRAM Mem (kB)	32	32	24	24	24	24	16	16	24	24	32	32	16	16	16	16	8	8
Data Flash / EE Mem (kB)	32/2	32/2	32/2	32/2	32/2	32/2	32/2	32/2	0	0	32/2	32/2	32/2	32/2	0	0	0	0
Cyc ADC Chn	2x8	2x8	2x8	2x8	2x8	2x8	2x8	2x8	2x5	2x5	2x8	2x8	2x8	2x8	2x8/2x5	2x8/2x5	2x8/2x5	2x8/2x5
SAR ADC Chn	1x16	1x16	1x16	1x16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PWM uE Chn	8	8	8	8	8	8	8	8	8	8	8	8	8	8	0	0	0	0
PWM stnd Chn	8	8	8	8	0	0	0	0	0	0	8	8	8	8	8	8	8	8
DAC	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
Quad Decoder	1	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1
DMA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
CMP	4	4	3	3	3	3	2	2	2	2	3	3	3	3	2	2	2	2
QSCI	3	3	3	3	3	3	2	2	2	2	3	3	2	2	2	2	2	2
QSPI	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2
I2C	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
FlexCAN	1	1	1	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0
Package	100	80	100	80	80	64	80	64	64	48	100	80	100	80	64	48	64	48

Agenda

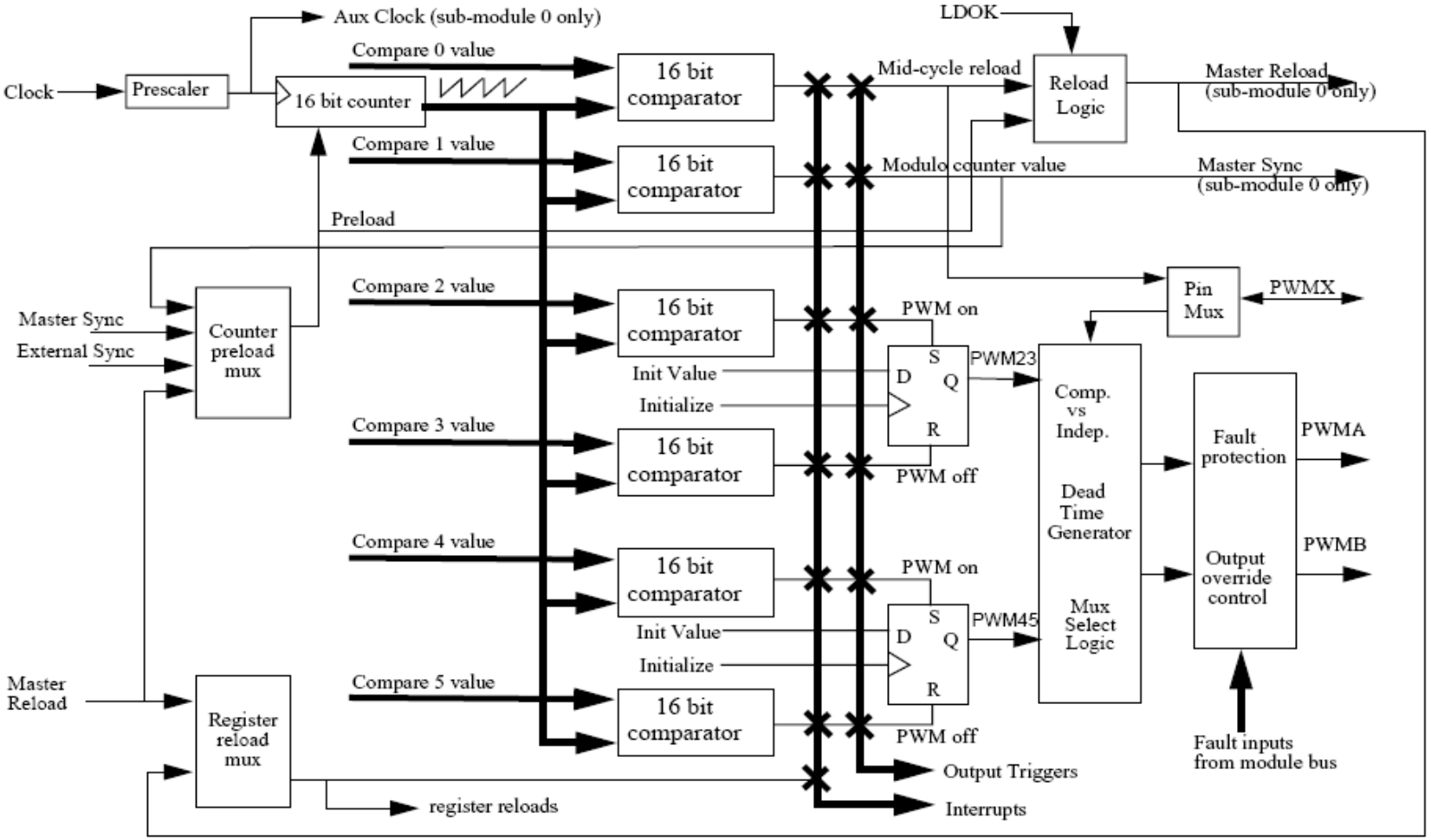
- Linear Regulator
- Non-Isolated SMPS
- Isolated SMPS
- Resonant SMPS
- Digital Control of SMPS
  - Advantages of Digital Control
  - MCU Requirements
  - Example of suitable MCU's
  - Key MCU Peripherals
  - Example of SMPS Application
- Hands on (Step down Converter)

Enhanced Flex Pulse Width Modulator (eFlexPWM)

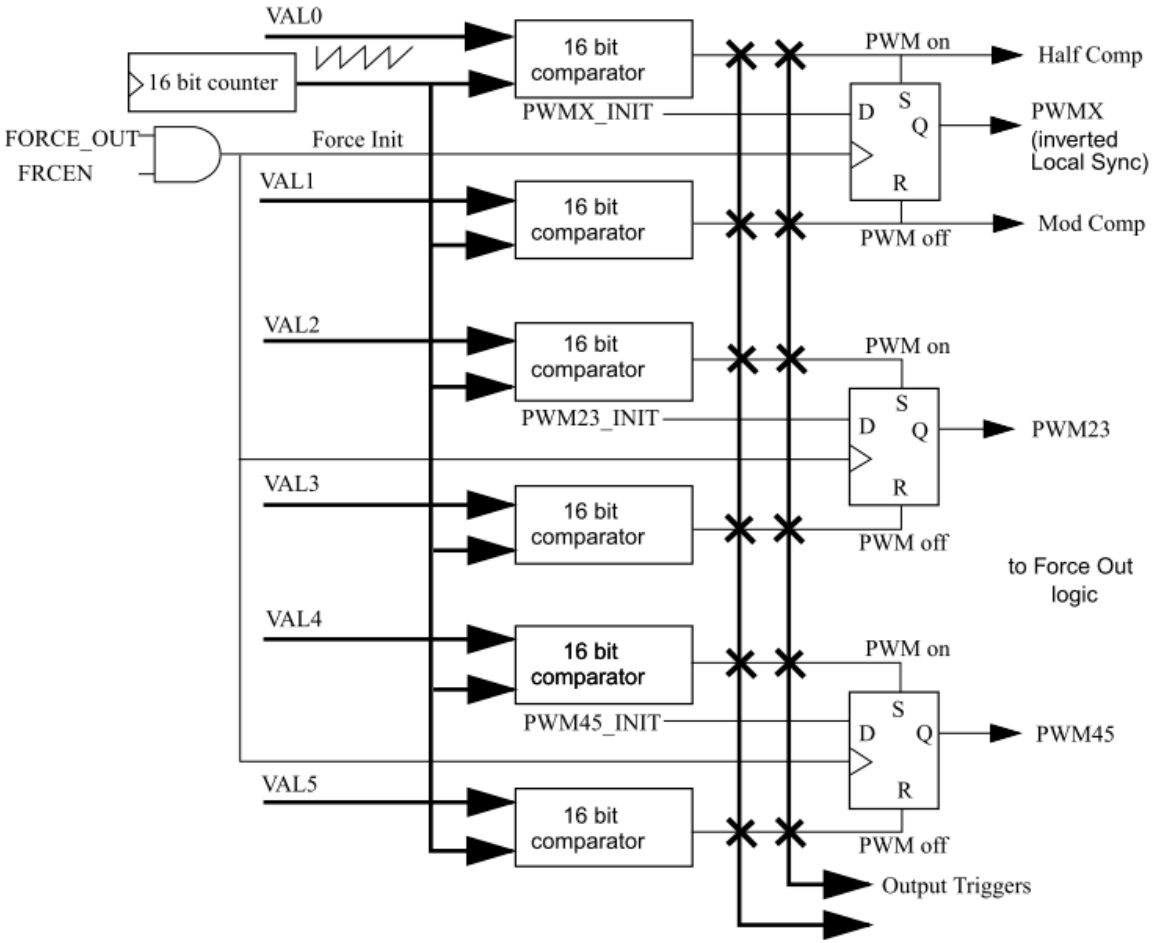
- Four independent sub-modules with own time base, two PWM outputs + 1 auxiliary PWM input/output
- 16 bits resolution for center, edge aligned, and asymmetrical PWMs
- Fractional delay for enhanced resolution of the PWM period and edge placement
- Complementary pairs or independent operation
- Independent control of both edges of each PWM output
- Synchronization to external hardware or other PWM sub-modules
- Double buffered PWM registers
- Integral reload rates from 1 to 16 include half cycle reload
- Half cycle reload capability
- Multiple output trigger events per PWM cycle
- Support for double switching PWM outputs
- Fault inputs can be assigned to control multiple PWM outputs
- Programmable filters for fault inputs
- Independently programmable PWM output polarity
- Independent top and bottom deadtime insertion
- Individual software control for each PWM output
- Software control, and swap features via FORCE_OUT event
- Compare/capture functions for unused PWM channels
- Enhanced dual edge capture functionality



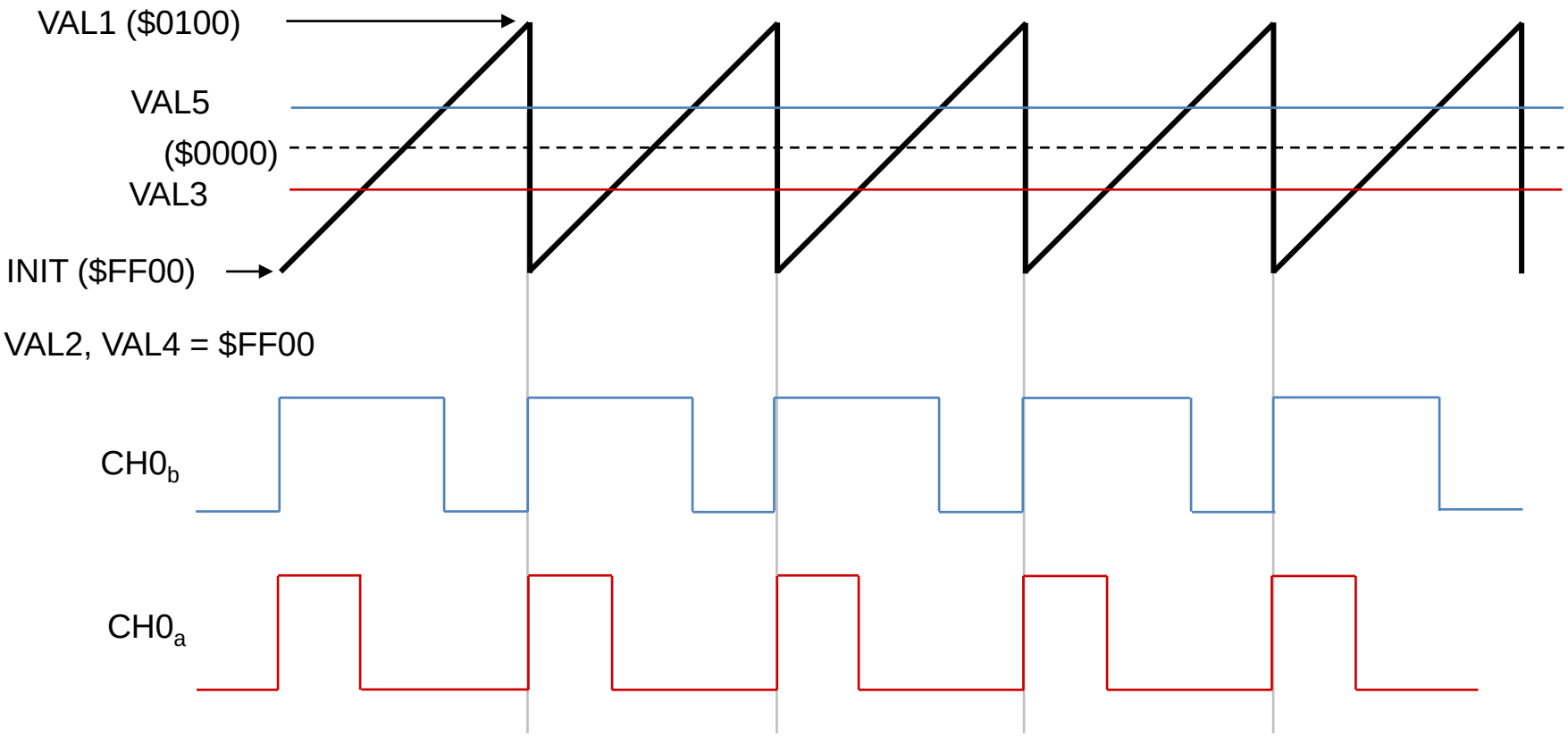
eFlexPWM - Sub-Module Detail



eFlexPWM – PWM Generation

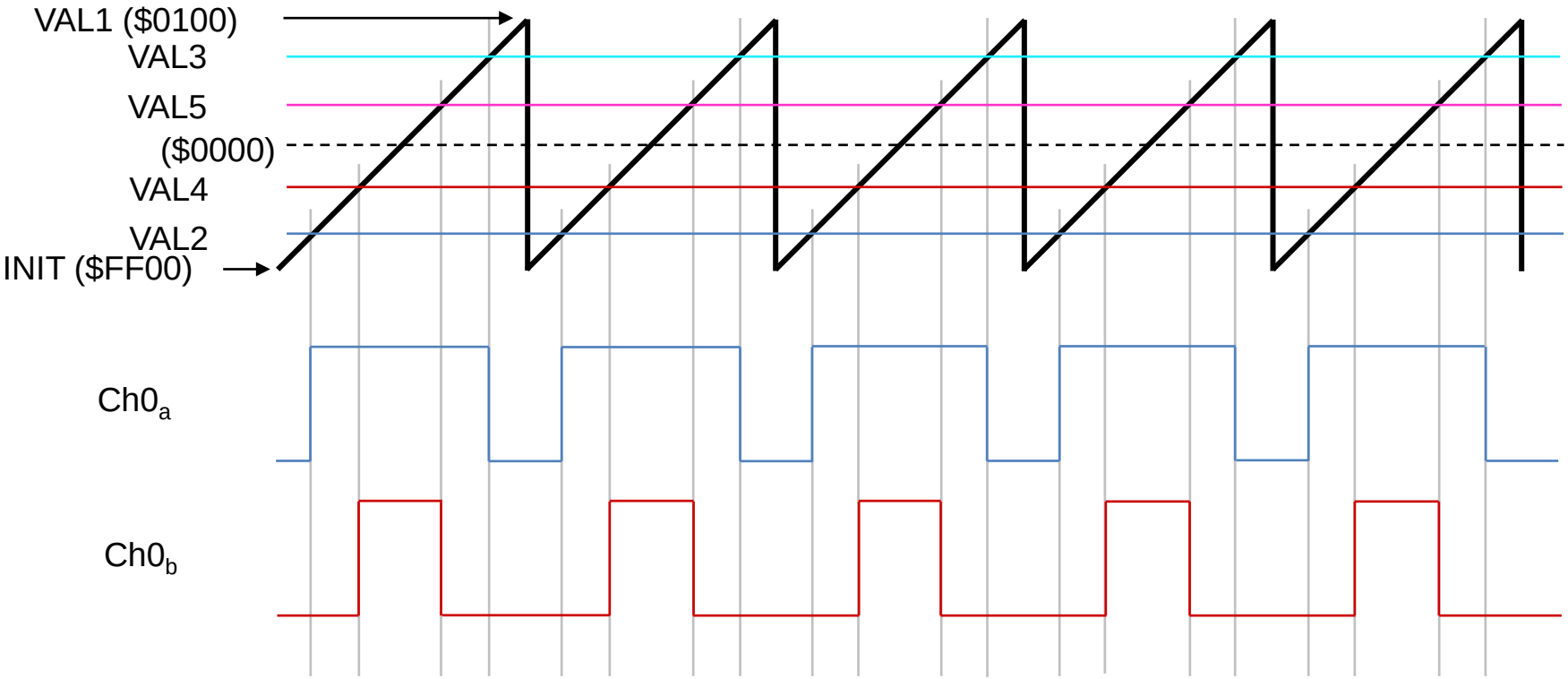


eFlexPWM – Edge Aligned PWM Generation



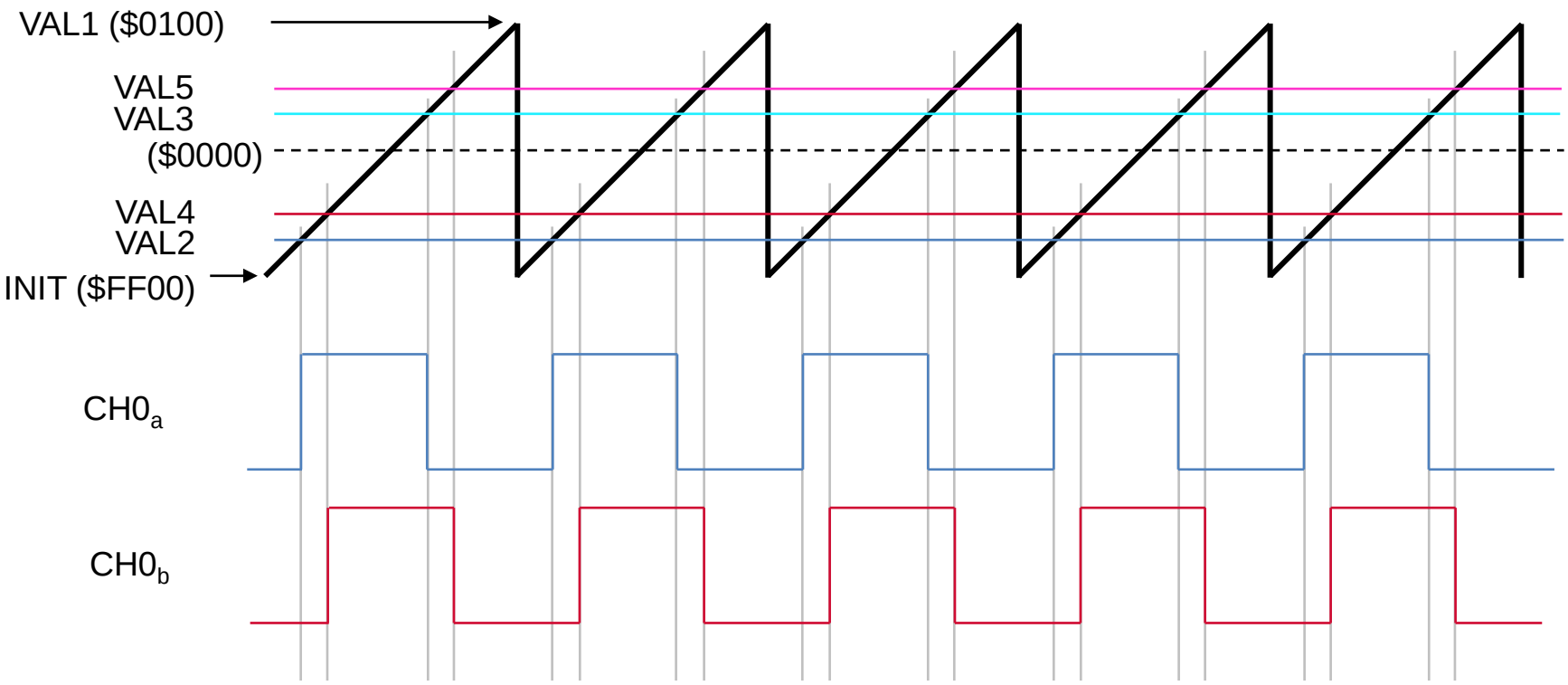
- All PWM-on values are set to the init value, and never changed again. Positive PWM-off values generate pulse widths above 50% duty cycle. Negative PWM-off values generate pulse widths below 50% duty cycle . This works well for bipolar waveform generation.

eFlexPWM – Center Aligned PWM Generation



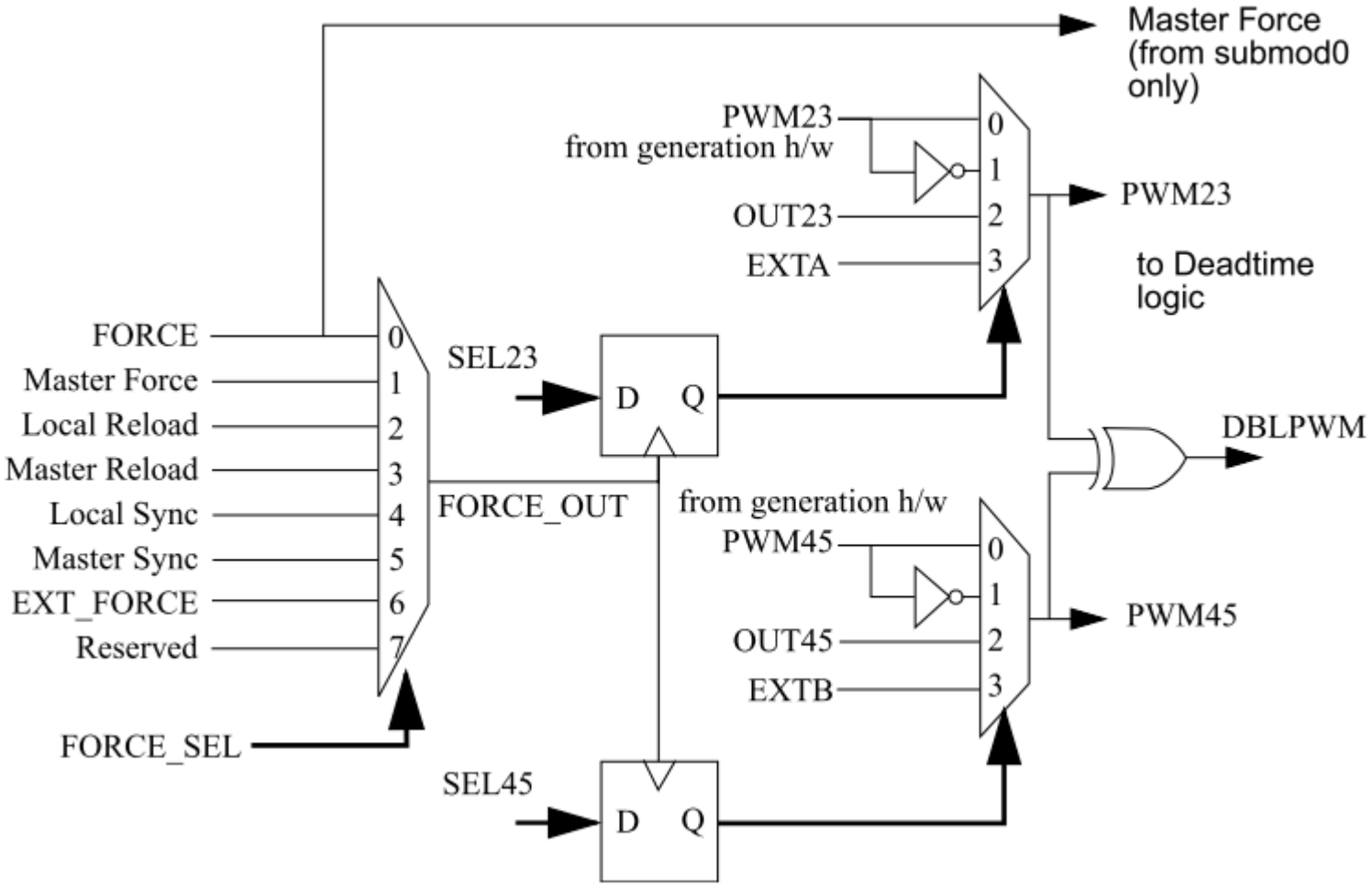
- When the Init value is the signed negative of the Modulus value, the PWM module works in signed mode. Center-aligned operation is achieved when the turn-on and turn-off values are the same number, but just different signs.

eFlexPWM – Shifted PWM Generation

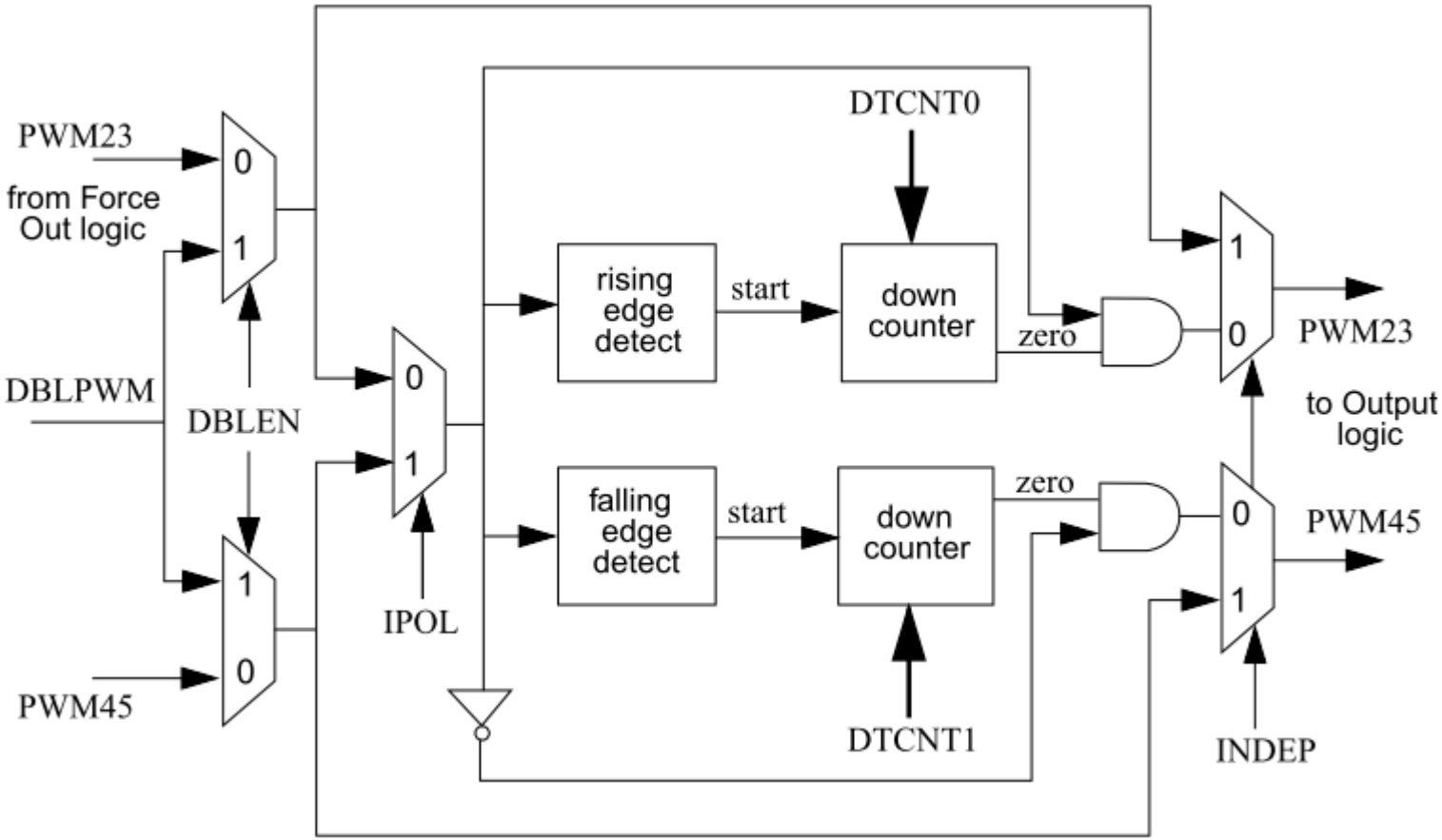


- In this example, both PWMs have the same duty-cycle. However, the edges are shifted relative to each other by simply biasing the compare values of one waveform relative to the other.

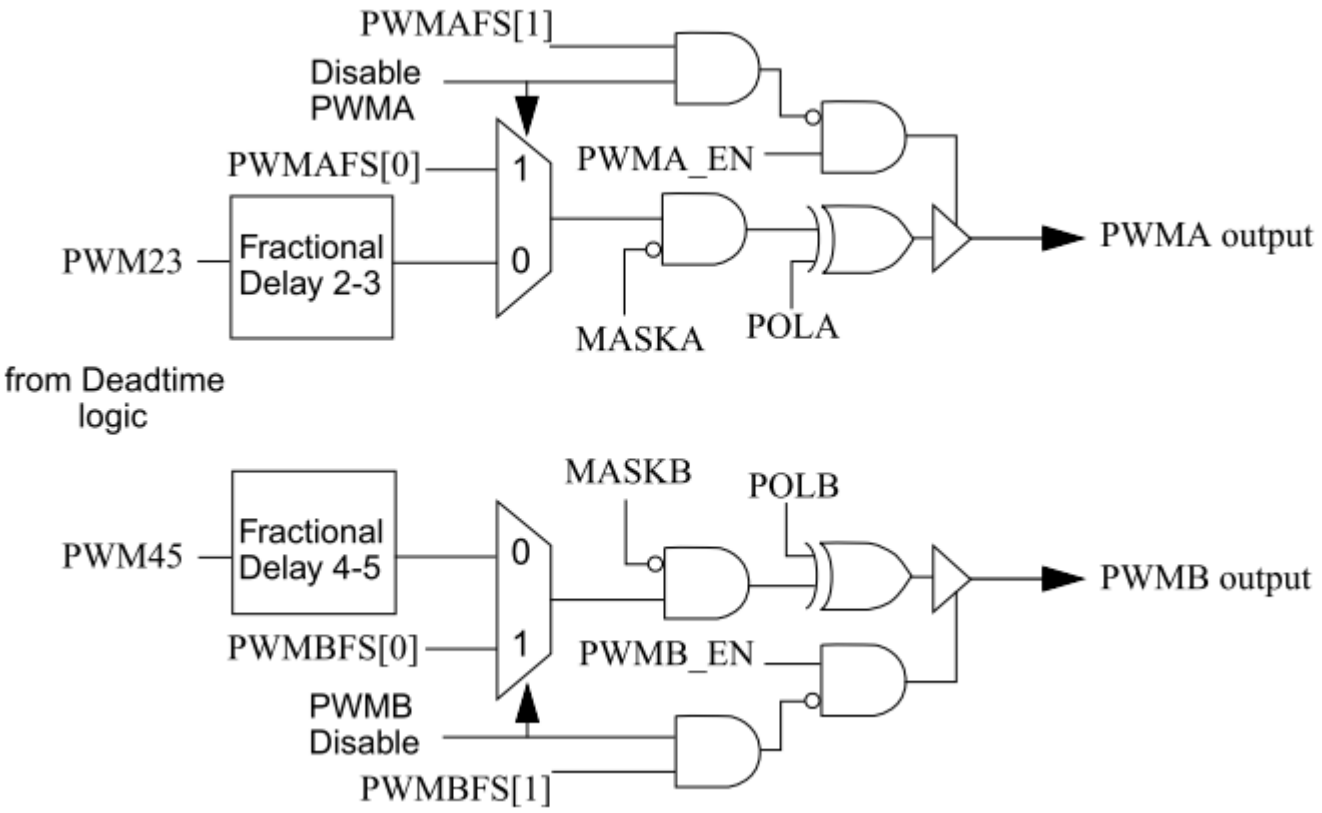
eFlexPWM – Force Output Logic



eFlexPWM – Complementary and Deadtime Logic

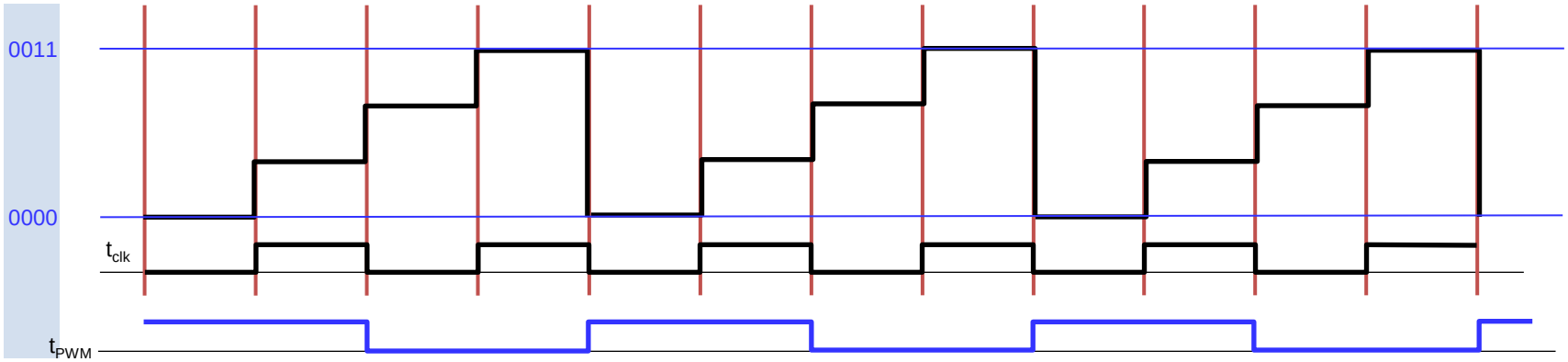


eFlexPWM – Fractional Delay and Output Logic



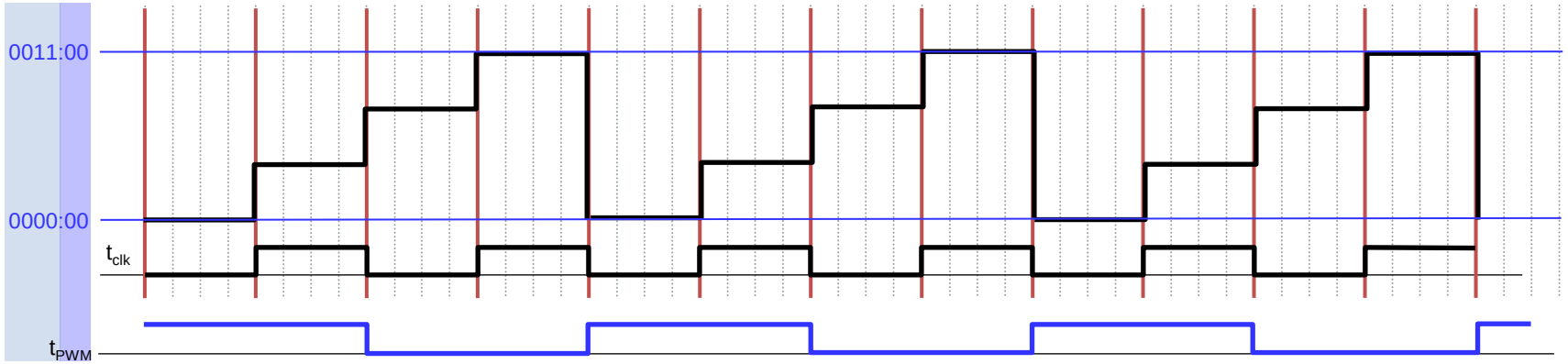
eFlexPWM – High Resolution Duty Cycle Generation

- PWM resolution is given by input clock of PWM module



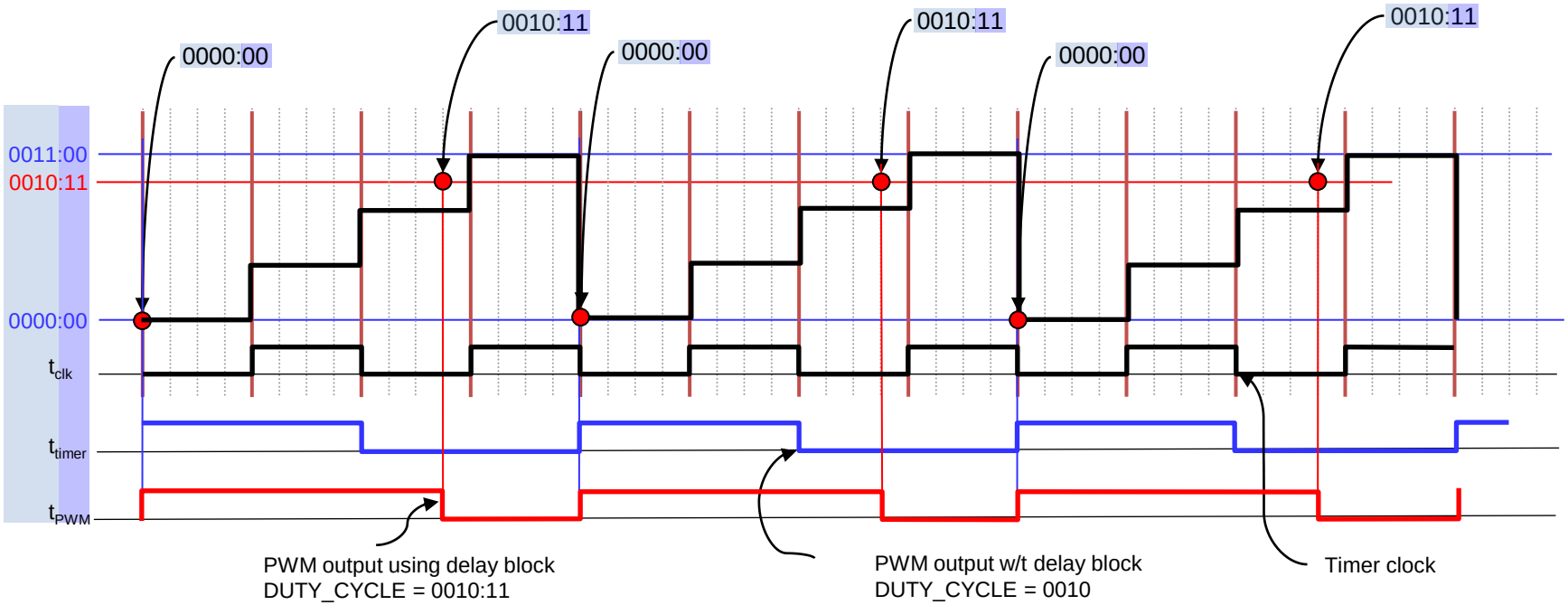
eFlexPWM – High Resolution Duty Cycle Generation

- PWM resolution is given by input clock of PWM module
- The PWM resolution can be enhanced by analog delay circuit, which can place edge between two edges, derived from input clock
- *Example*
  - Consider 2-bit analog delay block
  - Let's generate PWM signal with MODULO=4:0, DUTY_CYCLE=2:3 (68.75 %)



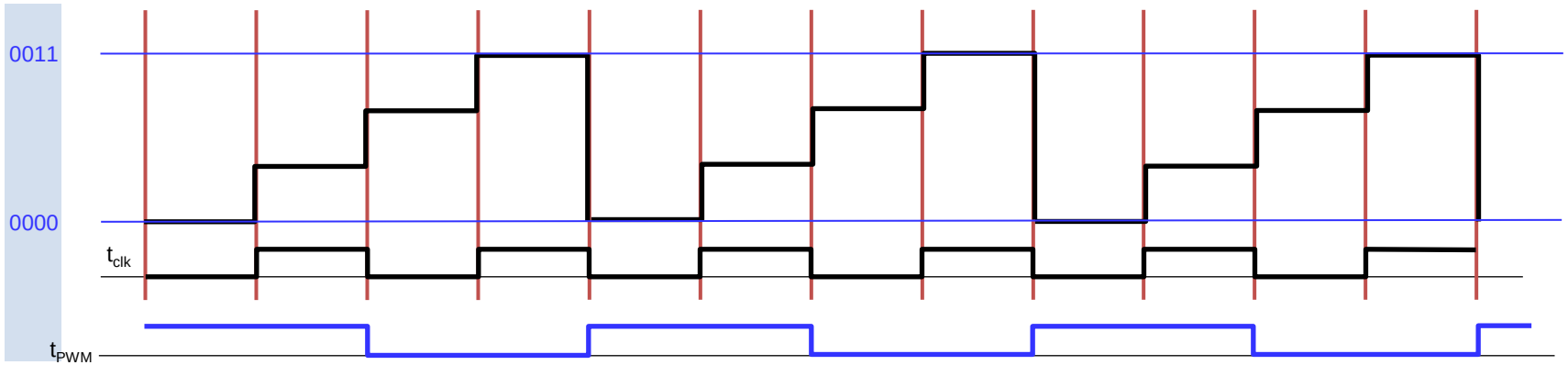
eFlexPWM – High Resolution Duty Cycle Generation

- At high resolution duty cycle generation
  - The leading edge is usually aligned with digital clock
  - The falling edge is generated by delay block
  - The analog delay is constant every PWM period



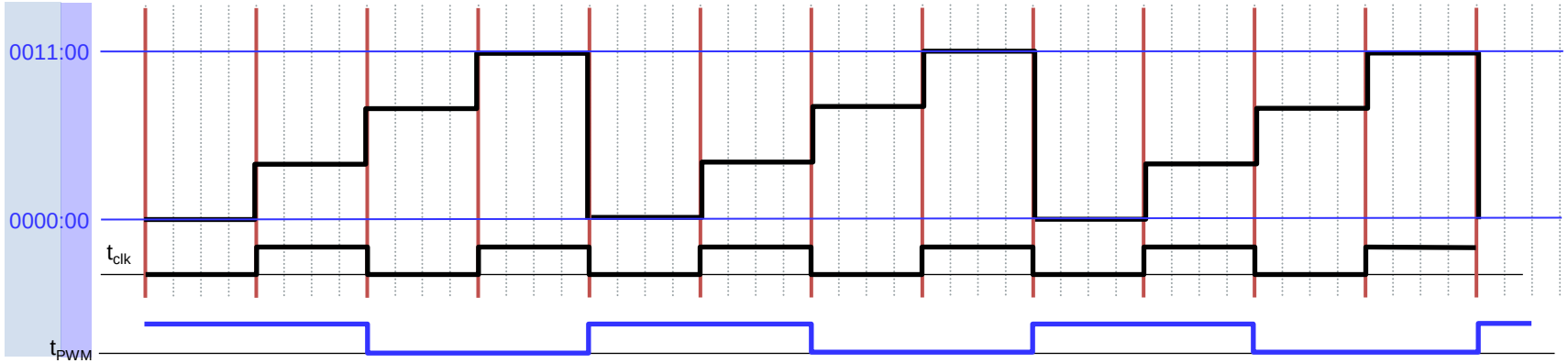
eFlexPWM – High Resolution Frequency Generation

- *Example*
  - Consider 2-bit analog delay block
  - Let's generate PWM signal with MODULO=4:2, DUTY_CYCLE=2:1 (50 %)



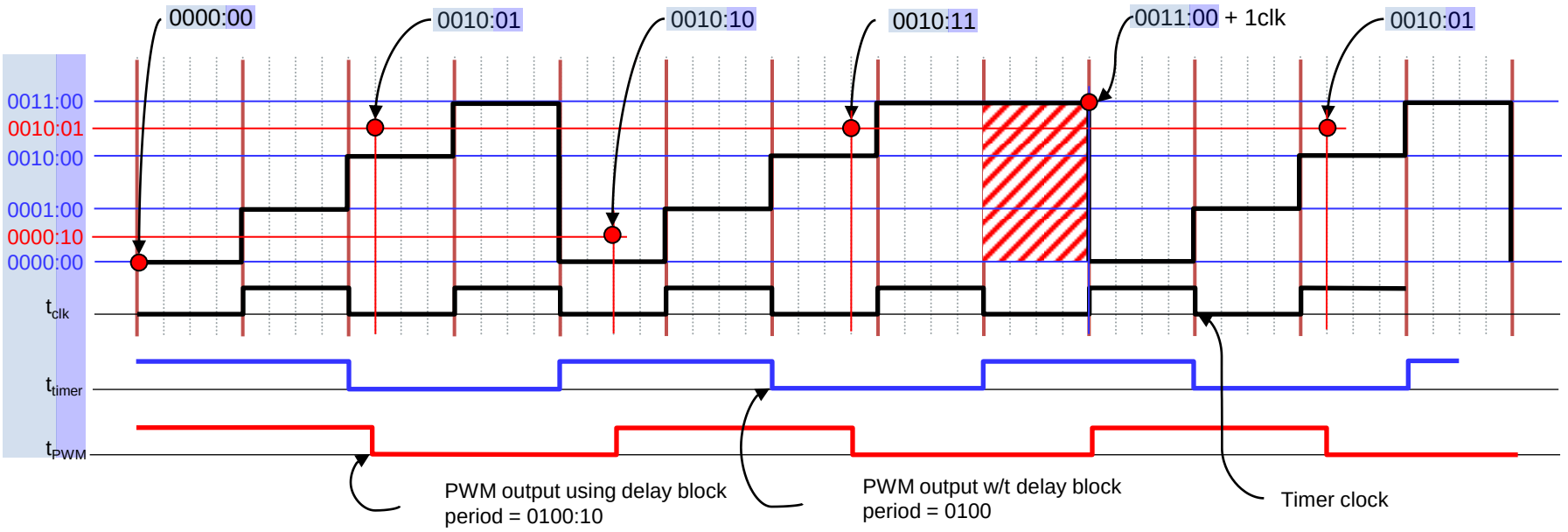
eFlexPWM – High Resolution Frequency Generation

- *Example*
  - Consider 2-bit analog delay block
  - Let's generate PWM signal with MODULO=4:2, DUTY_CYCLE=2:1 (50 %)



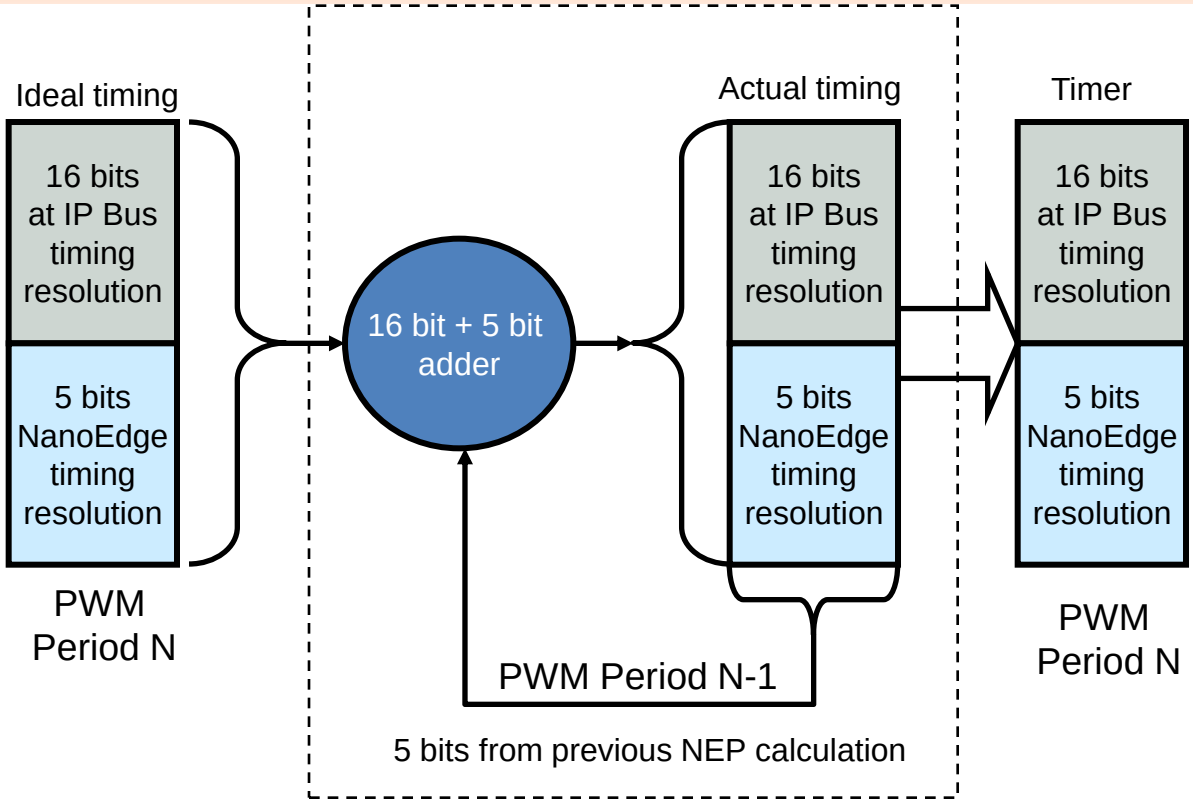
eFlexPWM – High Resolution Frequency Generation

- At high resolution frequency generation
  - Both edges are generated by delay block
  - The analog delay is changing edge by edge every PWM period
  - The analog delay must be calculated every edge or requires some hardware support



eFlexPWM – HR Frequency Generation HW Support

- Need to calculate the next edge position for rising and falling edges within very short period
- Software not fast enough, so need hardware adder
- Diagram shows 21 bit adder to control both edges automatically setting new comparator values after each edge has been triggered



- PWM reload times are restricted to 16-bit IP bus timing (truncation of 21 bit value). Any residual left over from PWM period N-1 needs to be added back to period N.

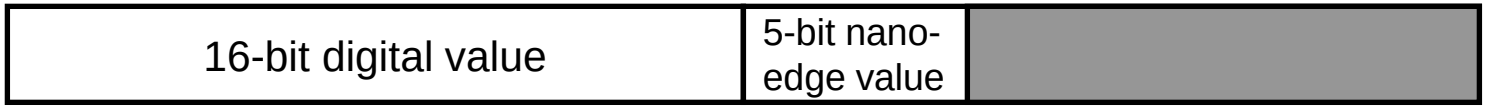
eFlexPWM – HR Frequency Generation

from User Perspective

- The new edge calculation is seem less from user perspective
- The user sets required 21-bit (16+5 bit) values into corresponding value registers only
- The 5-bit delay block corresponds to 1.92 GHz input clock (for 60MHz PWM module input clock)

PWM Value Register

NanoEdge™ placement not used. 16-bit value only.



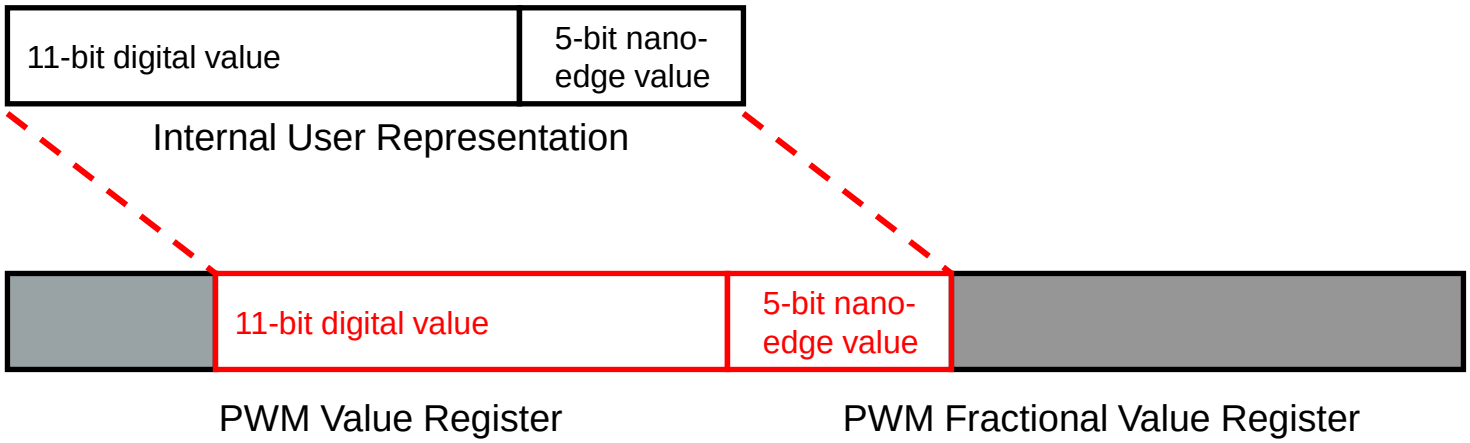
PWM Value Register PWM Fractional Value Register

NanoEdge™ placement enabled. 21-bit (32-bit) value.

eFlexPWM – HR Frequency Generation

from User Perspective

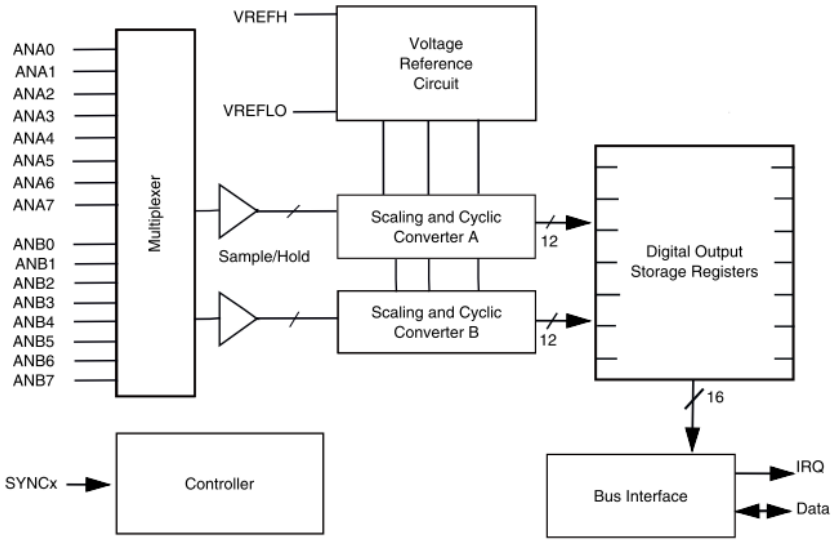
- Example of high resolution calculation
  - For high frequency the digital value is usually less than 11 bits. For example, 200 kHz edge-aligned PWM has resolution less than 9 bits
  - Therefore we can keep calculation in 16 bits
  - Result of calculation is moved right by 5 bits and written into 32-bit register



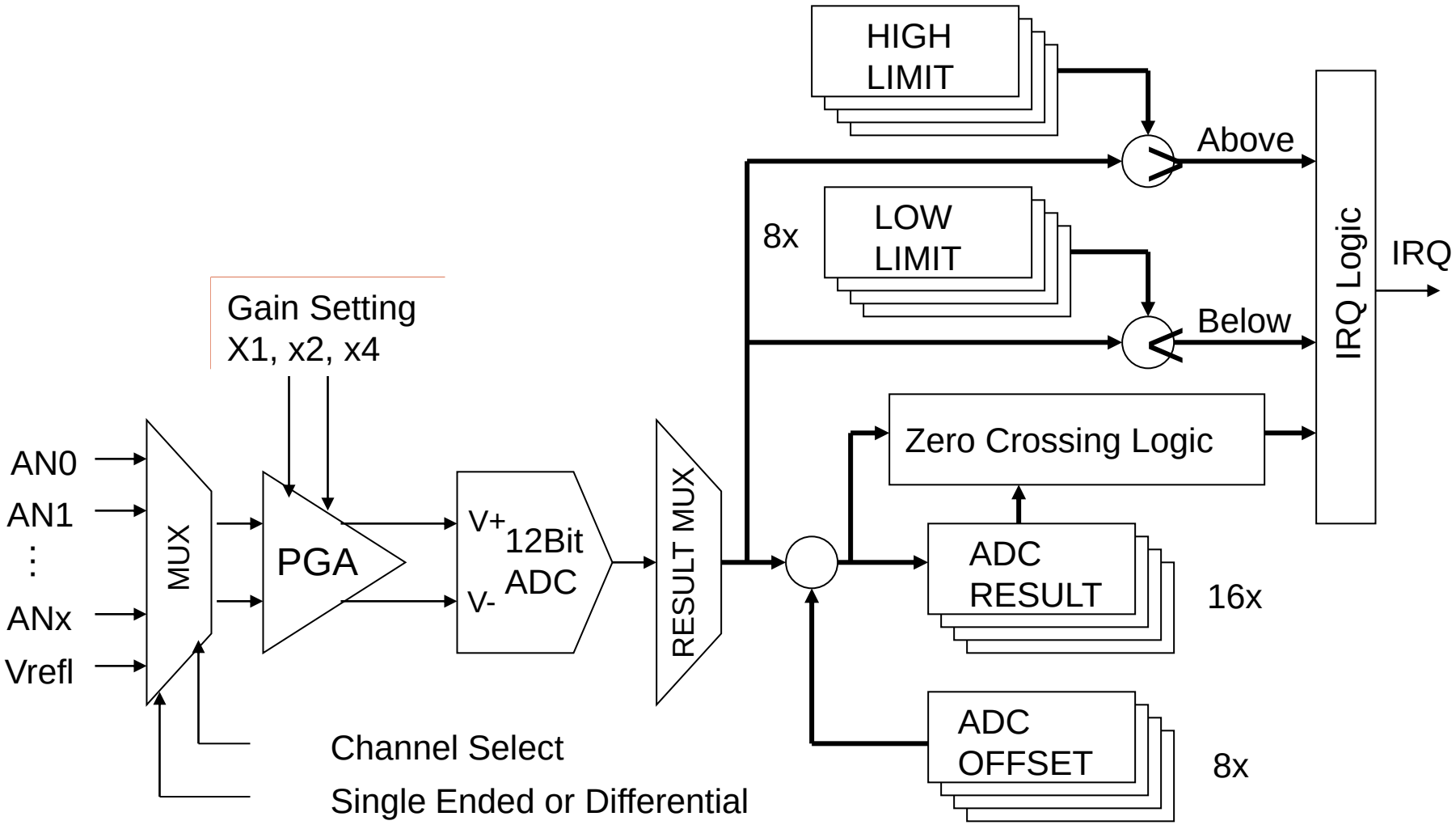
NanoEdge™ placement enabled. 21-bit (32-bit) value.

A/D Converter

- 12-bit resolution
- Maximum ADC clock frequency of 20 MHz with 50 ns period
- Sampling rate up to 6.66 million samples per second
- Single conversion time of 8.5 ADC clock cycles (8.5 × 50 ns = 450 ns)
- Additional conversion time of 6 ADC clock cycles (6 × 50 ns = 300 ns)
- ADC to PWM synchronization through the SYNC0/1 input signal sequentially scans and stores up to sixteen measurements
- Scans and stores up to eight measurements each on two ADC converters operating simultaneously and in parallel
- Scans and stores up to eight measurements each on two ADC converters operating asynchronously to each other in parallel
- Multi-triggering support
- Gains the input signal by x1, x2, or x4
- Optional interrupts at end of scan if an out-of-range limit is exceeded or there is a zero crossing
- Optional sample correction by subtracting a pre-programmed offset value
- Signed or unsigned result
- Single-ended or differential inputs
- PWM outputs with hysteresis for three of the analog inputs

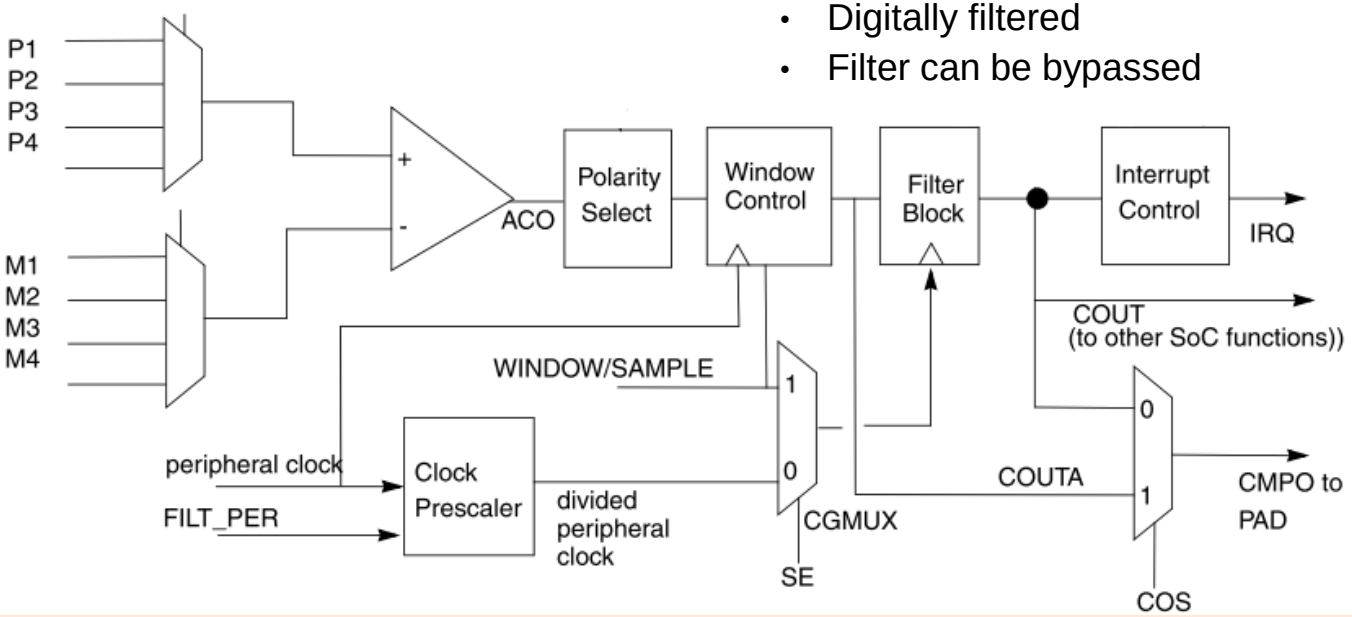


A/D Converter



Analog Comparator

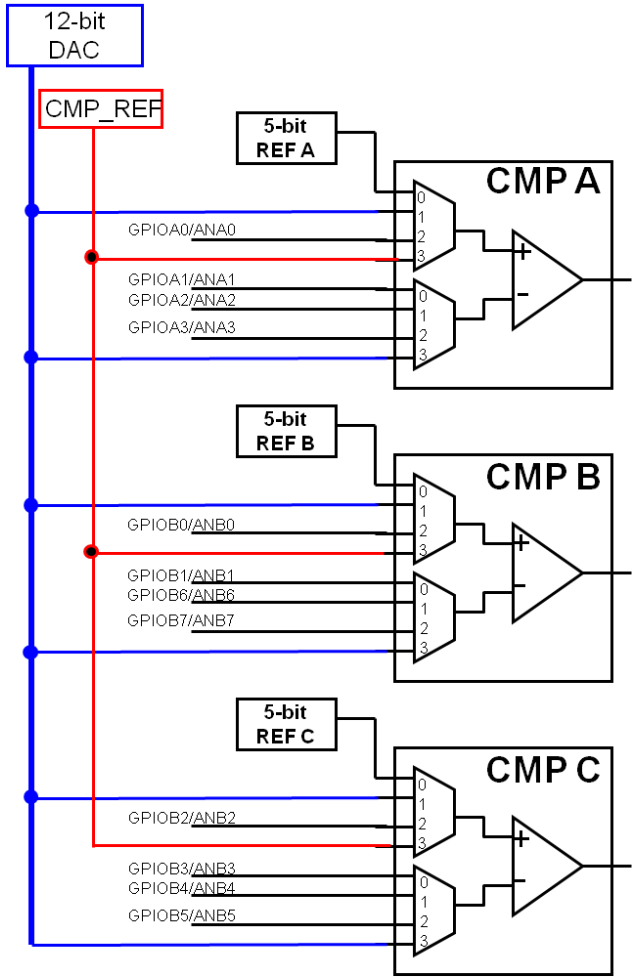
- Operates over the entire supply range
- Less than 40 mV of input offset
- Less than 15 mV of hysteresis
- Inputs may range from rail to rail
- Selectable interrupt on rising edge, falling edge, or both edges of comparator output
- Selectable inversion on comparator output
- Two software selectable performance levels:
  - Shorter propagation delay at the expense of higher power
  - Low power, with longer propagation delay
- Comparator output may be:
  - Sampled
  - Windowed (ideal for certain PWM zero-crossing-detection applications)
  - Digitally filtered
  - Filter can be bypassed



56F82xx Comparators Interconnection

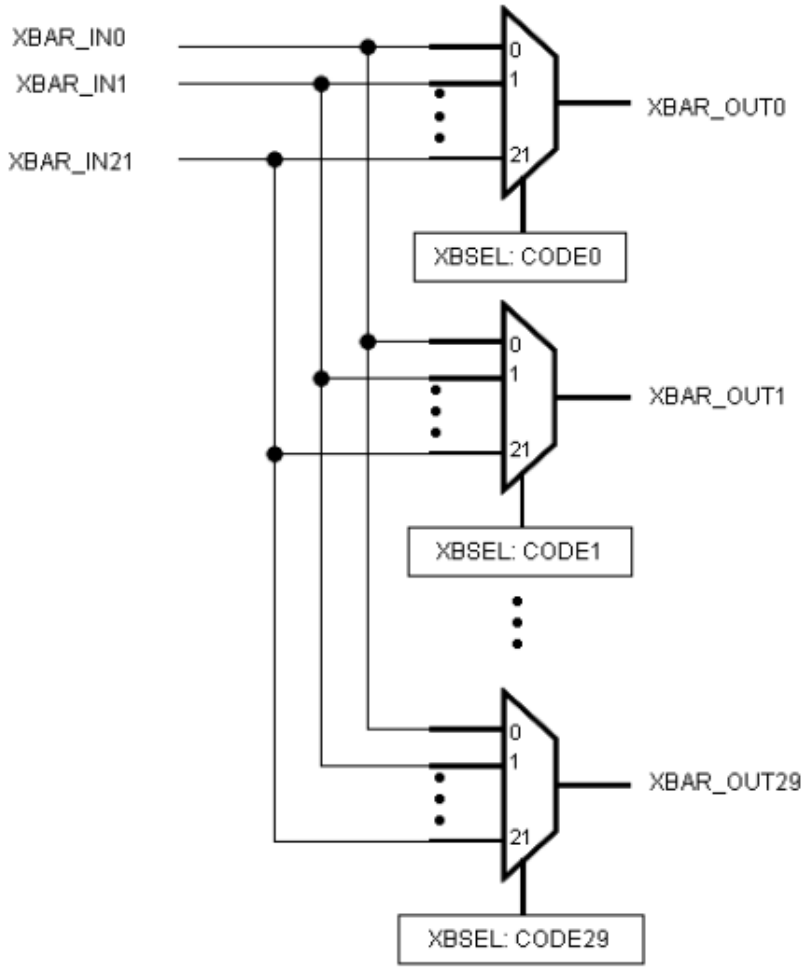
	CMPA	CMPB	CMPC
P0	VREF A	VREF B	VREF C
P1	DACO	DACO	DACO
P2	ANA0	ANB0	ANB2
P3	cmpref	cmpref	cmpref
M0	ANA1	ANB1	ANB3
M1	ANA2	ANB6	ANB4
M2	ANA3	ANB7	ANB5
M3	DACO	DACO	DACO

ADC PIN	COMP	COMP PIN
ANA0	CMPA	P2
ANA1	CMPA	M0
ANA2	CMPA	M1
ANA3	CMPA	M2
ANB0	CMPB	P2
ANB1	CMPB	M0
ANB2	CMPC	P2
ANB3	CMPC	M0
ANB4	CMPC	M1
ANB5	CMPC	M1
ANB6	CMPB	M1
ANB7	CMPB	M2

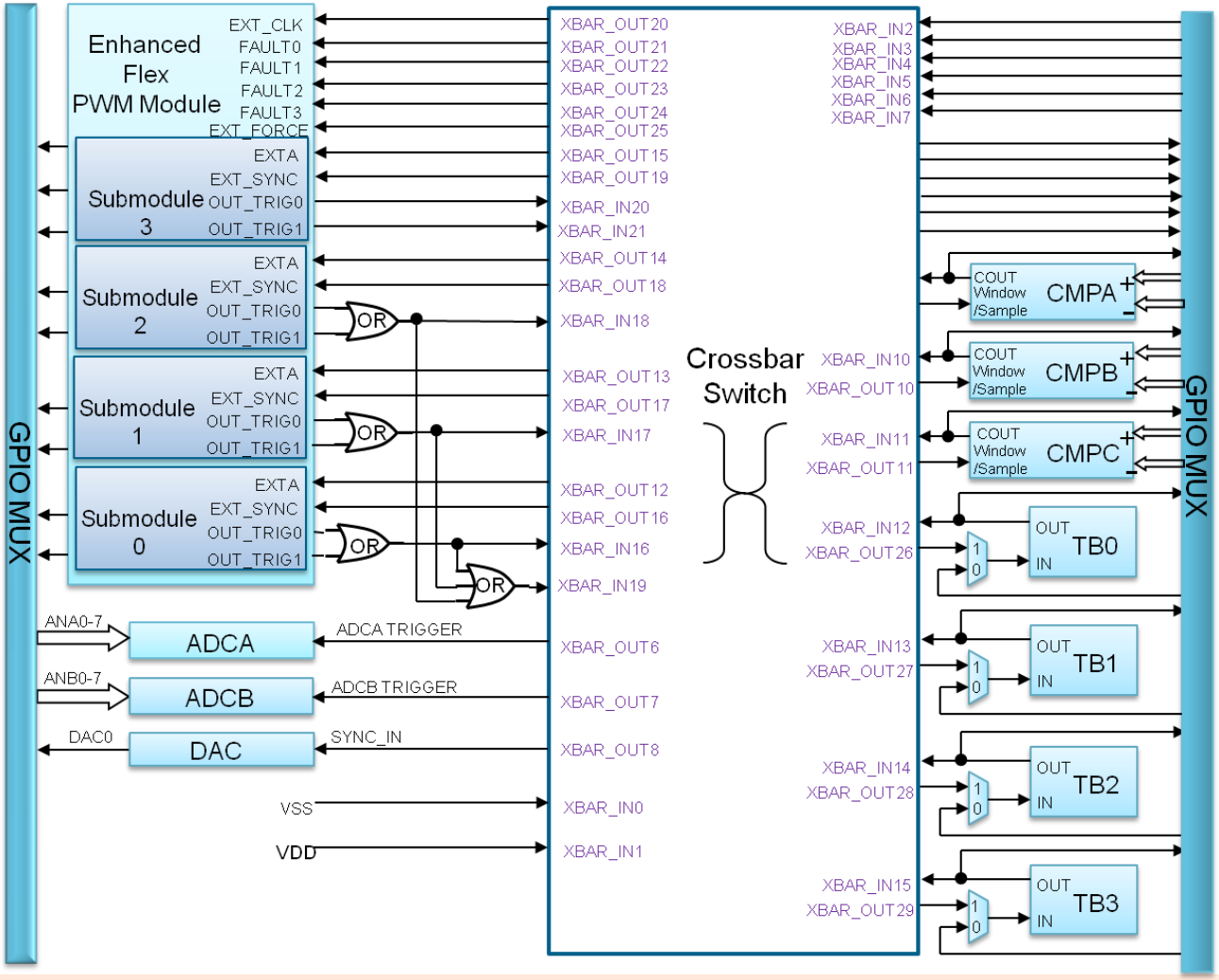


Crossbar Switch - MC56F824x/5x

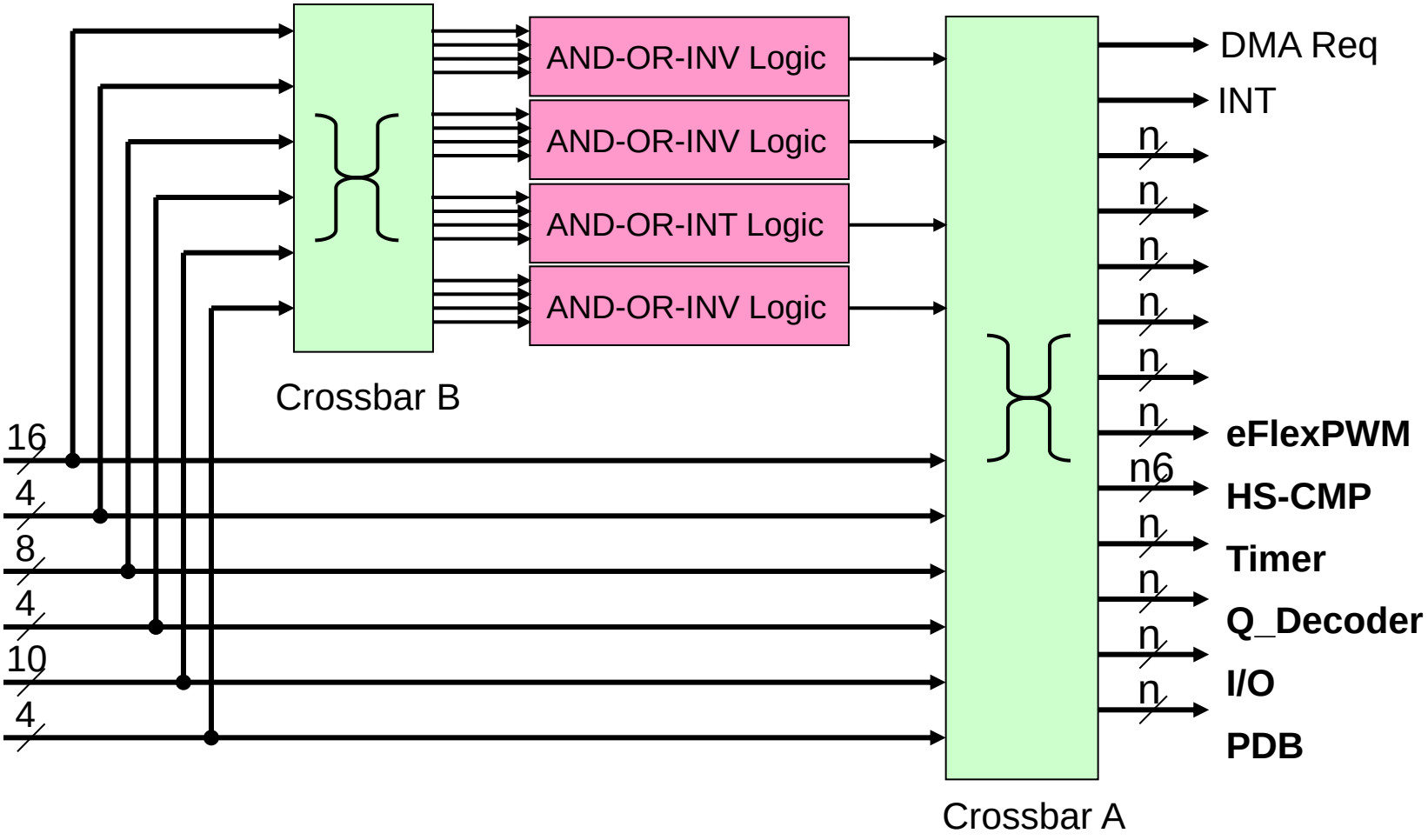
- Flexible signal interconnection among peripherals
- Connects any of 22 signals on left side to the output on right side (multiplexer)
- Total 30 multiplexers
- All multiplexers share the same set of 22 signals
- Increase flexibility of peripheral configuration according to user needs



Crossbar Inter-module Connection - MC56F824x/5x



Crossbar Inter-module Connection - MC56F84xx



Agenda

- Linear Regulator
- Non-Isolated SMPS
- Isolated SMPS
- Resonant SMPS
- Digital Control of SMPS
  - Advantages of Digital Control
  - MCU Requirements
  - Example of suitable MCU's
  - Key MCU Peripherals
  - Example of SMPS Application
- Hands on (Step down Converter)

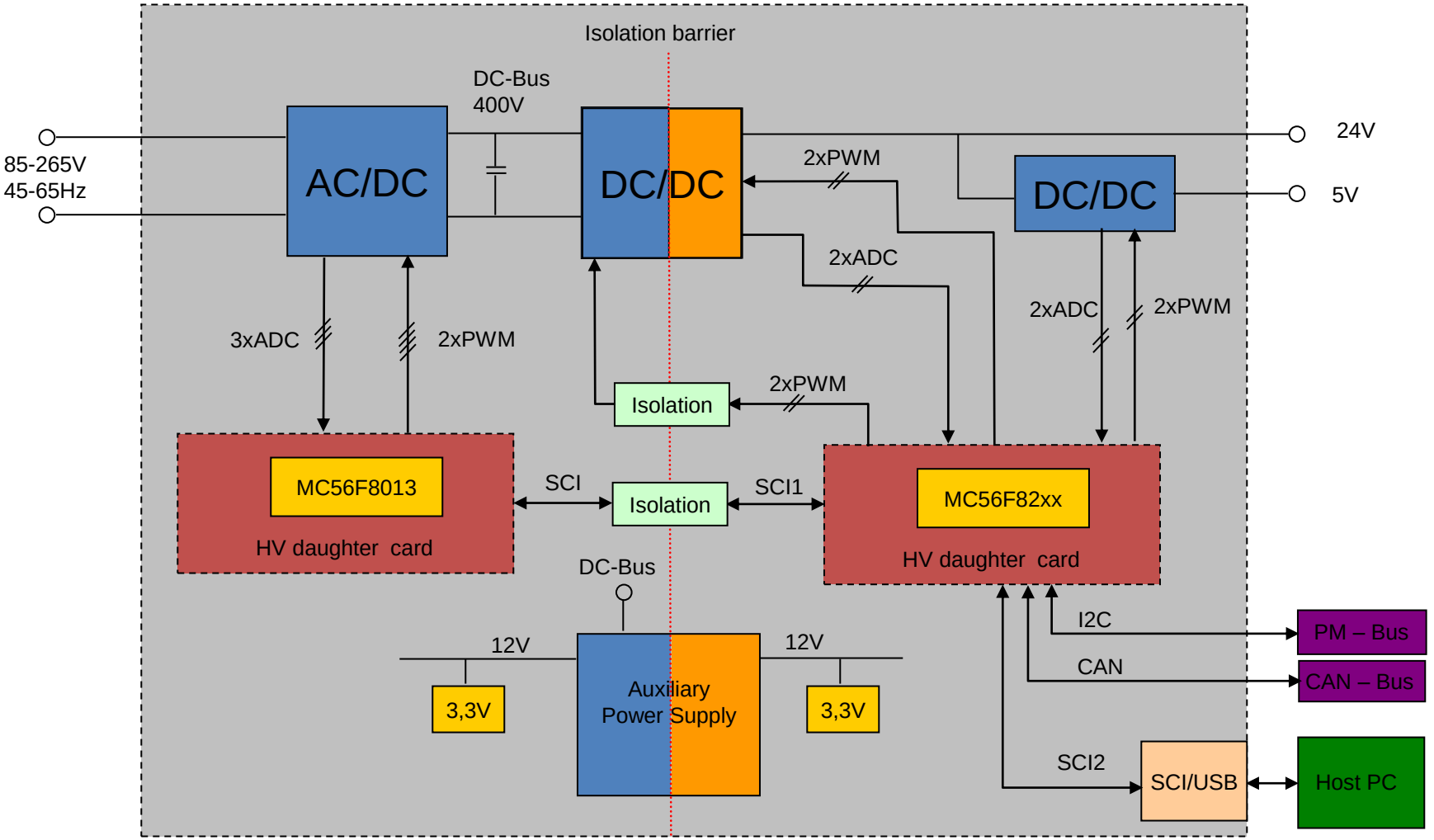
LLC Resonant Converter

- Used SMPS Topology
  - Primary Side: Two Phase Interleaved PFC (Average Current Control)
  - Secondary Side: Half Bridge LLC Resonant Converter with Synchronous Rectification for 12V output
  - Additional Synchronous Buck Converter for 5V output
- Fully Digital Control by Two DSCs:
  - Primary Side: MC56F8013
  - Secondary Side: MC56F8257

LLC Resonant Converter

- Input voltage
  - 85-265Vac @ 45-65Hz
- Output voltage
  - 24V/ 14 Amps (max.)
  - 5V/25 Amps (max.)
- Output Power
  - 350W shared by both voltage outputs. The power limit can be set individually by SW for each voltage output.
- Communication
  - PM Bus communication (HW ready)
  - CAN Communication (HW ready)
  - Communication with PC using USB
- Full Fault Protection
  - Over-voltage, Over-current, over-temperature on both primary and secondary side. Active controlled cooling

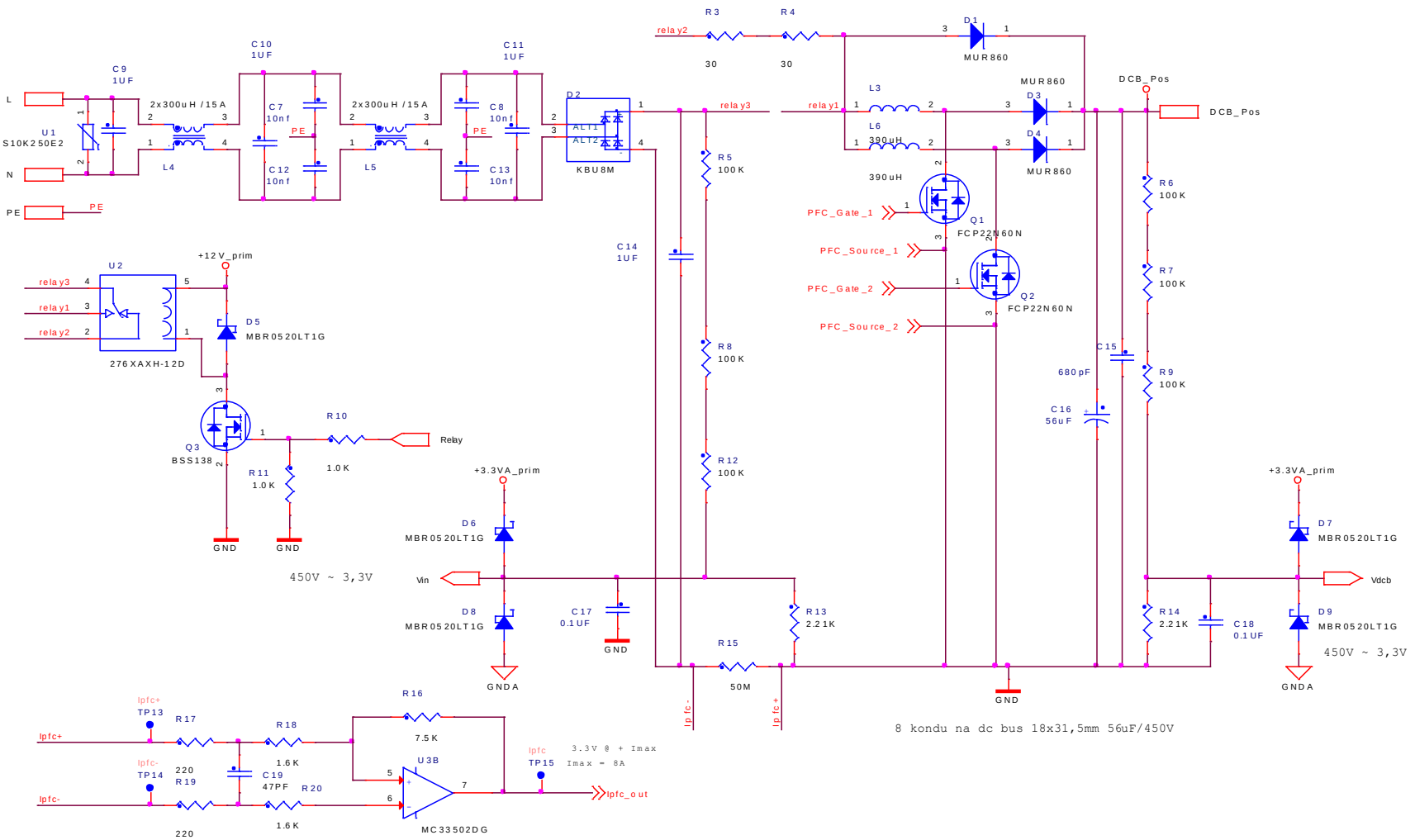
LLC Resonant Converter - Block Diagram



LLC Resonant Converter - Primary Side

- PFC Topology
  - Two Phase Interleaved Boost Converter
- PFC Control Algorithm
  - Fully Digital Average Current Control by DSC MC56F8013
- Measured Quantities
  - Input Rectified Voltage
  - Input Current
  - DC Bus Voltage
  - Heatsing Temperature
- Generated signals
  - 2x PWM signals for MOSFETs transistor (100kHz)
  - 1x PWM signal for cooling fan
  - 1x GPIO input relay control
- Fault Protection
  - HW over-current protection
  - SW over-voltage/under-voltage protection
  - SW over-temperature protection

LLC Resonant Converter - PFC Schematic



LLC Resonant Converter

- PFC SW Implementation

- Inner current loop
  - PI Controller running every 10 μs
- Outer voltage Loop
  - PI Controller with running every 500 μs
  - Optionally output power feedforward (sent from secondary side)
- Other Control Tasks
  - Cooling fan control based on heatsing temperature
  - Input relay control
  - Communication with secondary controller

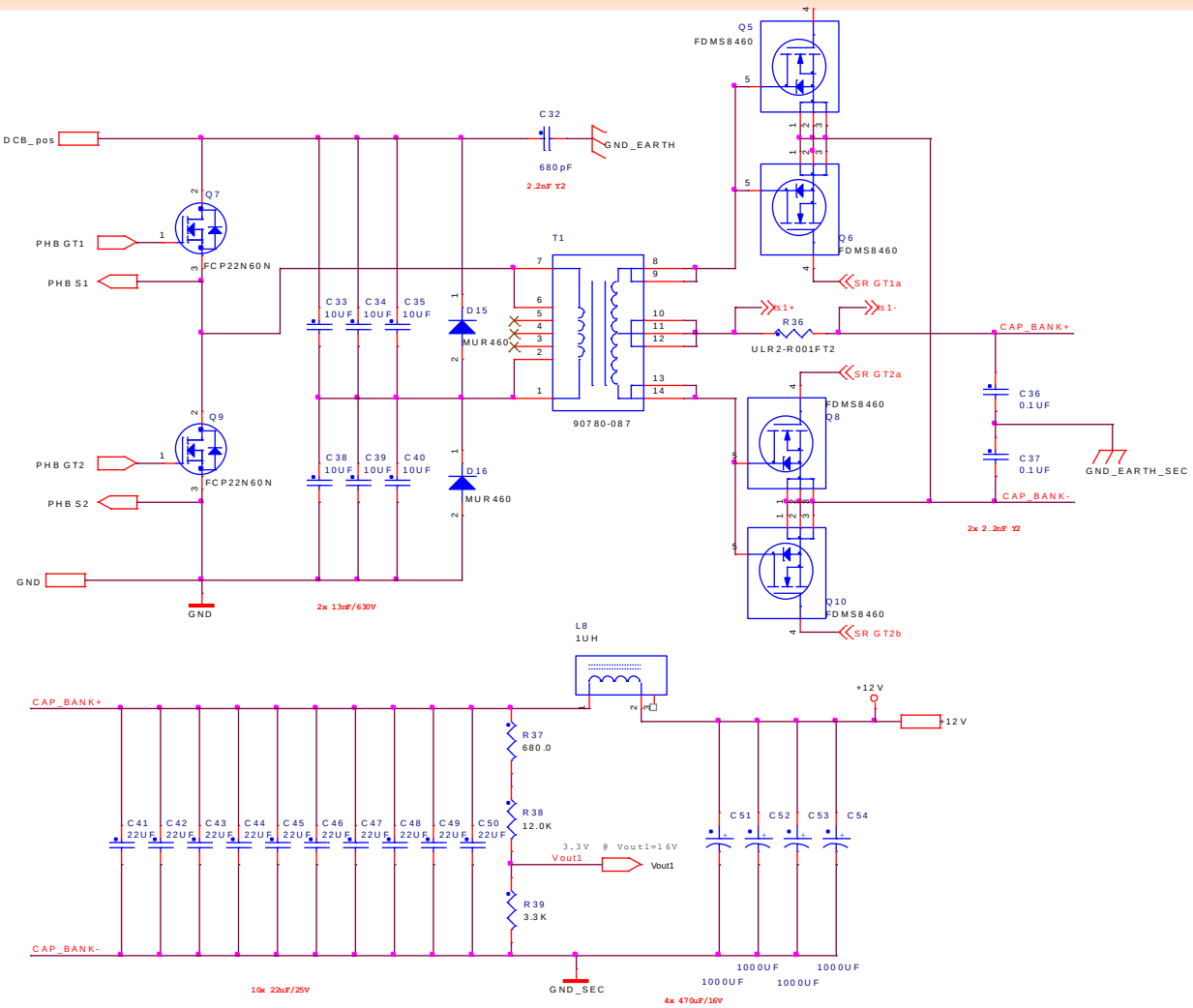
LLC Resonant Converter

- Secondary Side

- Main Converter Topology (24V Output)
  - Half Bridge LLC Resonant Converter with synchronous rectification
- Secondary Converter Topology (5V Output)
  - Synchronous Buck Converter
- Control Algorithm
  - Fully Digital Voltage Mode Control by DSC MC56F8257 for both converters
- Measured Quantities
  - 2x Output Voltage
  - 2x Output Current
  - Secondary Side PCB Temperature
- Generated Signals
  - 2x PWM signals for half bridge MOSFET transistors (50% duty cycle, 100kHz – 400kHz)
  - 2x PWM signals for synchronous rectification MOSFET transistors (50% duty cycle, 100kHz – 400kHz)
  - 2x PWM signals for secondary buck MOSFET transistors (500 kHz)
- Fault Protection
  - 2x HW over-current protection
  - 2x SW over-voltage protection
  - Over-temperature protection

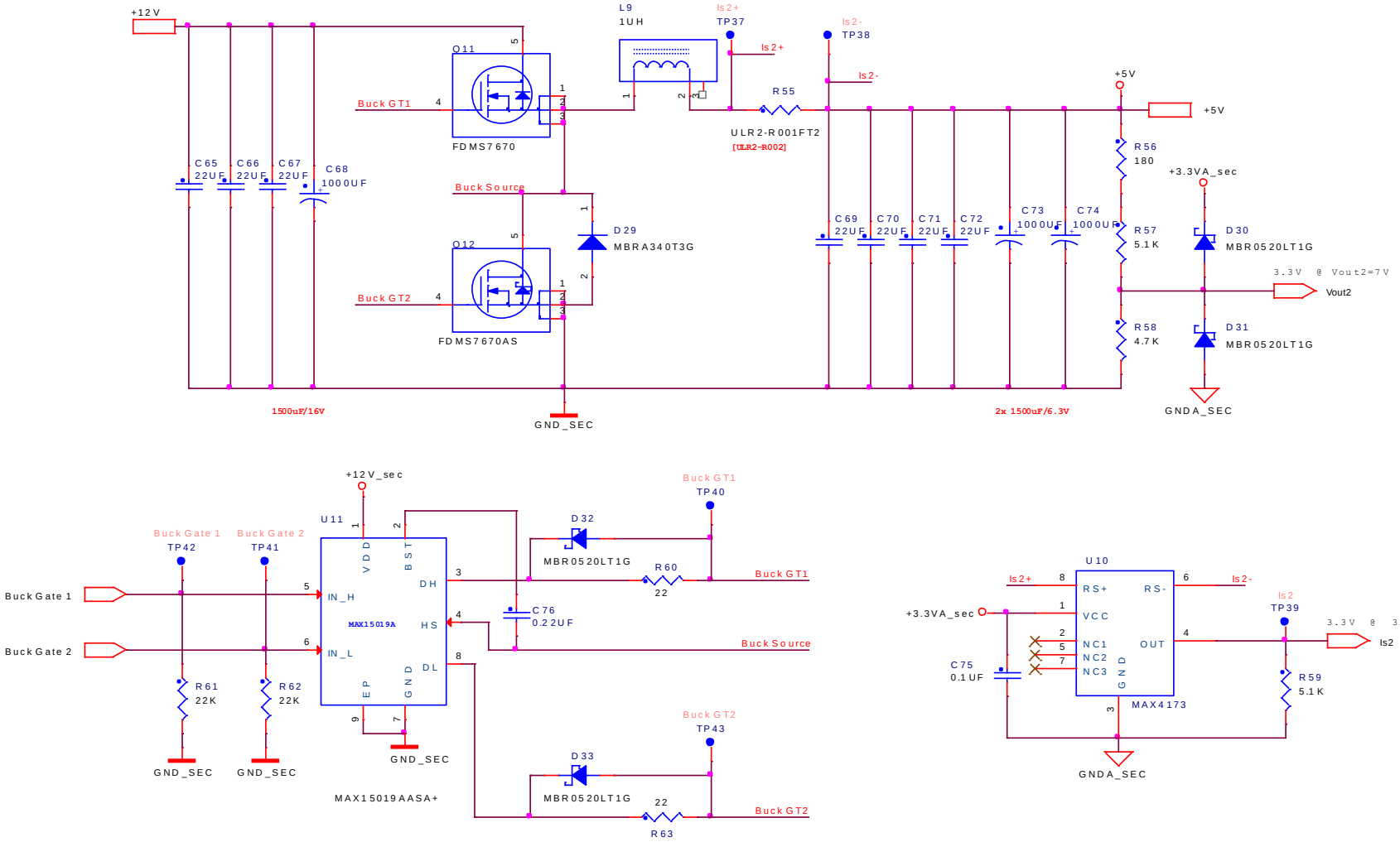
LLC Resonant Converter

- LLC Converter Schematic



LLC Resonant Converter

- Buck Converter Schematic



LLC Resonant Converter

- Secondary Side SW Implementation

- LLC Resonant Converter
  - PI Controller running every 10 μs
- Buck Converter
  - PID Controller running every 10 μs
- Other task Control
  - Communication with host PC
  - Communication with primary controller
  - Communication via PM Bus (Optional)
  - Communication via CAN (Optional)

LLC Resonant Converter

– Picture Gallery

LLC Resonant Converter

– Picture Gallery

Thank you