Principle and Design Application of Half-Bridge LLC Resonant Converter

OUTLINE

I. Introduction

II. Review of Switching Characteristics

III. Traditional Resonant Topologies

IV. Half-Bridge LLC Resonant Converter

V. Half Bridge LLC Resonant Converter

Operation Principle

VI. Design Guidelines and Example

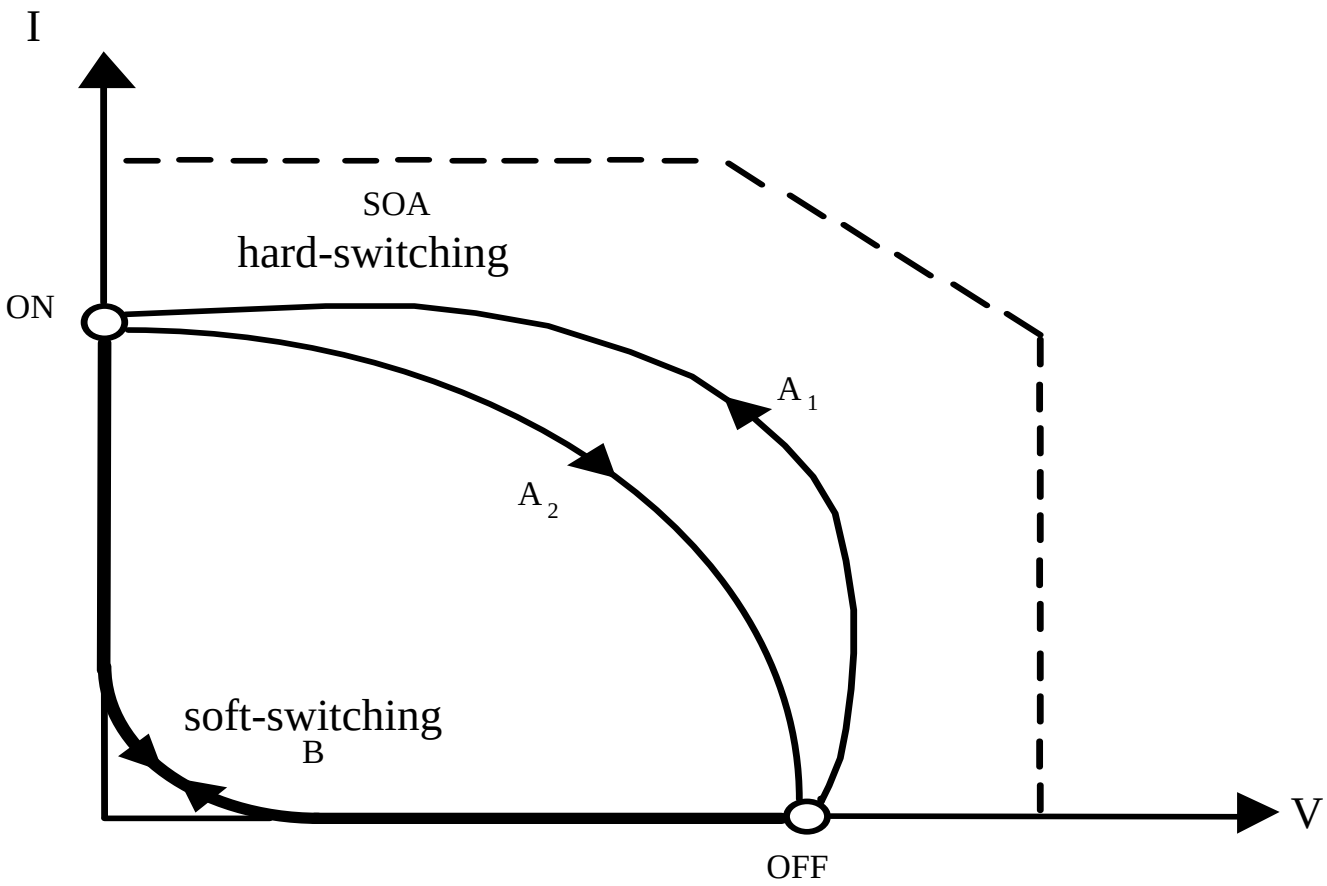
I. Introduction

- Typical applications of power electronics include AC-DC, DC-AC, AC-AC and DC-DC.
- The requirements of power converter include small size, light weight, high efficiency and high power density.
- Hard-switching PWM converters suffer from high switching losses, high switching stresses and high EMI noise.
- Soft-switching PWM converters can alleviate these problems in which a high switching frequency operation can be achieved.

II. Review of Switching Characteristics

- Limitations of hard-switching PWM converters
  - Operating frequency (50~200kHz)
  - Power density
  - EMI
- Review of soft-switching techniques
  - Zero-voltage switching (ZVS)
  - Zero-current switching (ZCS)

❑ Load-line trajectories of power switches



Load-line trajectories illustrating switching transitions

Switching losses

- Turn-on loss due to reverse-recovery current of the freewheeling diode

$$W_D = \int_0^{t_{on}} v_{DS}(t) i_{DS}(t) dt$$

- Turn-on loss by drain-to-source capacitance

$$W_{C_{ds}} = \int_0^{V_{DS}} v_{DS} C_{DS(v_{DS})} dv_{DS}$$

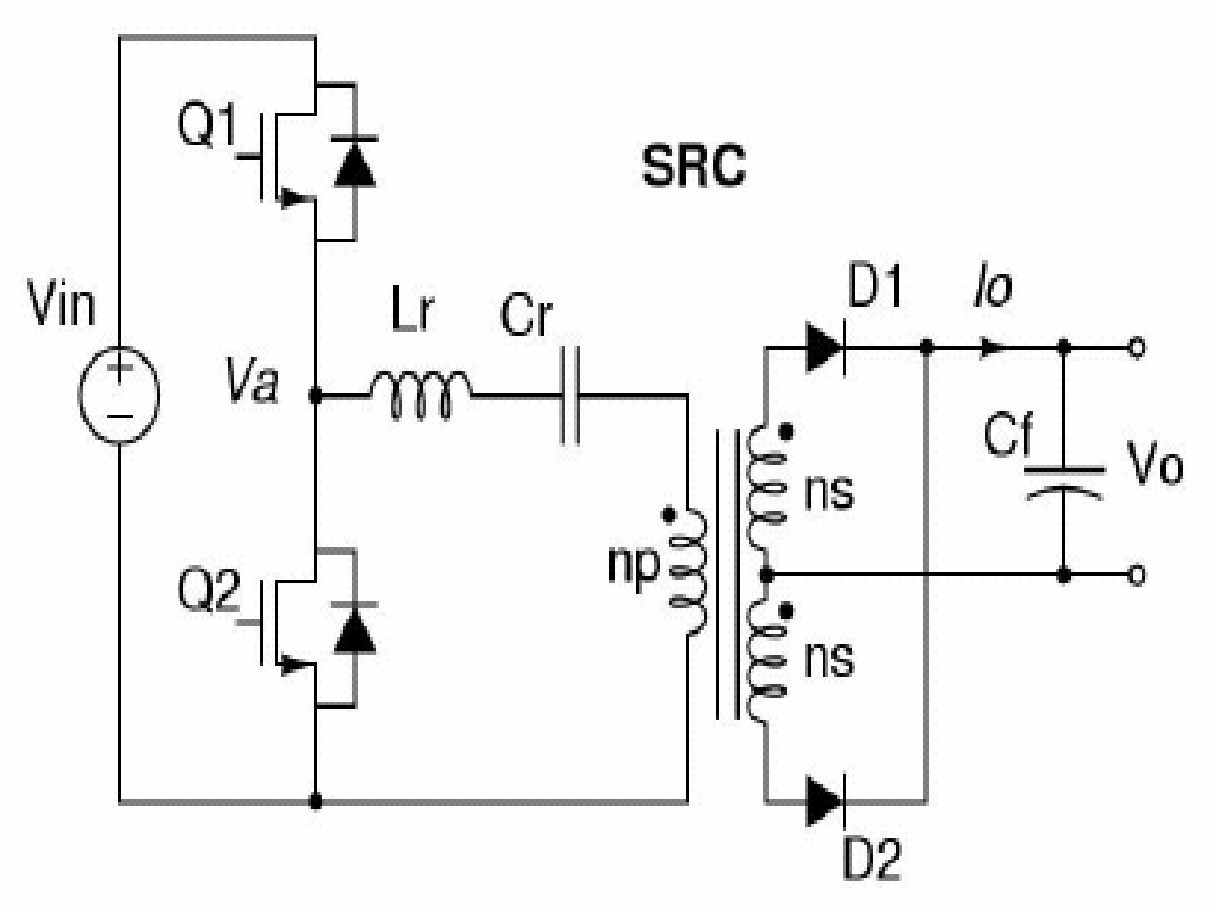
- Turn-off loss

$$W_{off} = \int_0^{t_{off}} v_{DS}(t) i_{DS}(t) dt$$

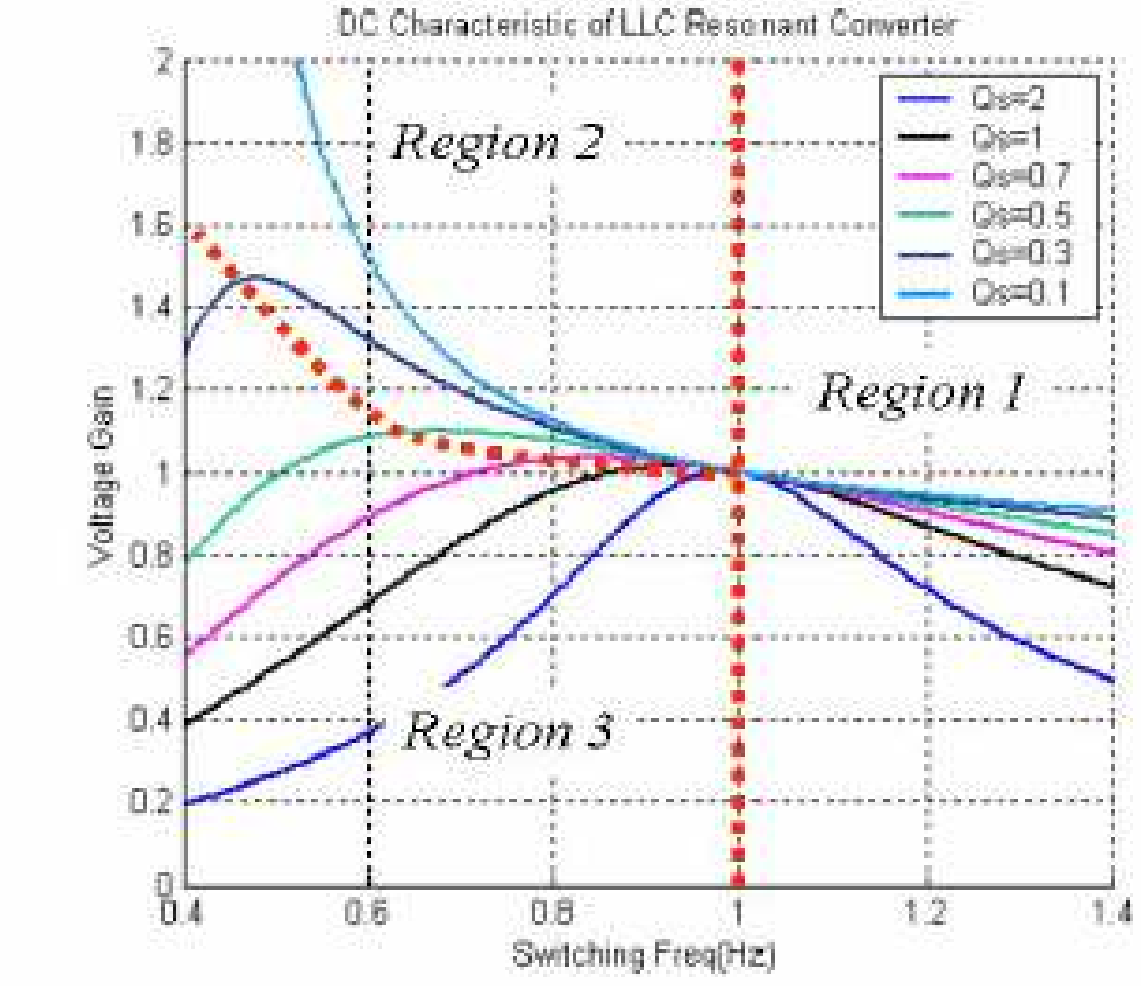
❑ Three Traditional Resonant Topologies

- ❖ **Series Resonant Converter (SRC)**
- ❖ **Parallel Resonant Converter (PRC)**
- ❖ **Series Parallel Resonant Converter(SPRC)**

❖ Series Resonant Converter

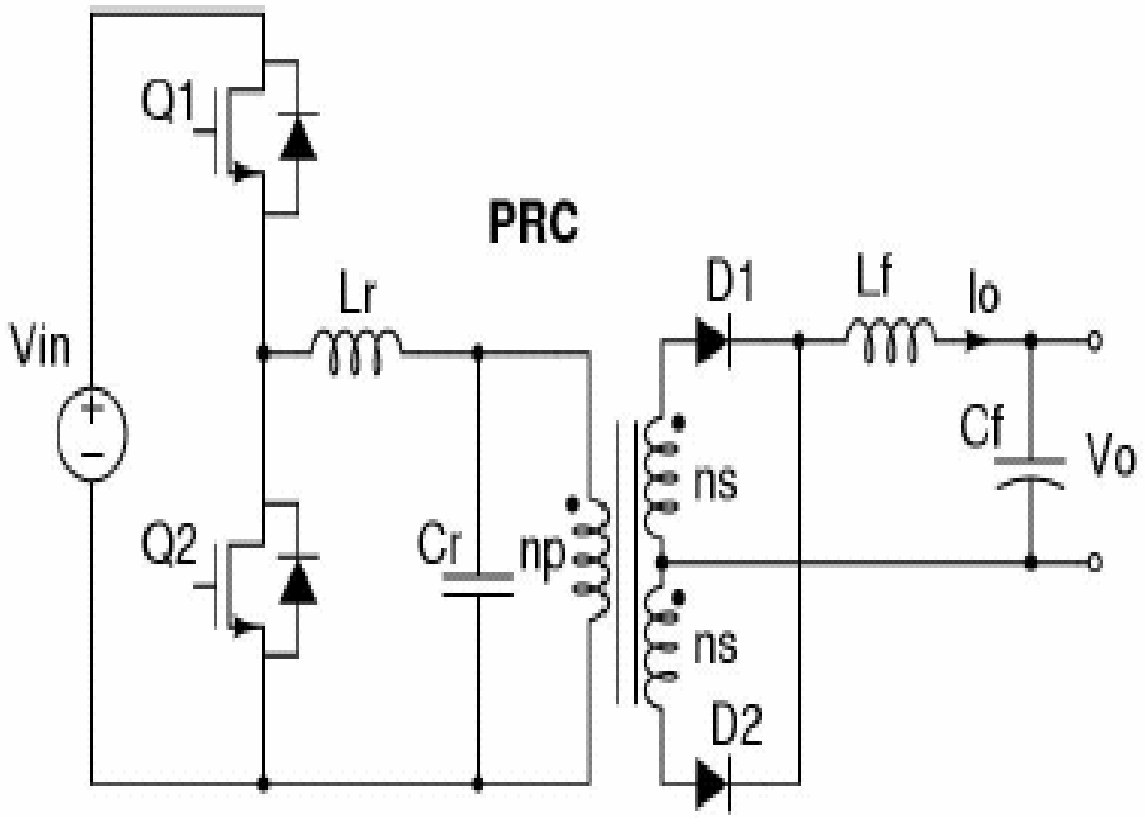


Half Bridge Series Resonant Converter

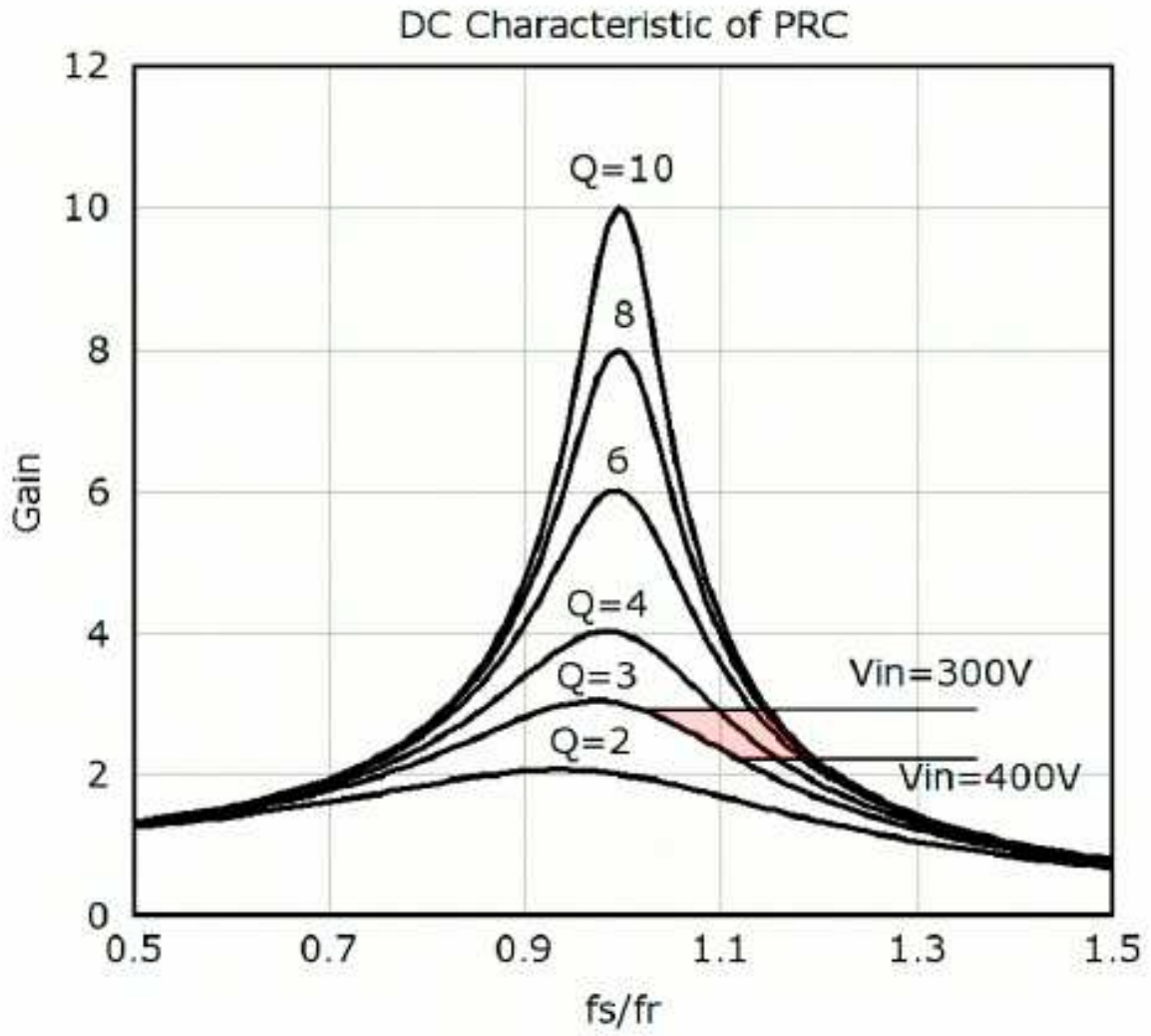


DC Characteristics and Operating Region of SRC

❖ Parallel Resonant Converter

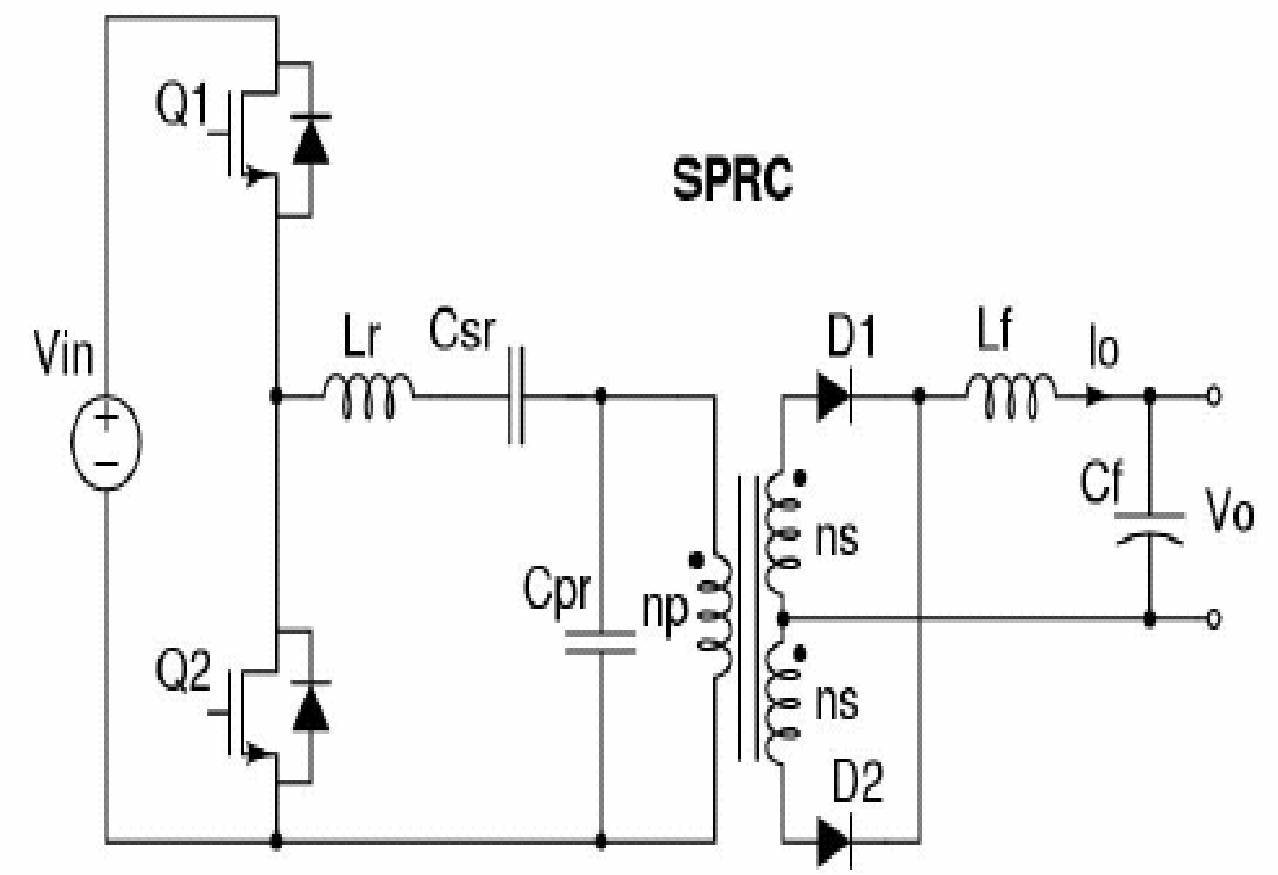


Half Bridge Parallel Resonant Converter

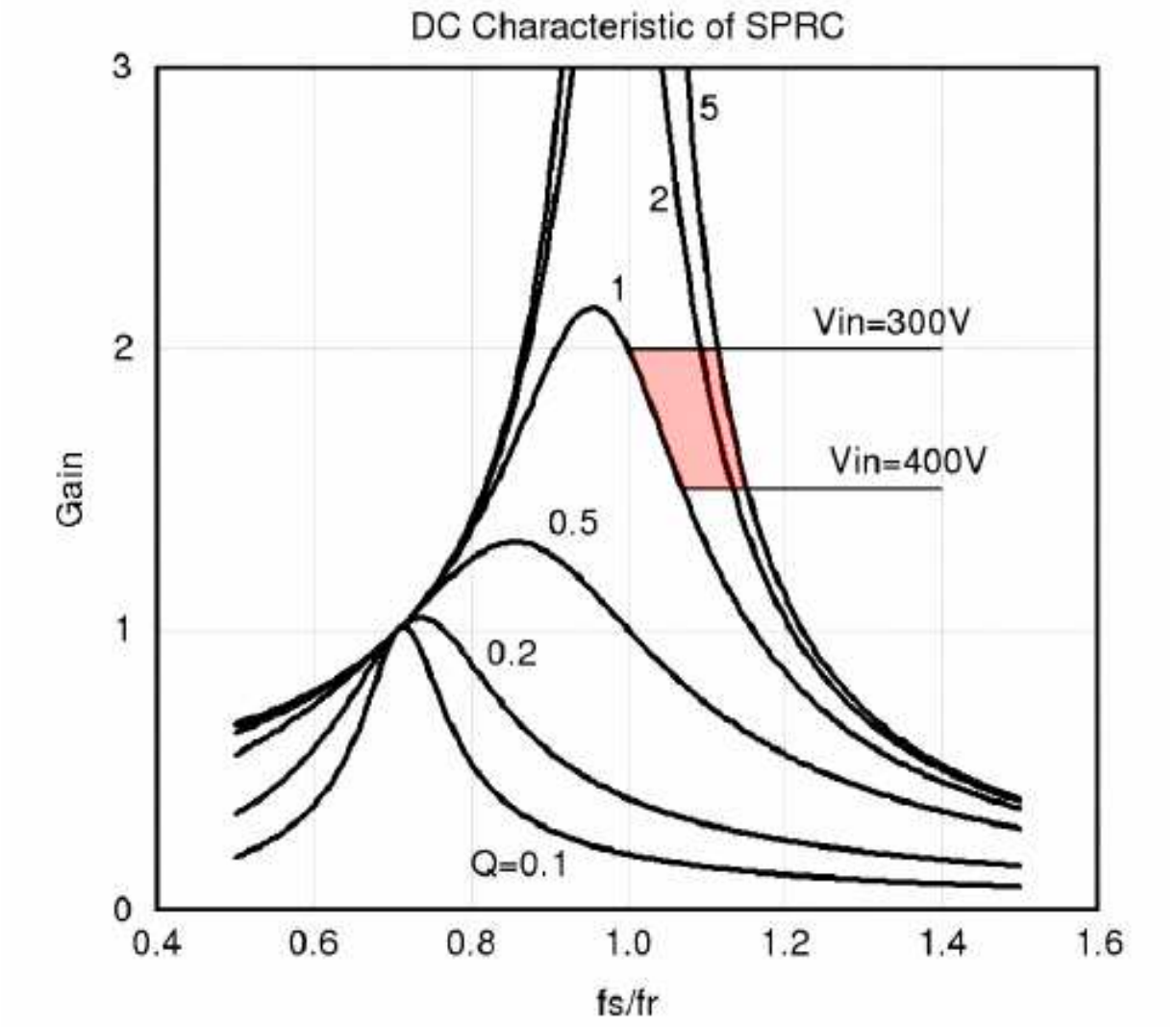


DC Characteristics and Operating Region of PRC

❖ Series Parallel Resonant Converter



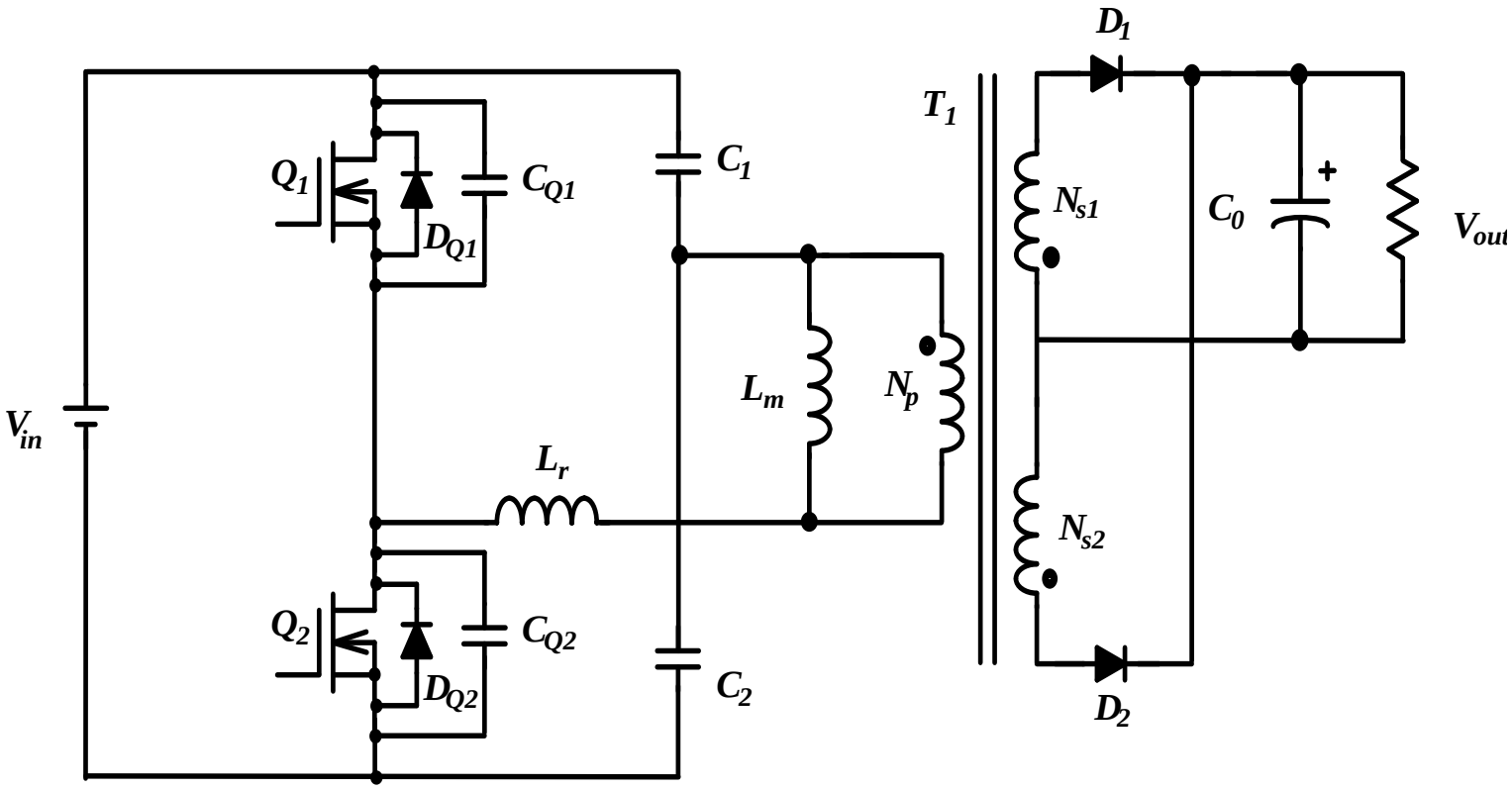
Half Bridge Series Parallel Resonant Converter



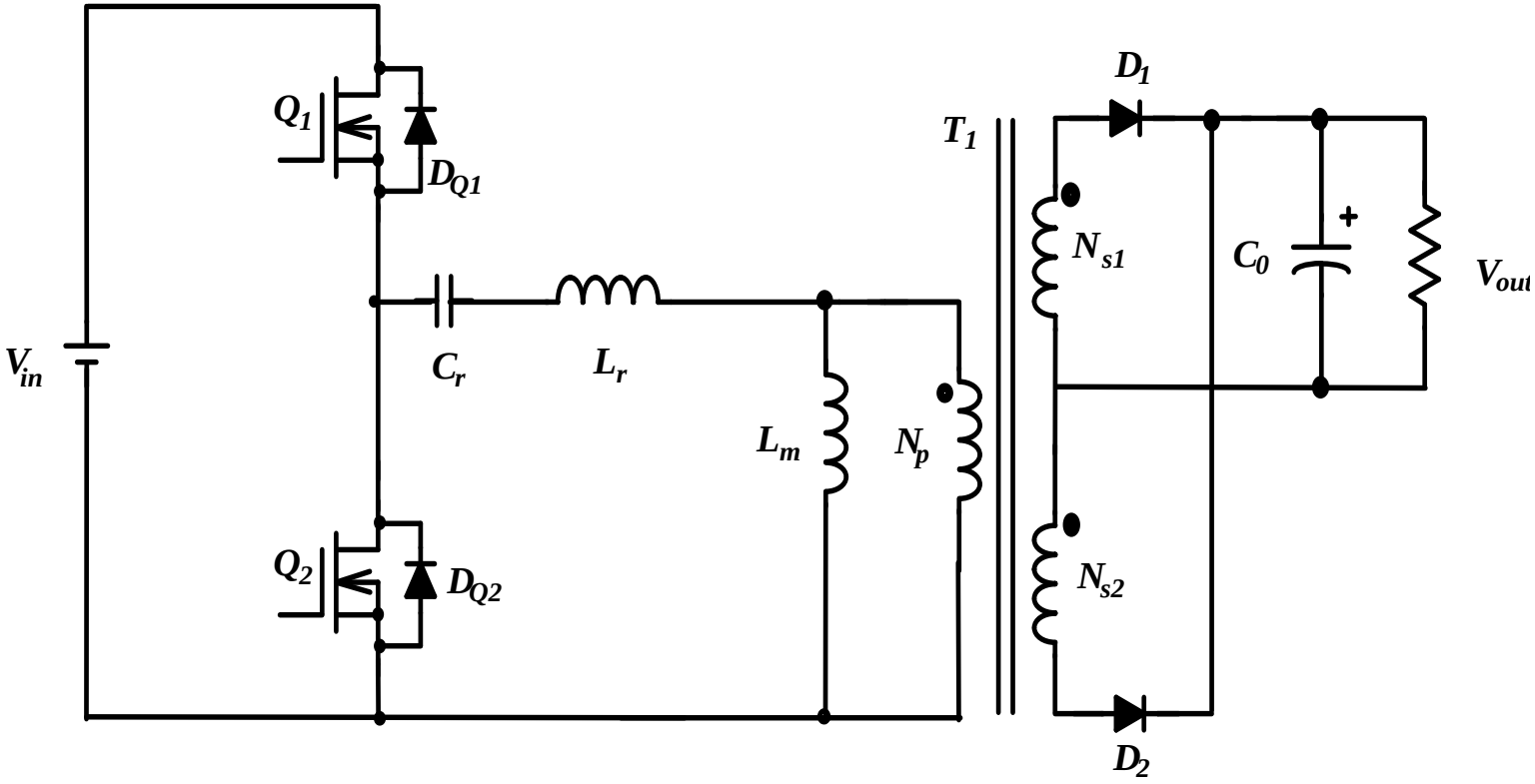
DC Characteristics and Operating Region of SPRC

IV. Half Bridge LLC Resonant Converter

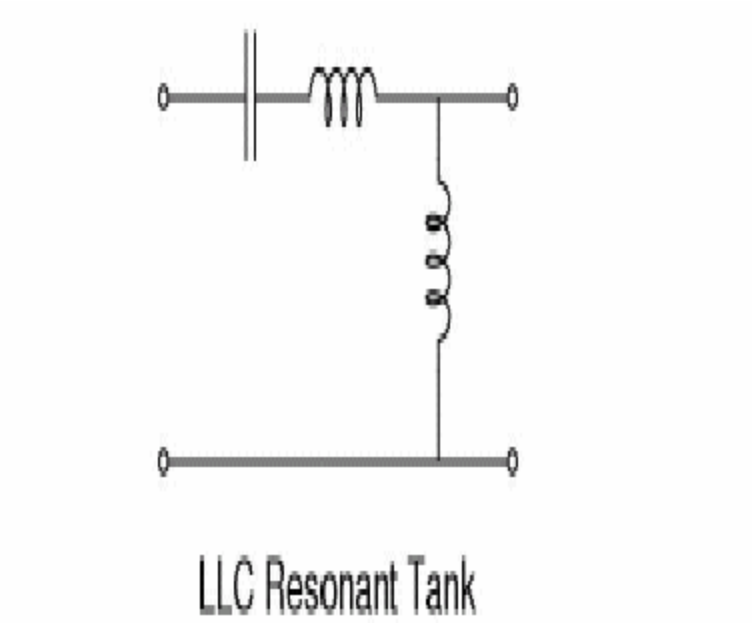
- Type 1 Half Bridge LLC Resonant Topologies



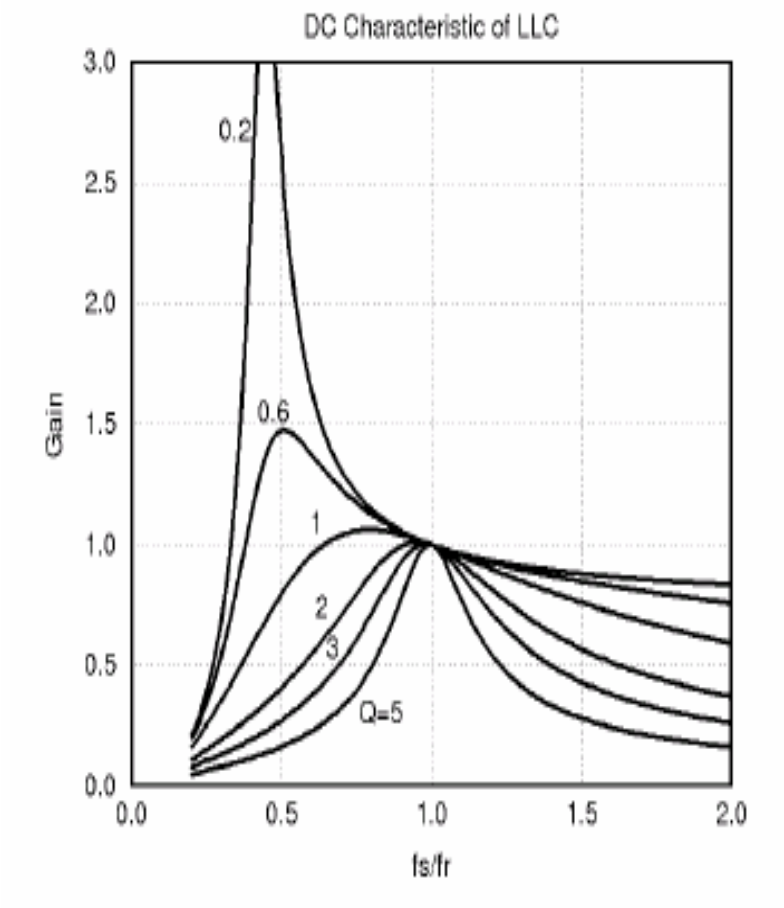
❑ Type 2 Half Bridge LLC Resonant Topologies



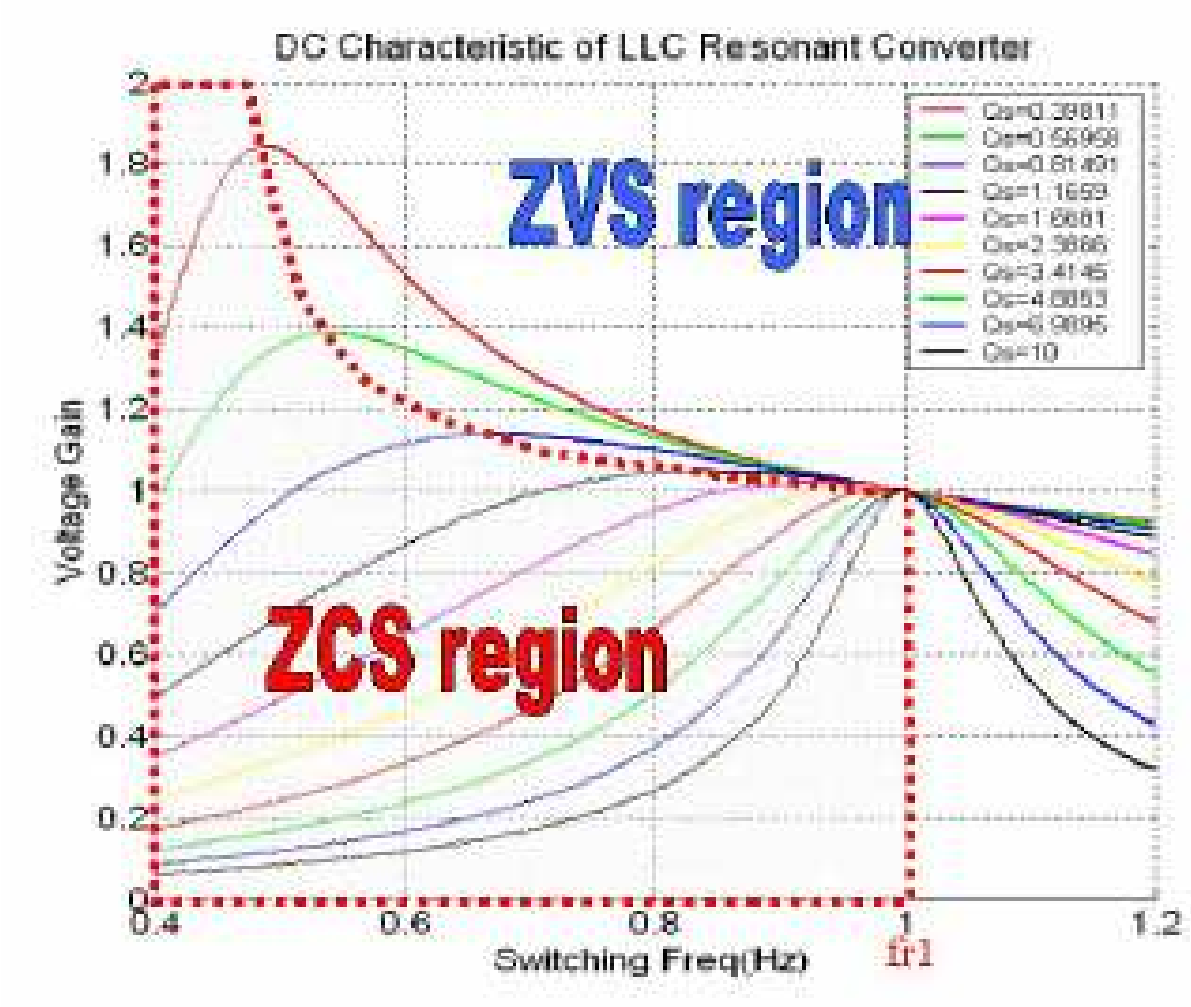
❖LLC Resonant Tank



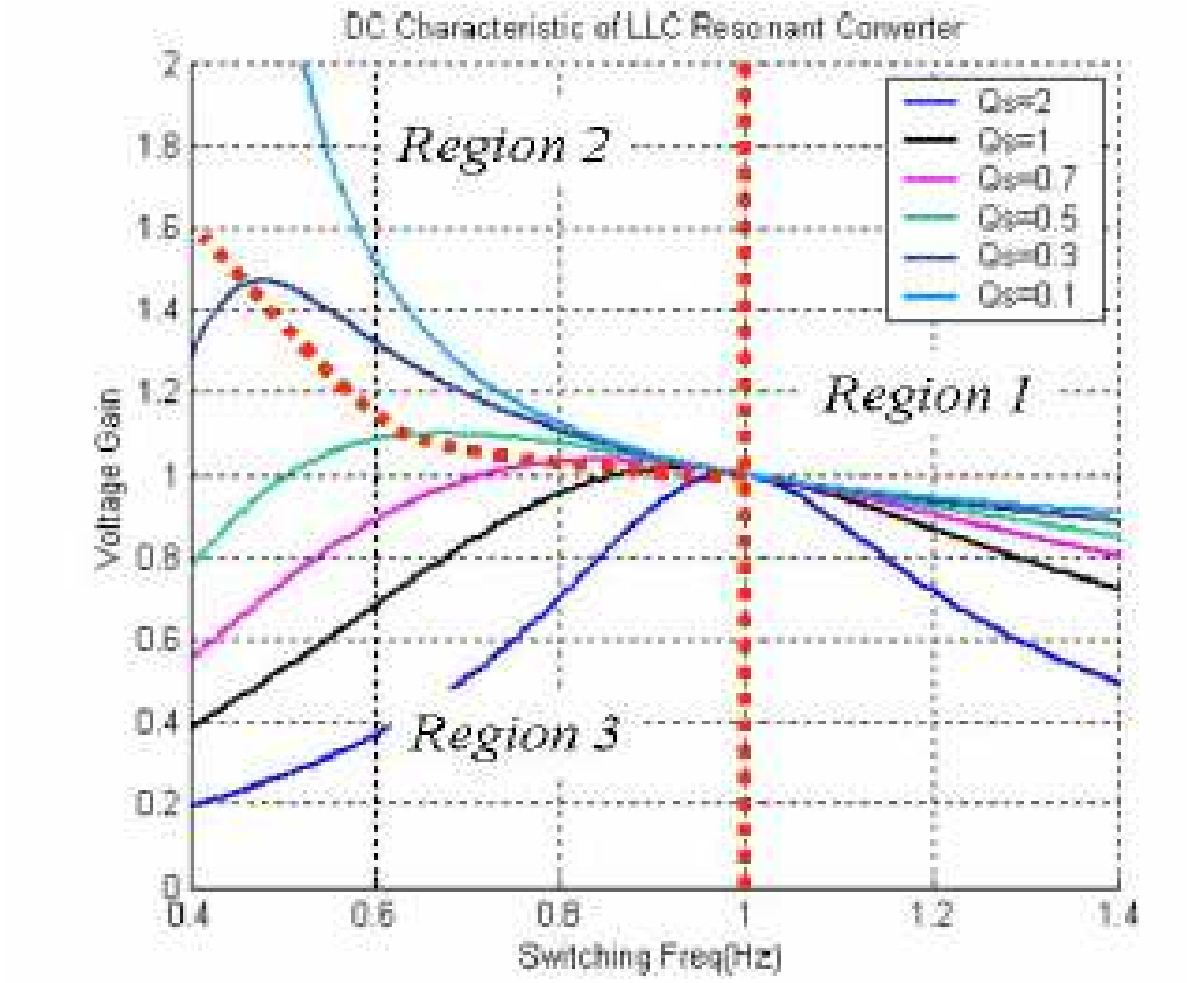
❖LLC DC Characteristics



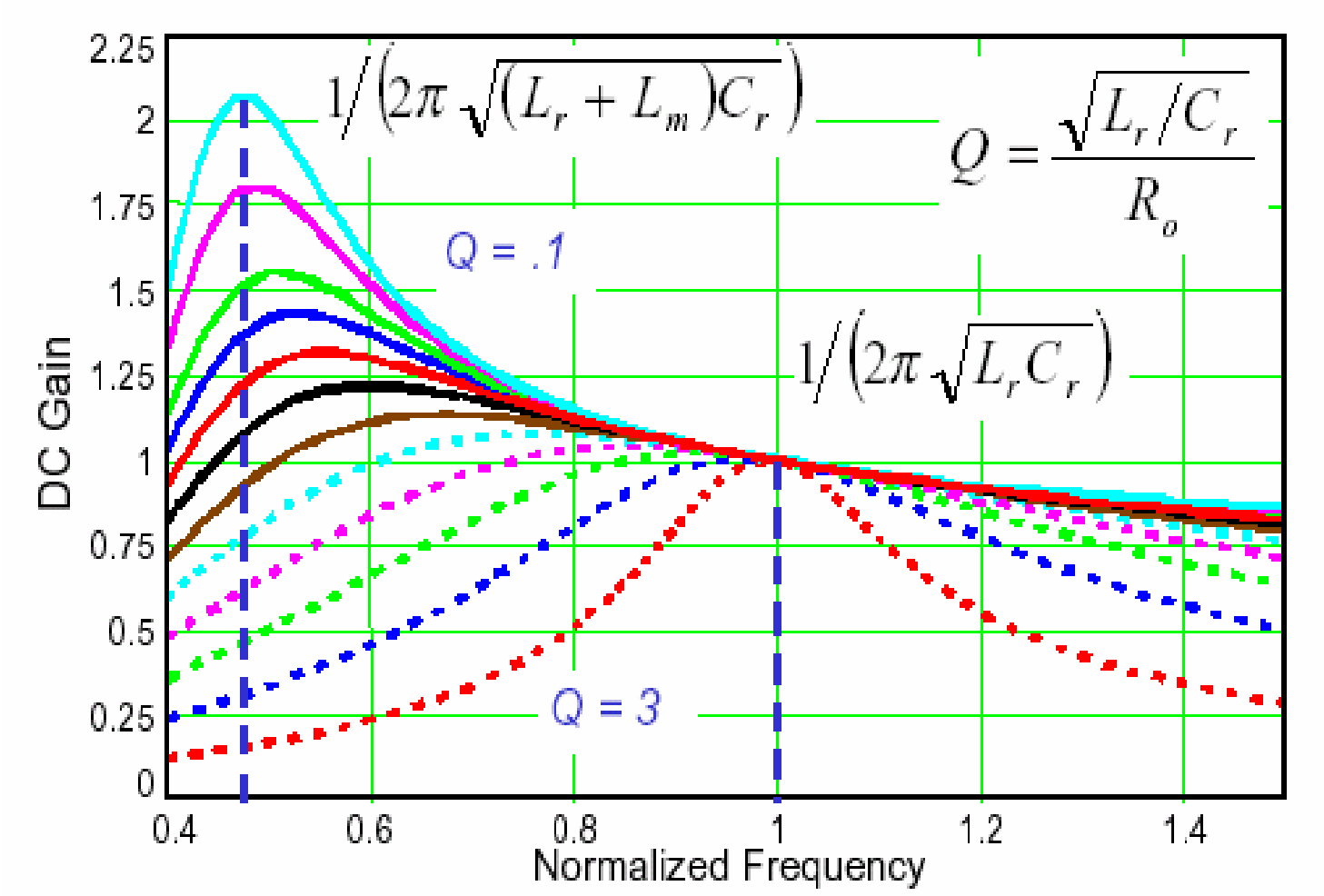
❖ LLC DC Characteristics for ZVS/ZCS Region



❖ LLC DC Characteristics for Three Operating Region

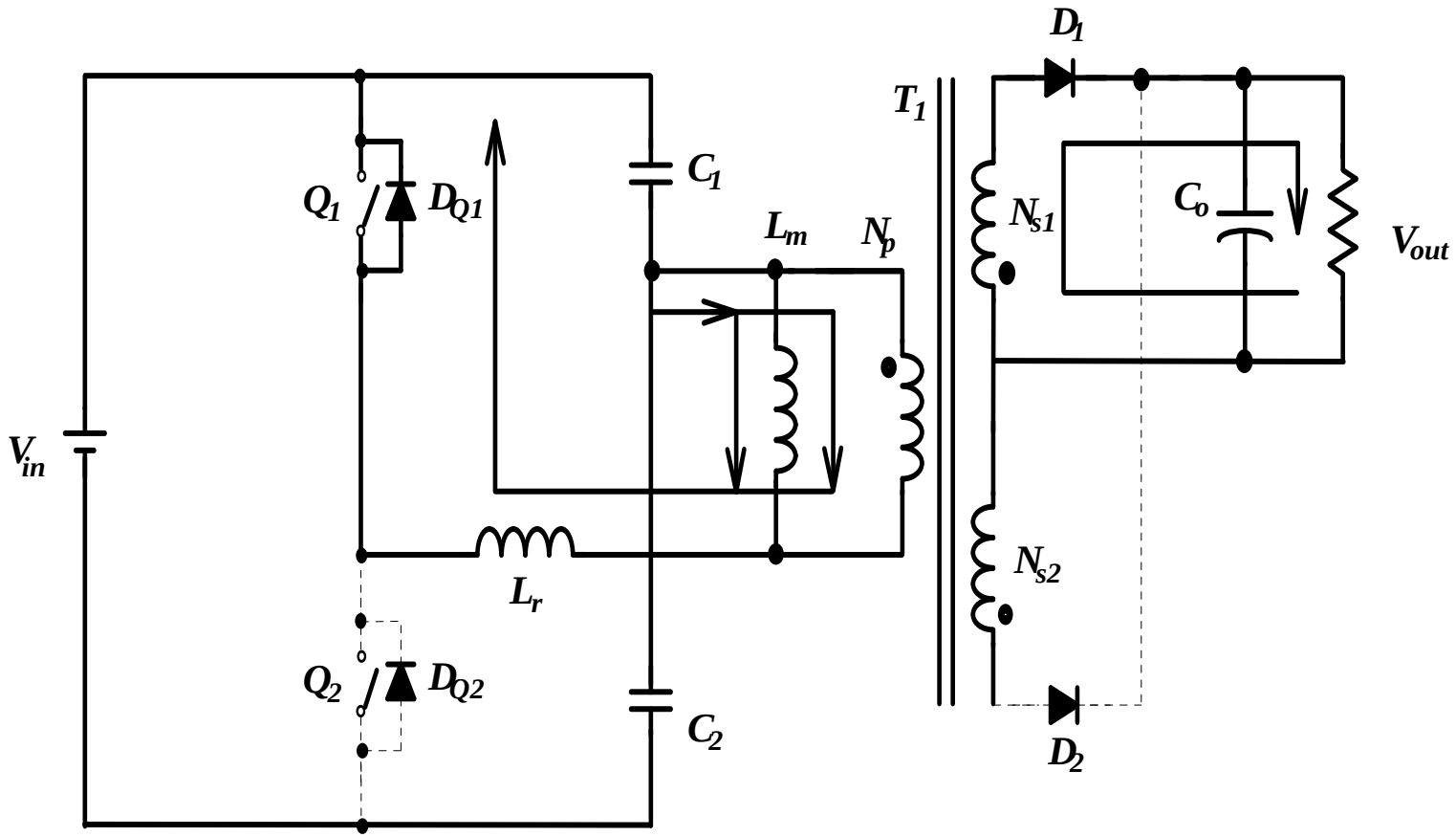


❖ LLC DC Characteristics for Two Resonant Frequency

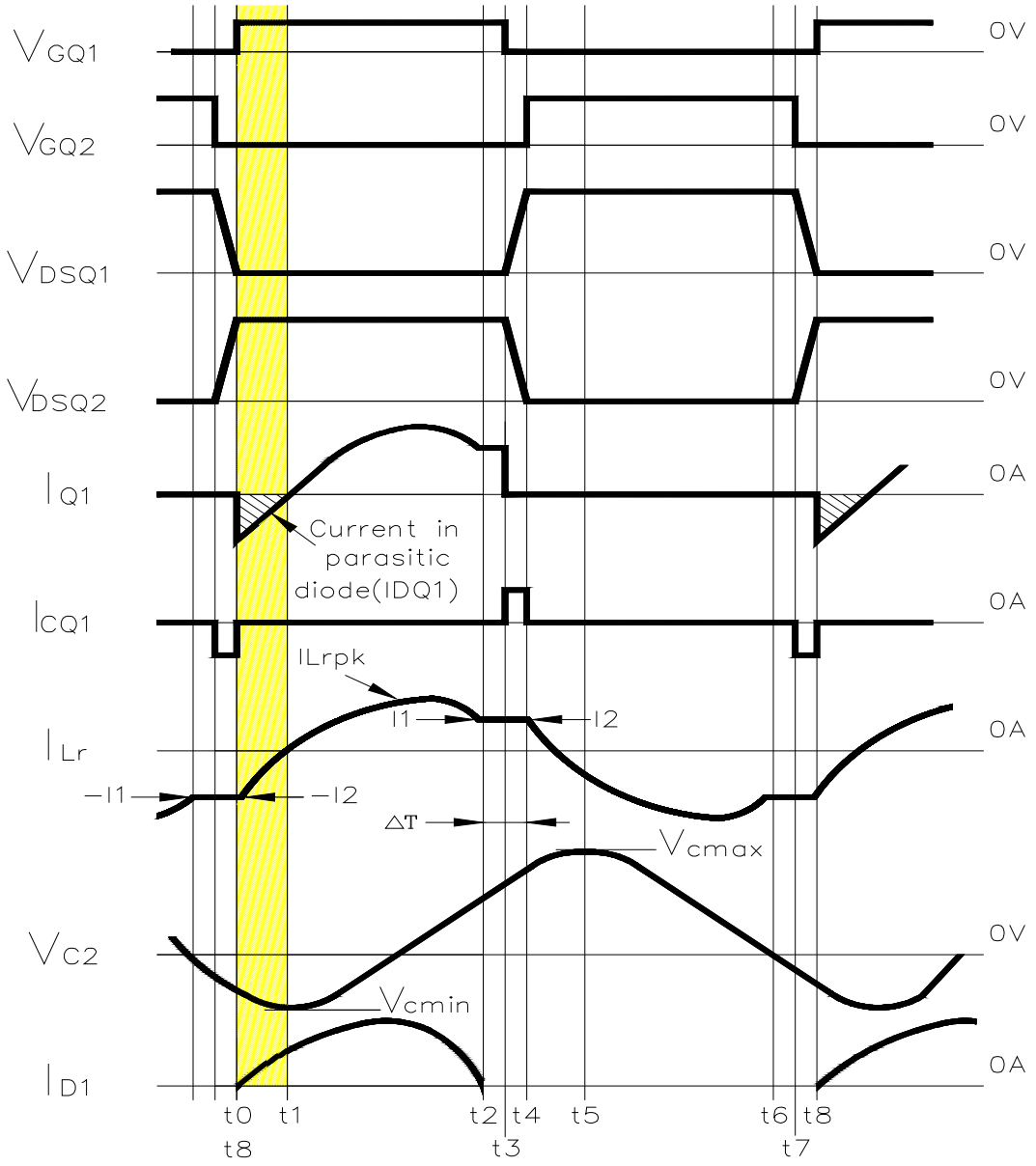


V. Half Bridge LLC Resonant Converter operation Principle

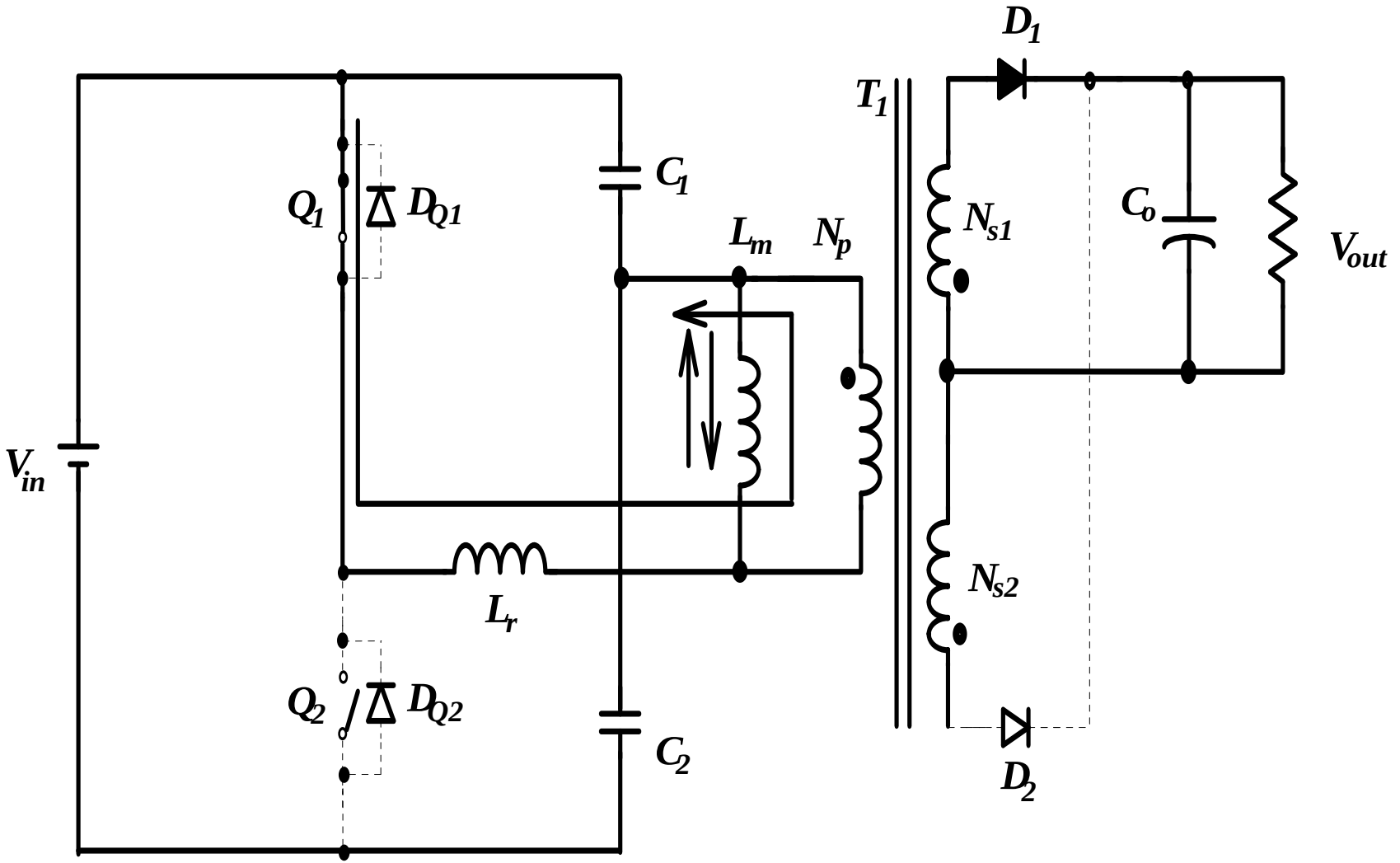
❖ **Mode 1 (t0~t1)**



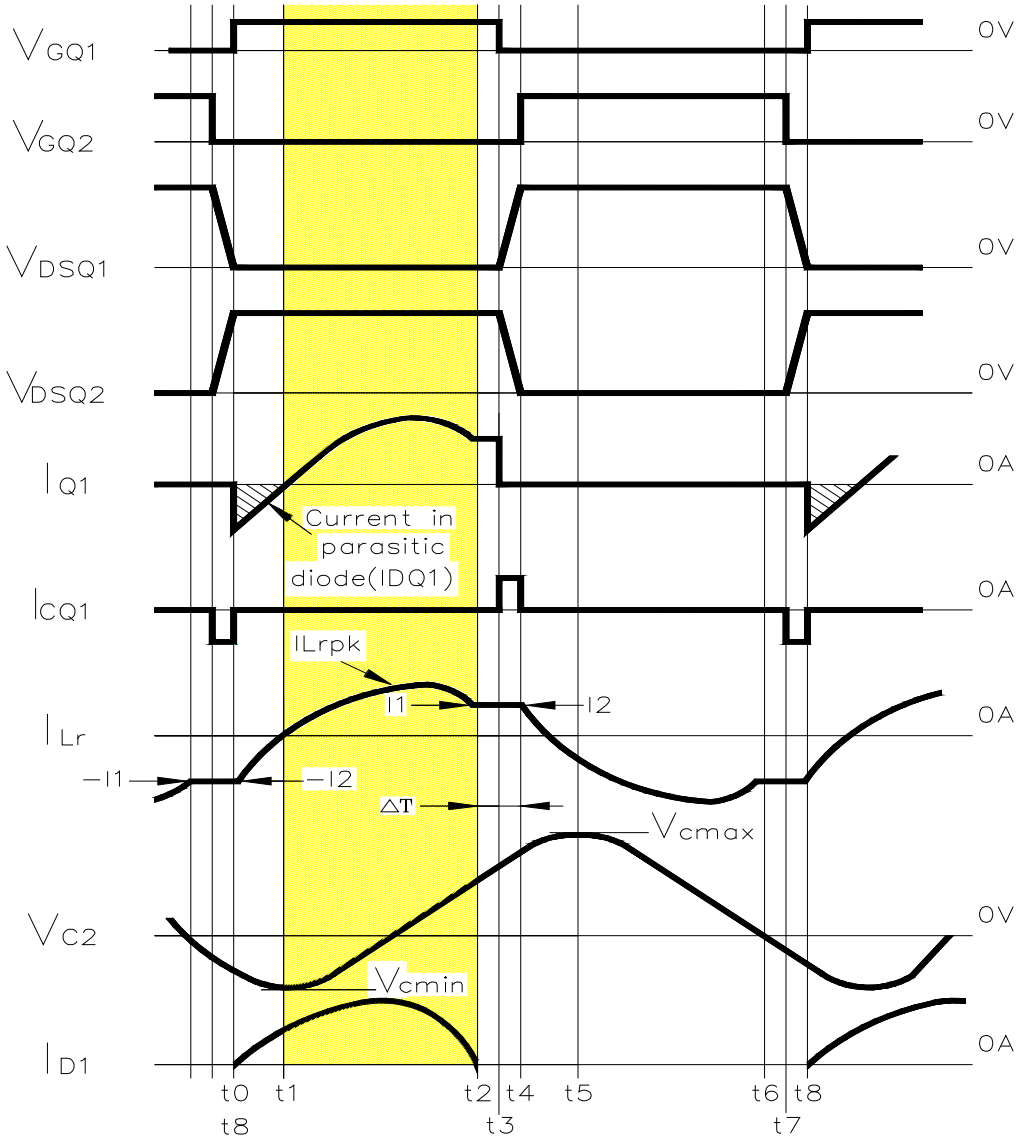
❖ Mode 1 (t0~t1)


VGQ1
VGQ2
VDSQ1
VDSQ2
IQ1
ICQ1
ILr
VC2
ID1
0V
0A
Current in parasitic diode(IDQ1)
ILrpk
I1
I2
-I1
-I2
ΔT
Vcmax
Vcmin
t0
t1
t2
t3
t4
t5
t6
t7
t8

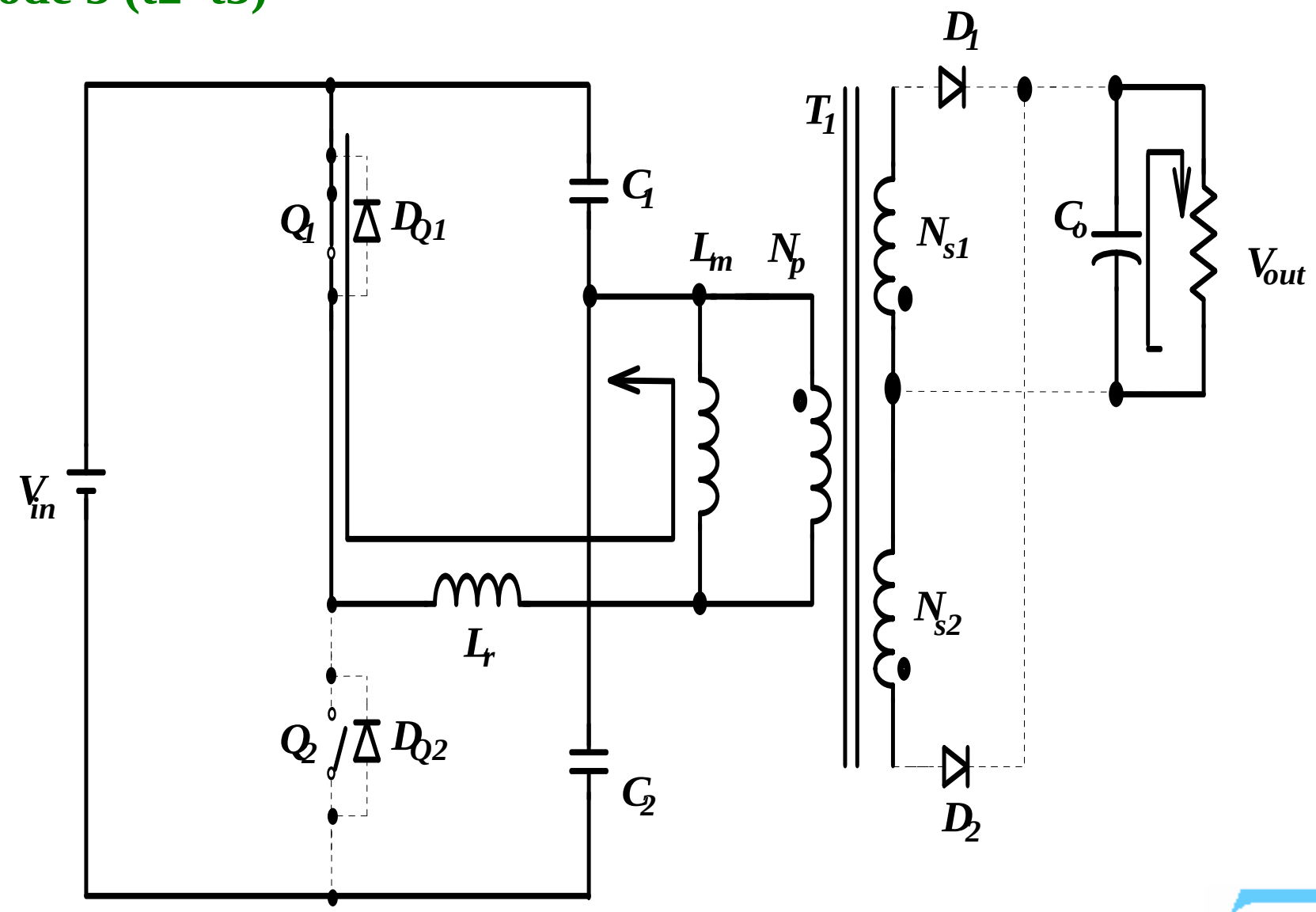
❖ Mode 2 (t1~t2)



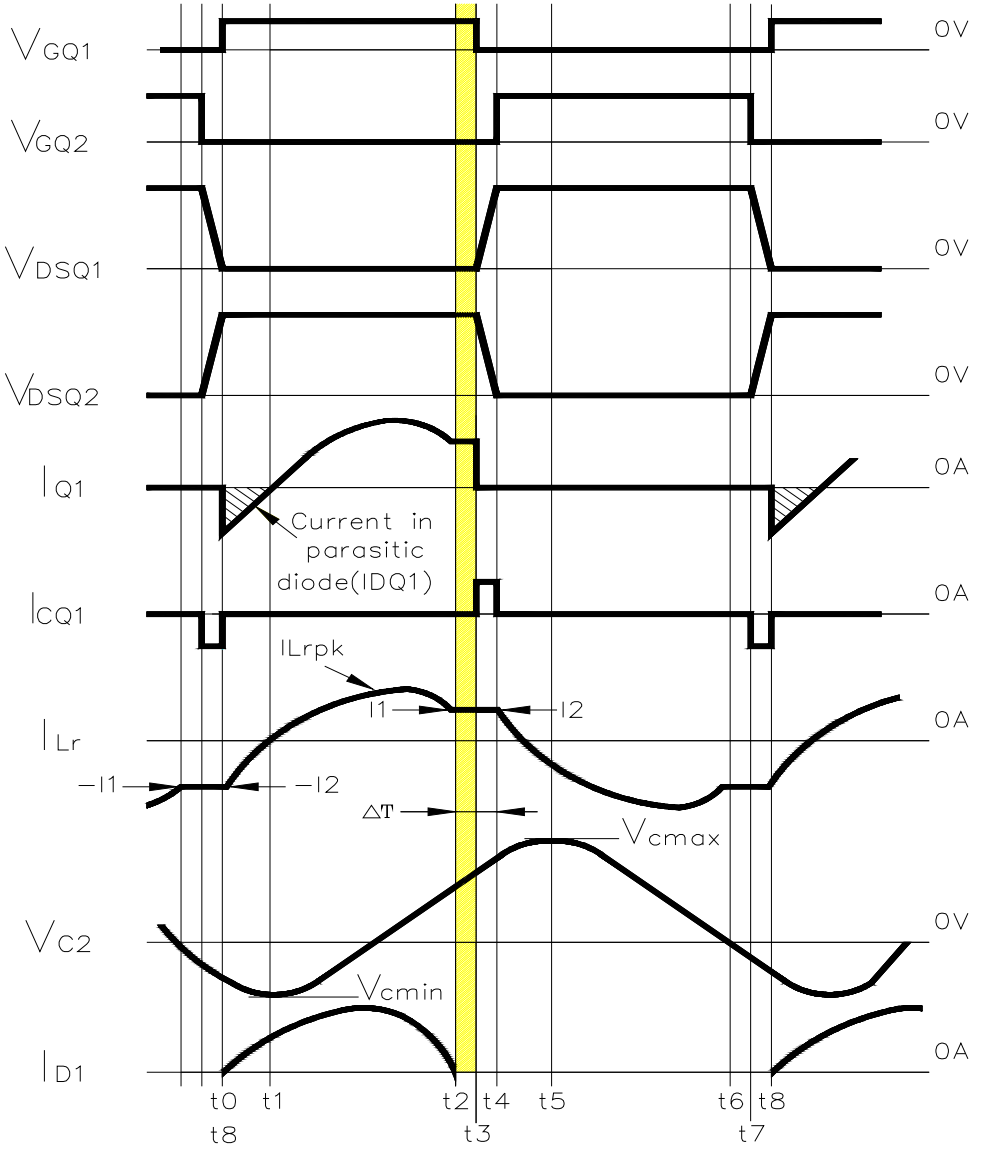
❖ Mode 2 (t1~t2)


VGQ1
VGQ2
VDSQ1
VDSQ2
IQ1
ICQ1
ILr
VC2
ID1
0V
0A
Current in parasitic diode(IDQ1)
ILrpk
I1
I2
-I1
-I2
ΔT
Vcmax
Vcmin
t0
t1
t2
t3
t4
t5
t6
t7
t8

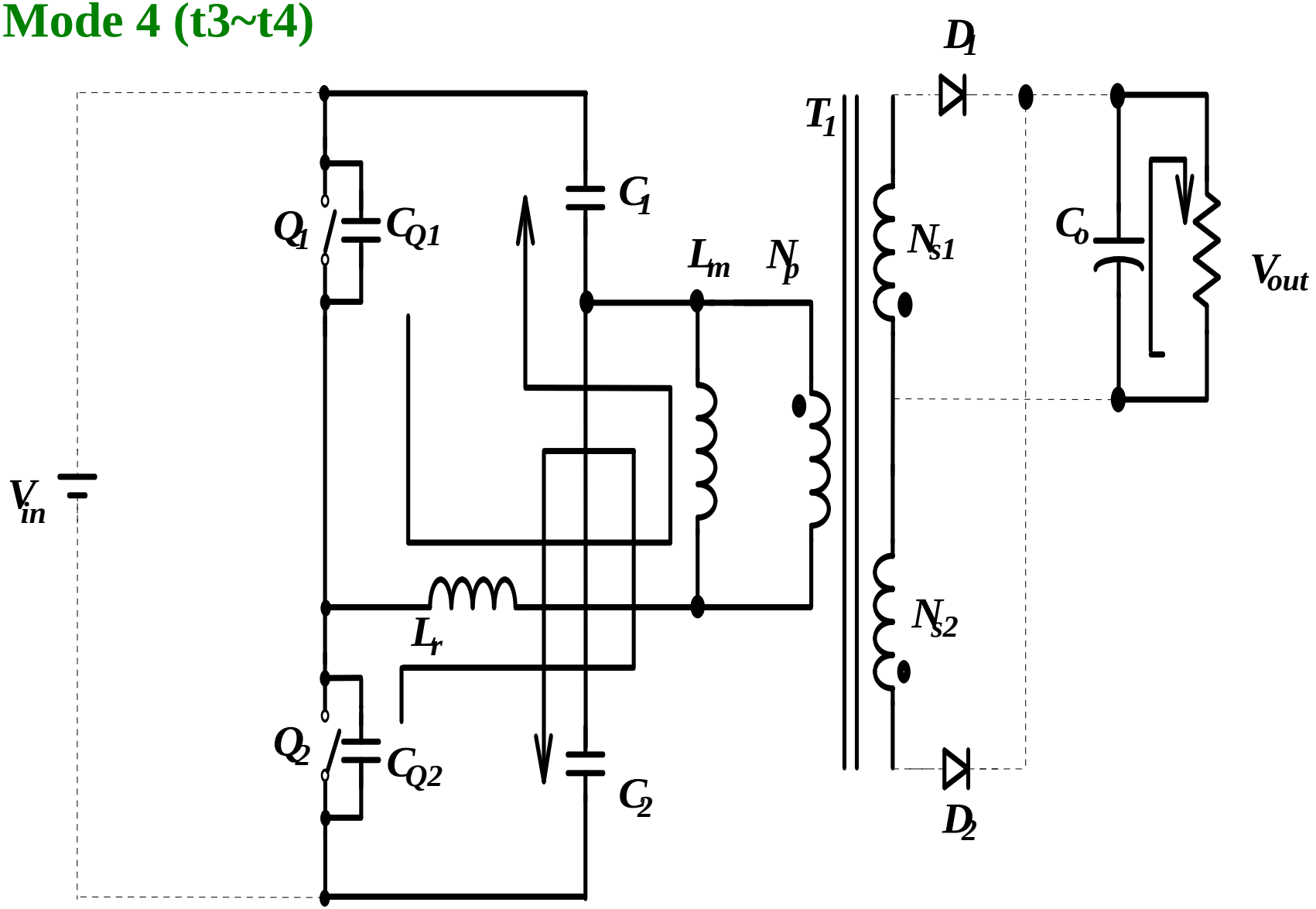
❖ Mode 3 (t2~t3)



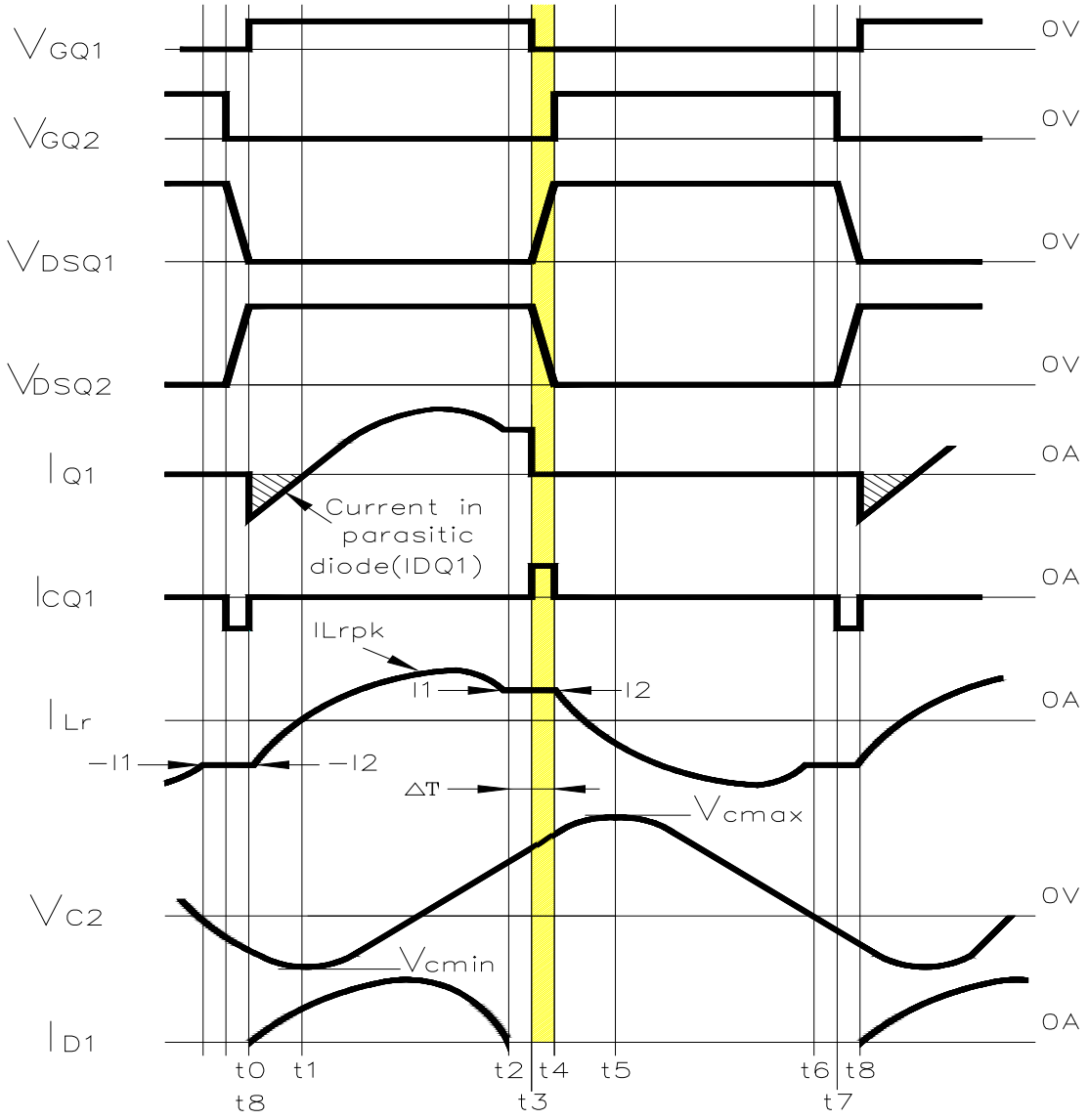
❖ Mode 3 (t2~t3)


VGQ1
VGQ2
VDSQ1
VDSQ2
IQ1
ICQ1
ILr
VC2
ID1
0V
0A
Current in parasitic diode(IDQ1)
ILrpk
I1
I2
−I1
−I2
ΔT
Vcmax
Vcmin
t0
t1
t2
t3
t4
t5
t6
t7
t8

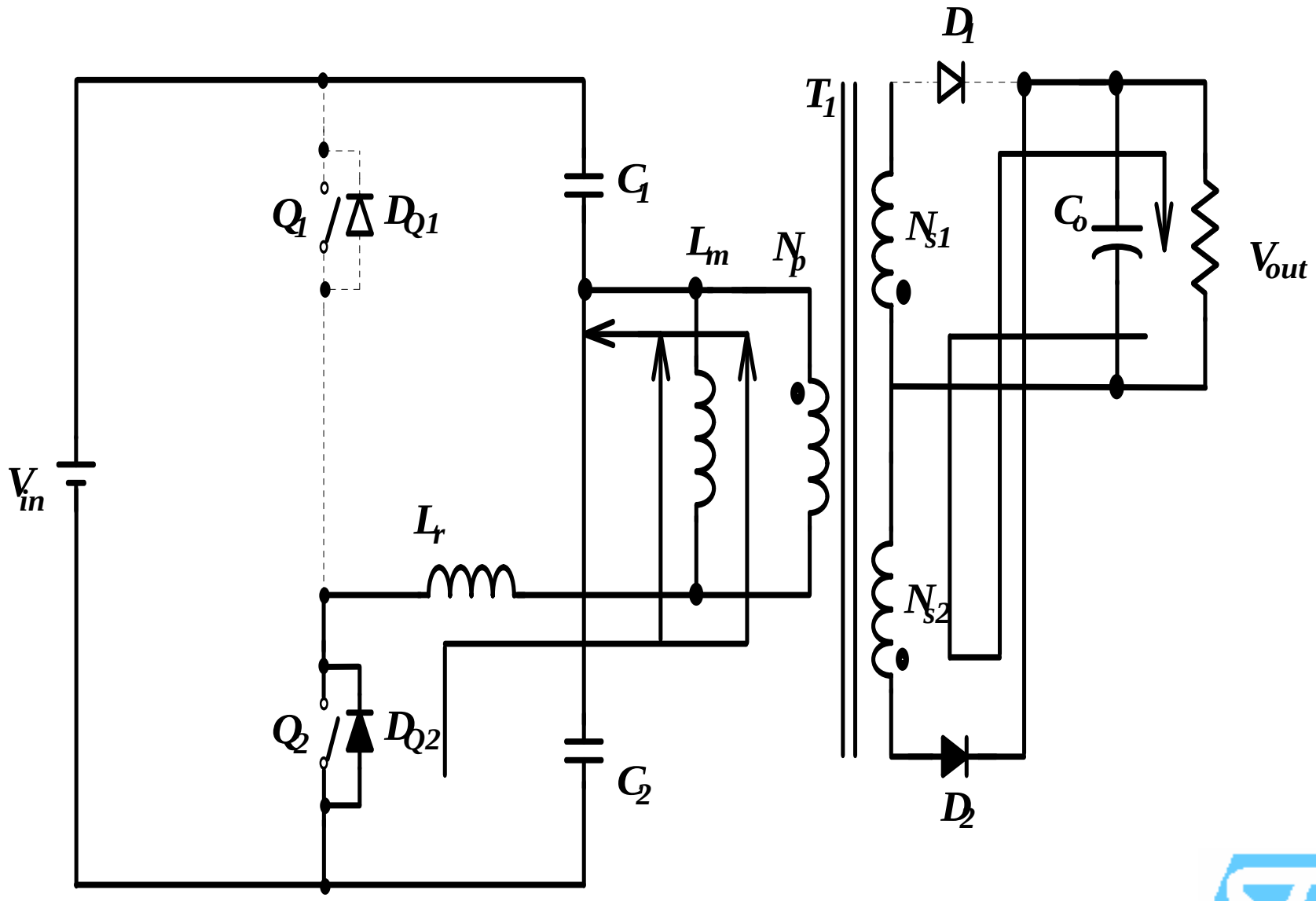
❖ Mode 4 (t3~t4)



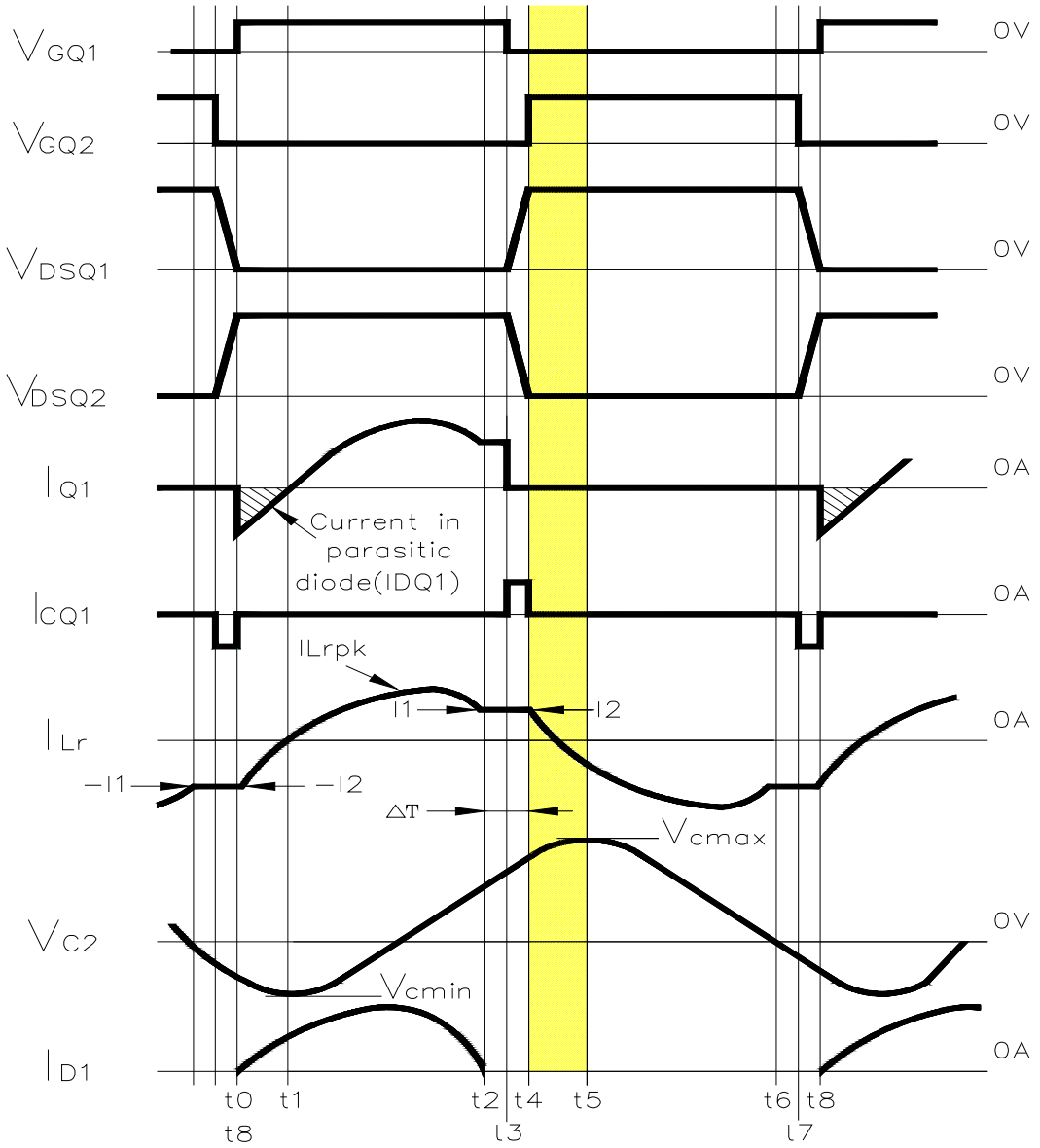
❖ Mode 4 (t3~t4)


VGQ1
VGQ2
VDSQ1
VDSQ2
IQ1
ICQ1
ILr
VC2
ID1
0V
0A
Current in parasitic diode(IDQ1)
ILrpk
I1
I2
-I1
-I2
ΔT
Vcmax
Vcmin
t0
t1
t2
t3
t4
t5
t6
t7
t8

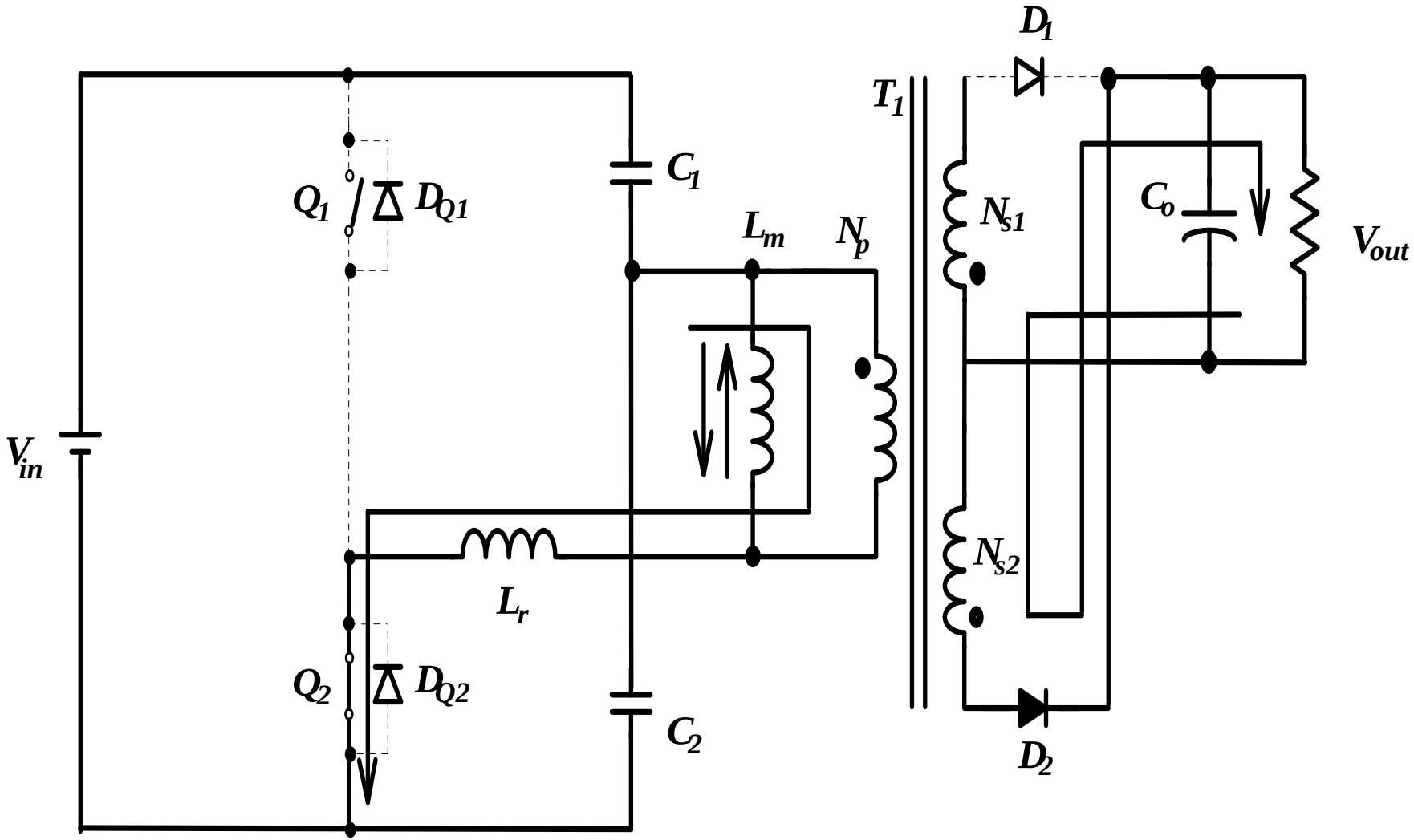
❖ Mode 5 (t4~t5)



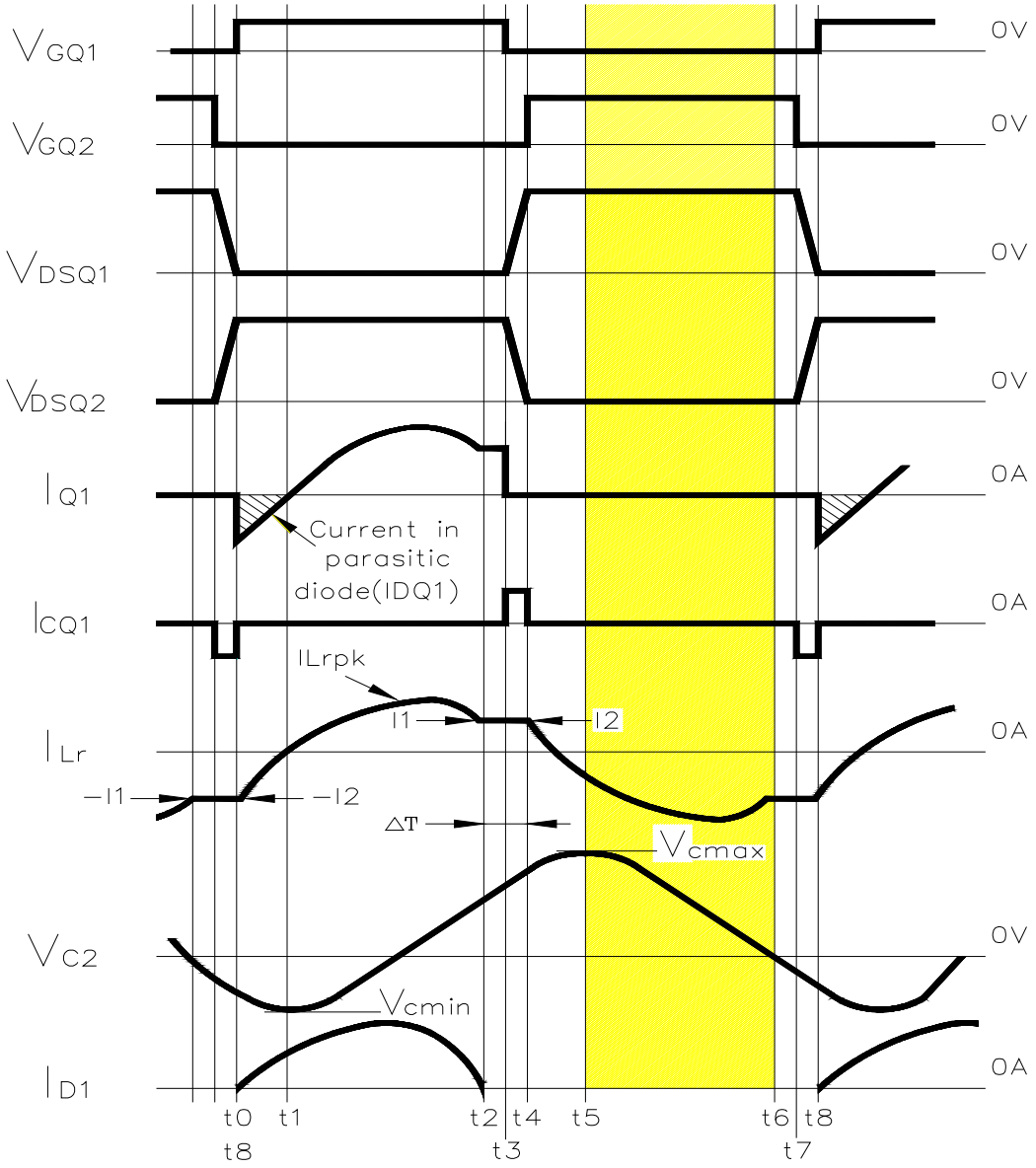
❖ Mode 5 (t4~t5)


VGQ1
VGQ2
VDSQ1
VDSQ2
IQ1
ICQ1
ILr
VC2
ID1
0V
0V
0V
0V
0A
0A
0A
0V
0A
Current in parasitic diode(IDQ1)
ILrpk
I1
I2
-I1
-I2
ΔT
Vcmax
Vcmin
t0
t1
t2
t3
t4
t5
t6
t7
t8
t8

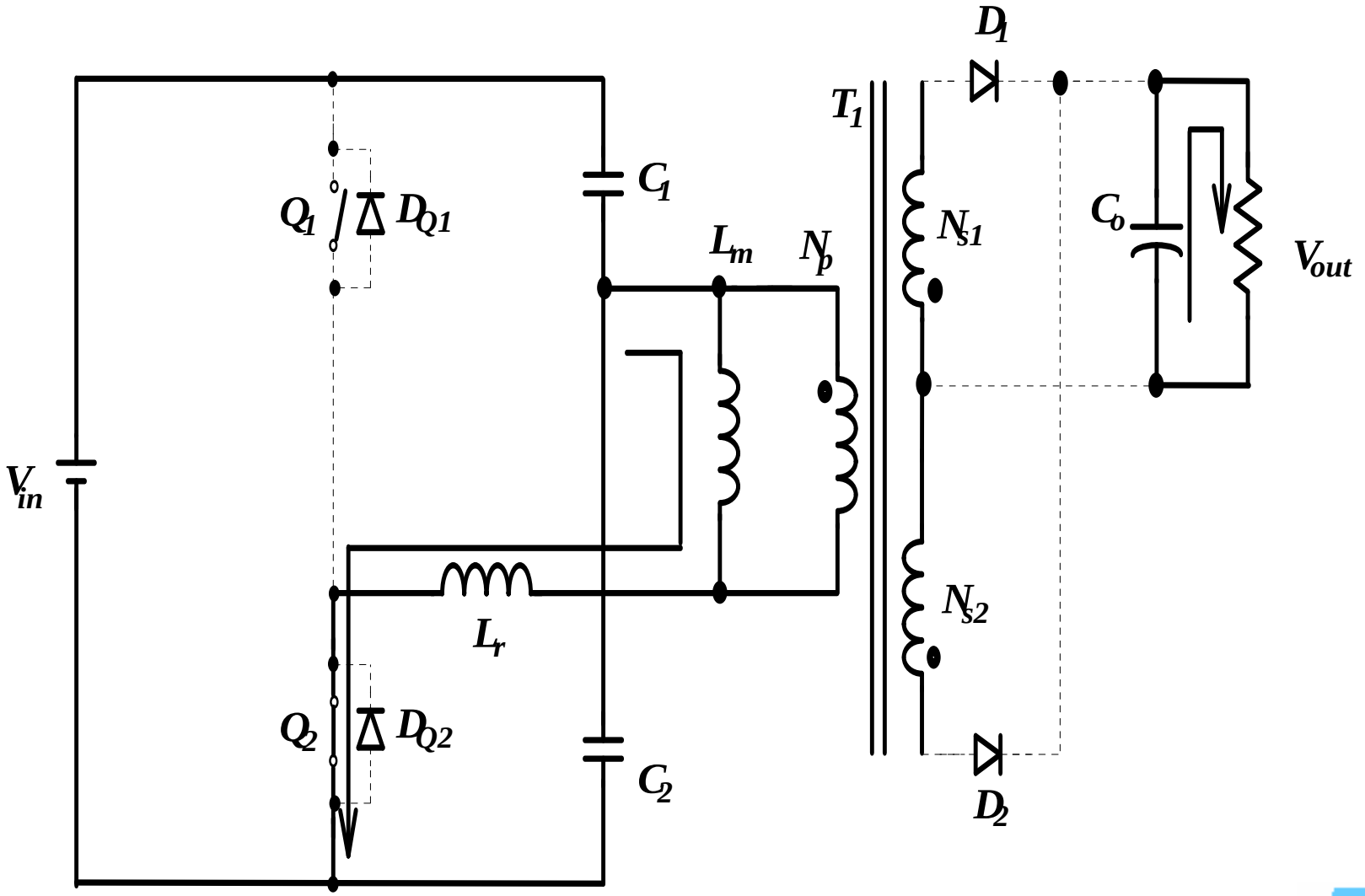
❖ Mode 6 (t5~t6)



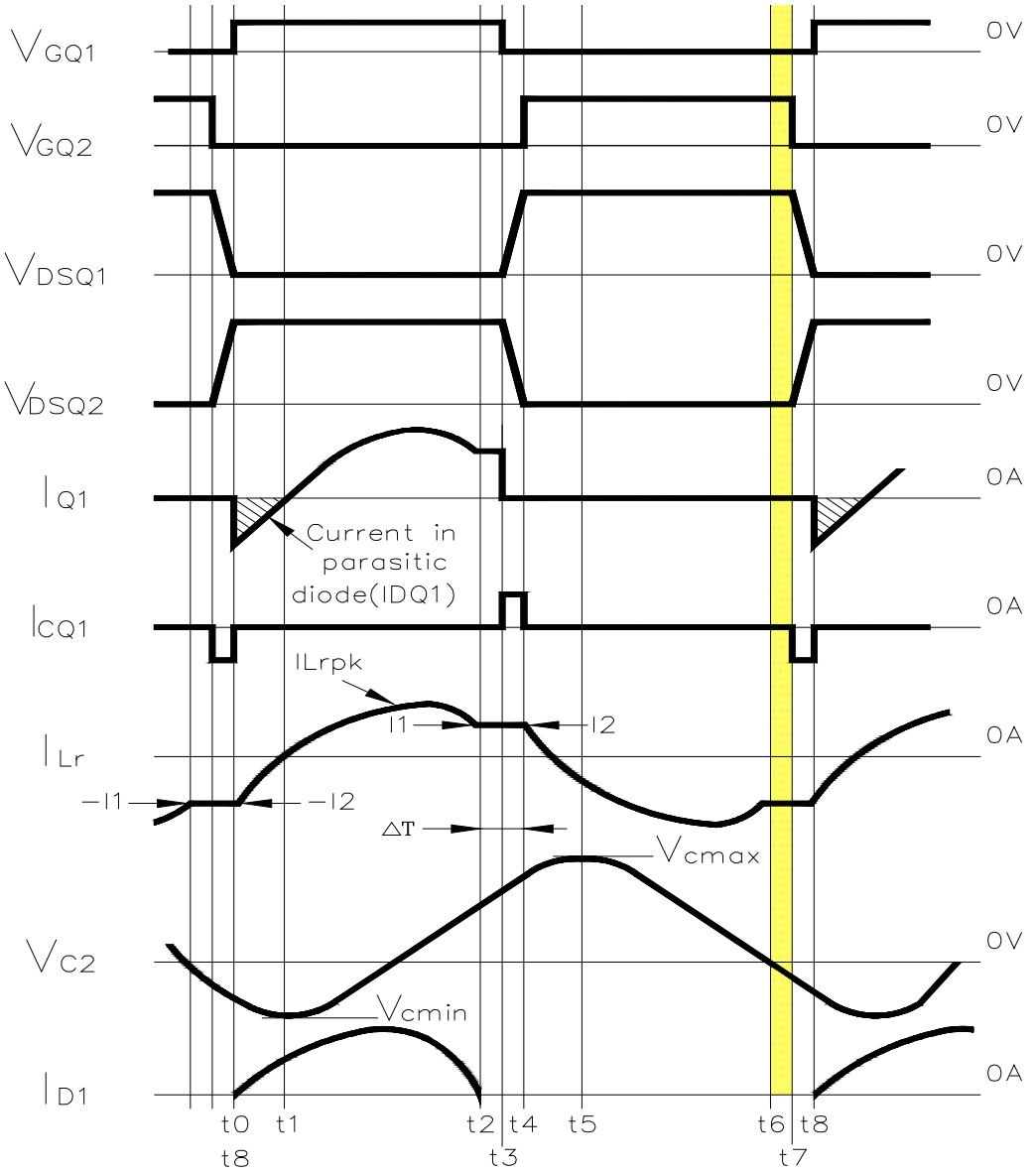
❖ Mode 6 (t5~t6)


VGQ1
VGQ2
VDSQ1
VDSQ2
IQ1
ICQ1
ILr
VC2
ID1
0V
0A
Current in parasitic diode(IDQ1)
ILrpk
I1
I2
-I1
-I2
ΔT
Vcmax
Vcmin
t0
t1
t2
t3
t4
t5
t6
t7
t8
t8

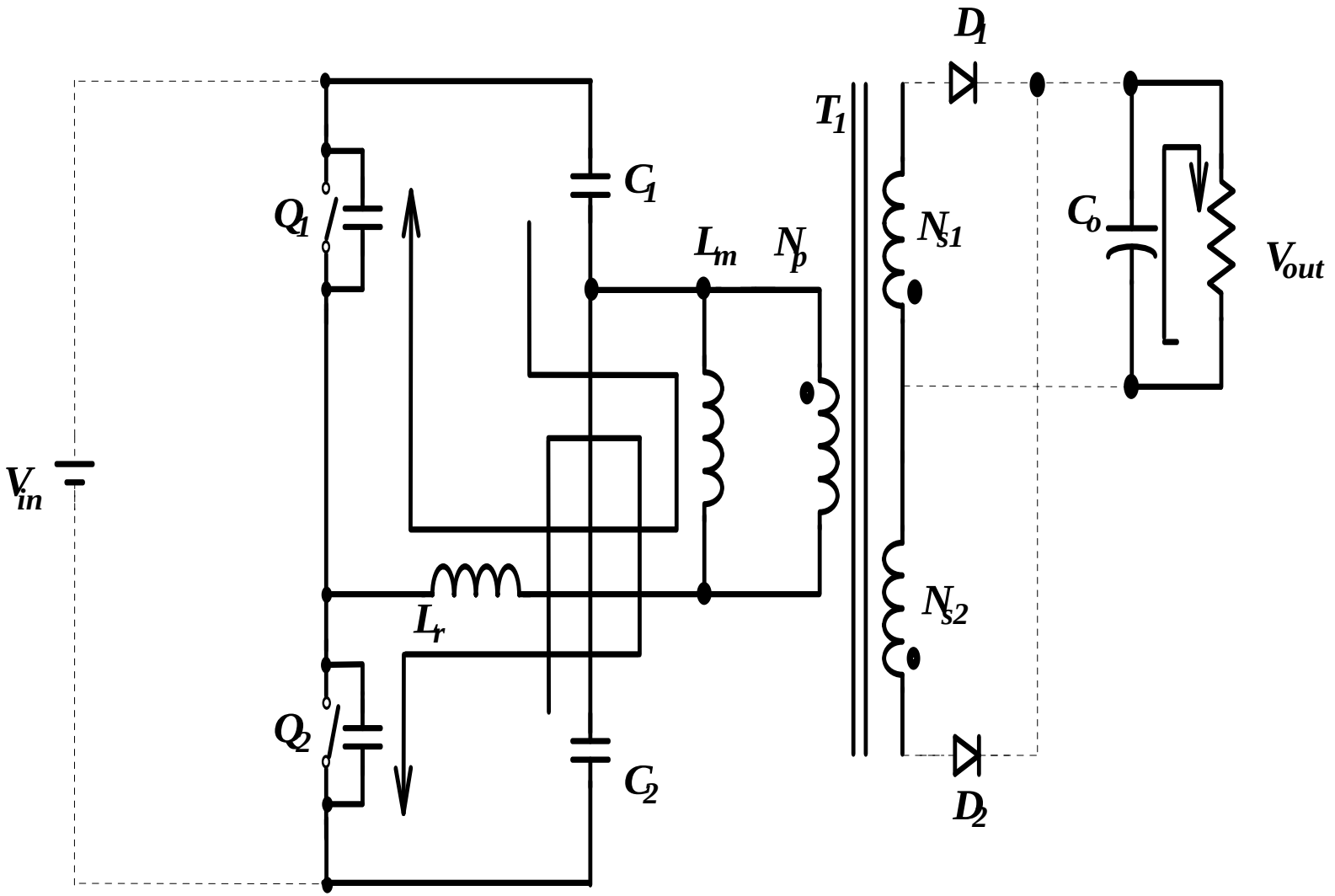
❖ Mode 7 (t6~t7)



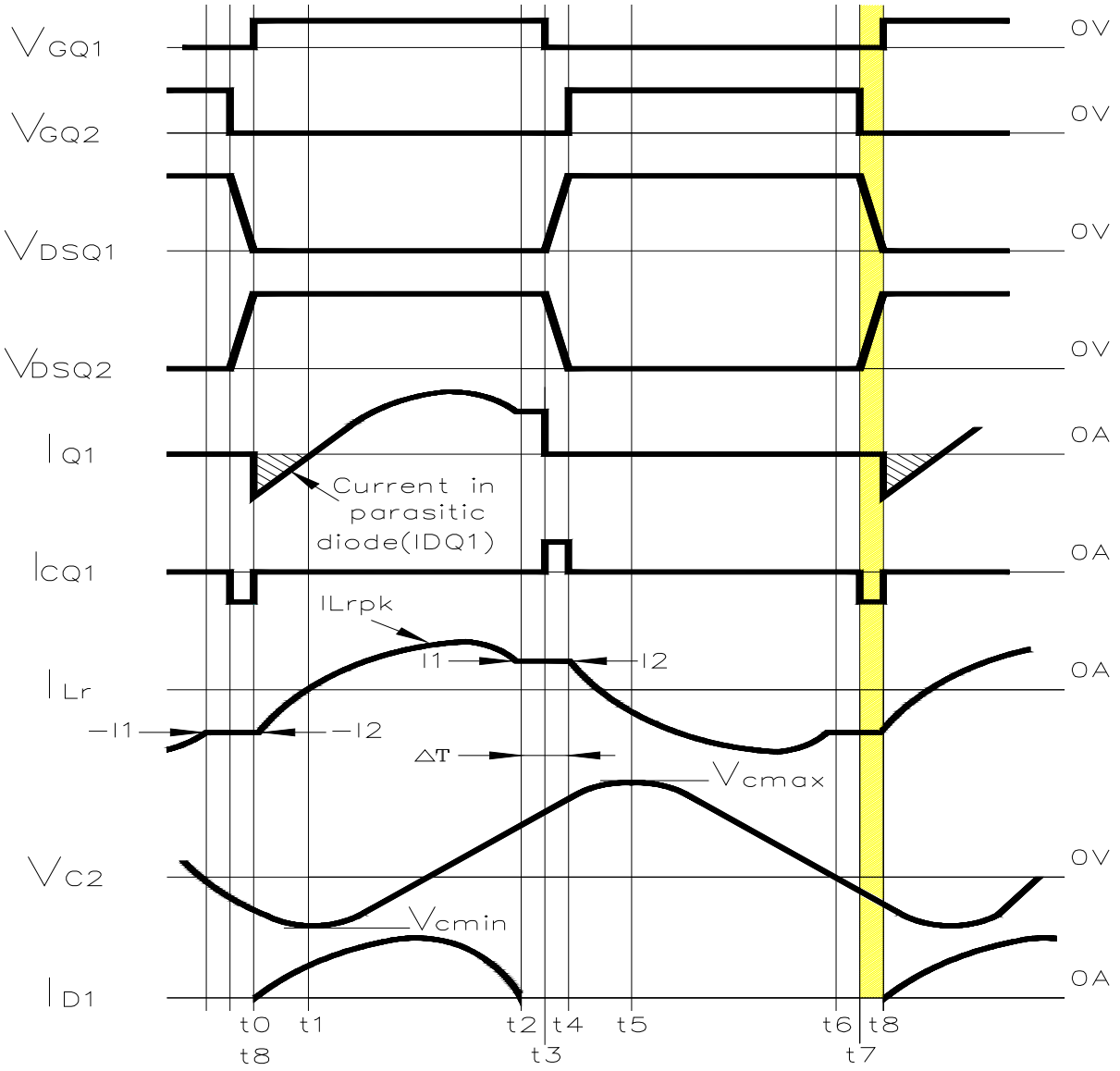
❖ Mode 7 (t6~t7)


VGQ1
VGQ2
VDSQ1
VDSQ2
IQ1
ICQ1
ILr
VC2
ID1
0V
0A
Current in parasitic diode(IDQ1)
ILrpk
I1
I2
-I1
-I2
ΔT
Vcmax
Vcmin
t0
t1
t2
t3
t4
t5
t6
t7
t8

❖ Mode 8 (t7~t8)



❖ Mode 8 (t7~t8)


VGQ1
VGQ2
VDSQ1
VDSQ2
IQ1
ICQ1
ILr
VC2
ID1
0V
0A
Current in parasitic diode(IDQ1)
ILrpk
I1
I2
-I1
-I2
ΔT
Vcmax
Vcmin
t0
t1
t2
t3
t4
t5
t6
t7
t8
t8

VI. Design guidelines and example

- Control Circuitry Design
  - ST L6599 Resonant Controller Featured Description
  - Pin function description
  - L6599 operate frequency
- Design Example and Test Result

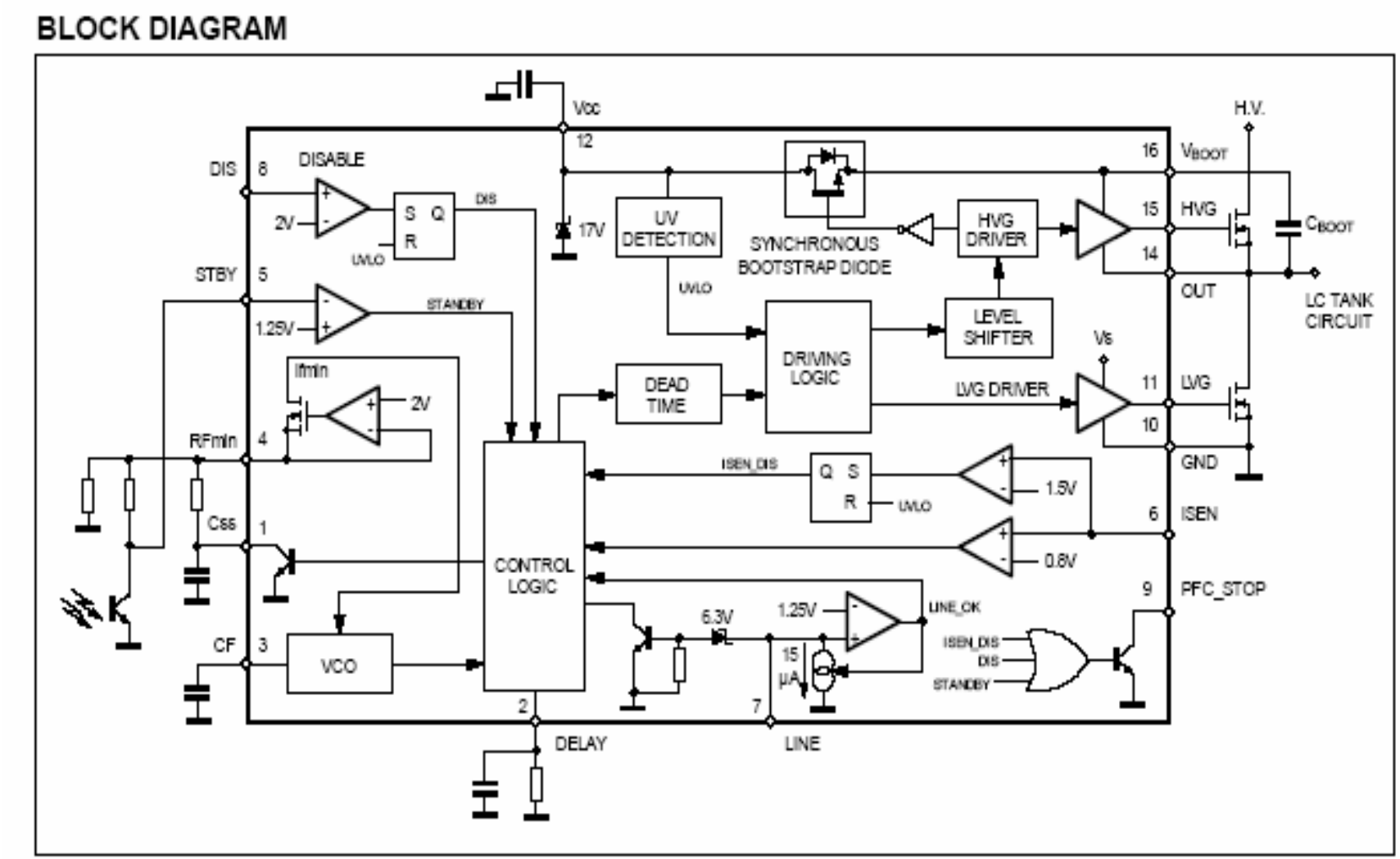
❑ Control Circuitry Design

❖ ST L6599 Resonant Controller Featured Description

MAIN FEATURES

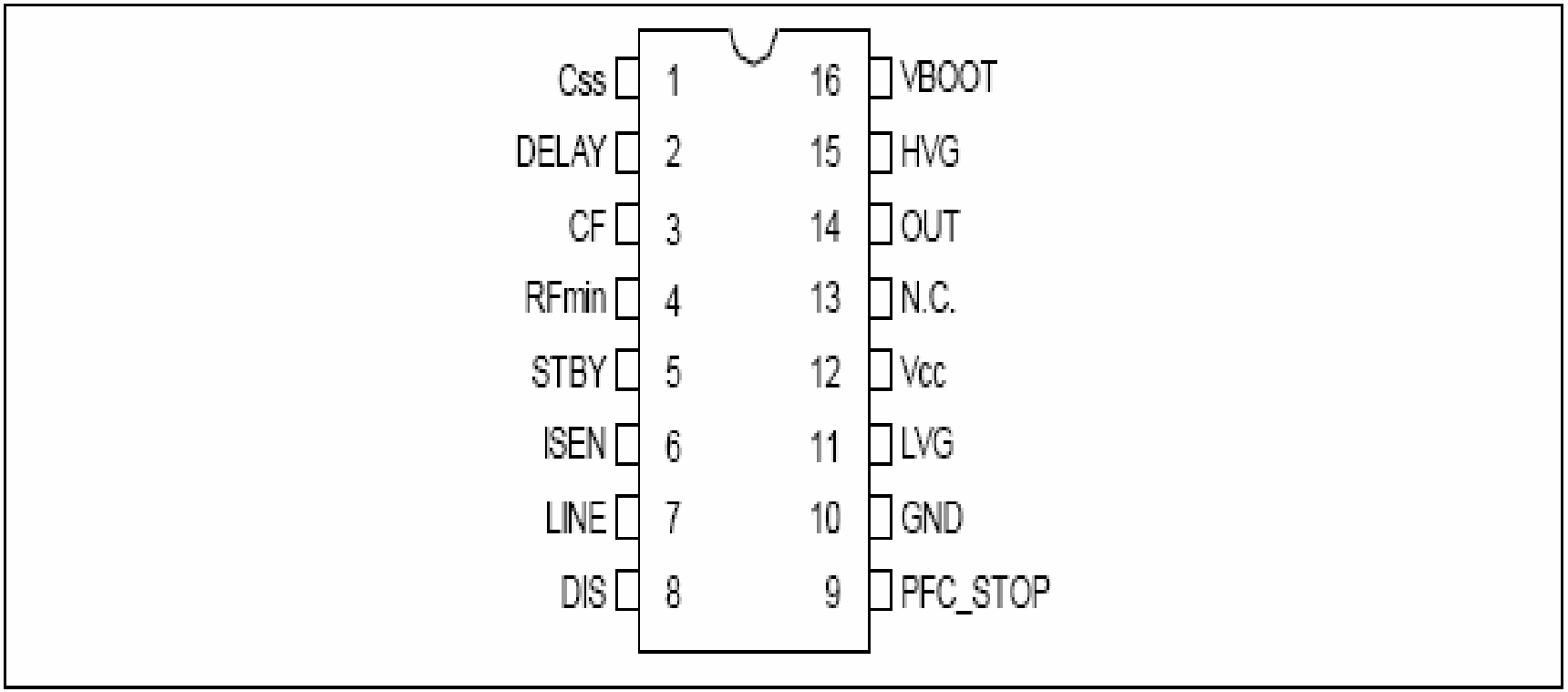
- 50% DUTY CYCLE, VARIABLE FREQUENCY CONTROL OF RESONANT HALF-BRIDGE
- UP TO 500 kHz OPERATING FREQUENCY
- INTERFACE WITH PFC CONTROLLER
- LATCHED DISABLE INPUT
- BURST-MODE OPERATION AT LIGHT LOAD
- INPUT FOR POWER-ON/OFF SEQUENCING
- OR BROWNOUT PROTECTION
- NON-LINEAR SOFT-START FOR MONOTONIC
- OUTPUT VOLTAGE RISE
  600V-RAIL COMPATIBLE HIGH-SIDE GATE
- DRIVER WITH INTEGRATED BOOTSTRAP
- DIODE AND HIGH dV/dt IMMUNITY
  -300/800 mA HIGH-SIDE AND LOW-SIDE

Internal Block Diagram of the L6599



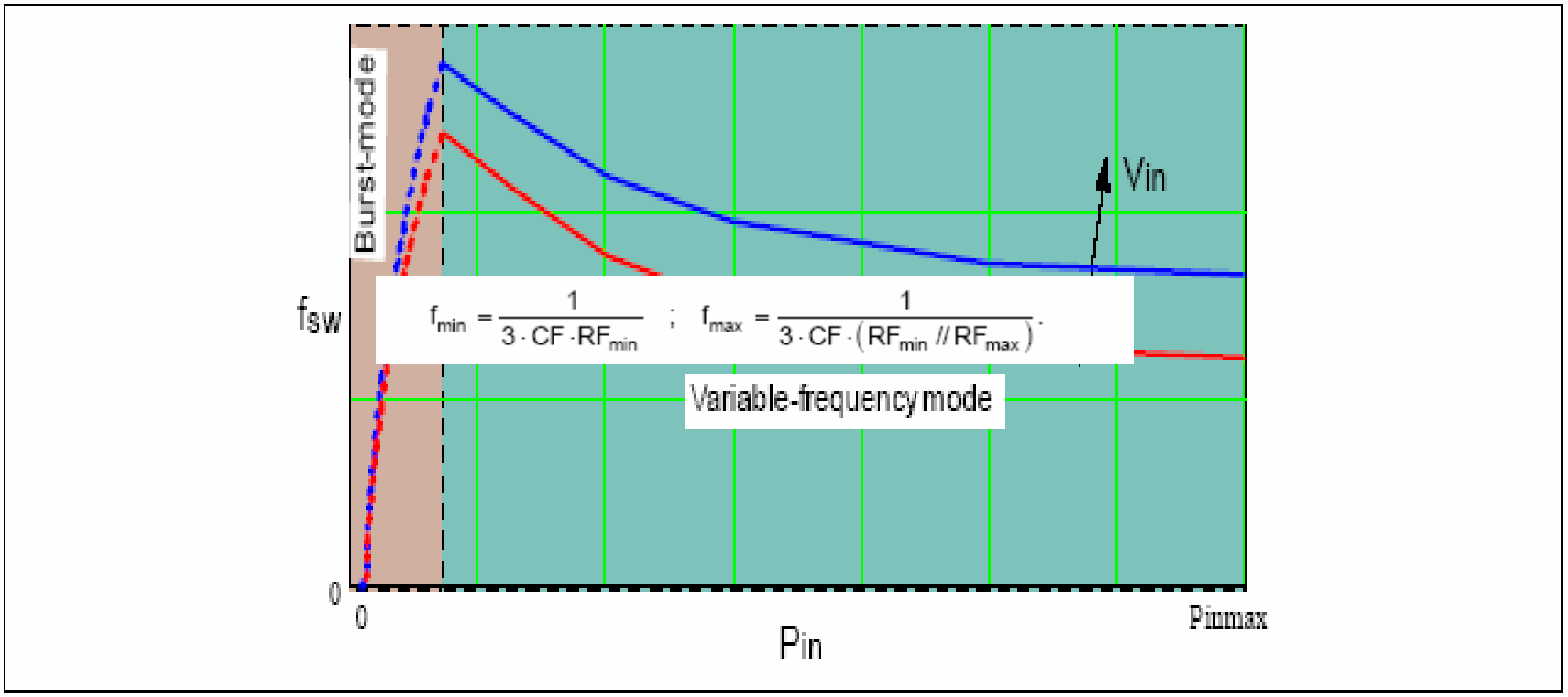
Pins Function of the L6599

PIN CONNECTION (Top view)



L6599 operate Frequency

Figure 1. Multi-mode operation of the L6599



Fmin & Fmax

$$f_{min} = \frac{1}{3 \cdot CF \cdot RF_{min}} \quad ; \quad f_{max} = \frac{1}{3 \cdot CF \cdot \left(RF_{min} \,//\, RF_{max} \right)}.$$

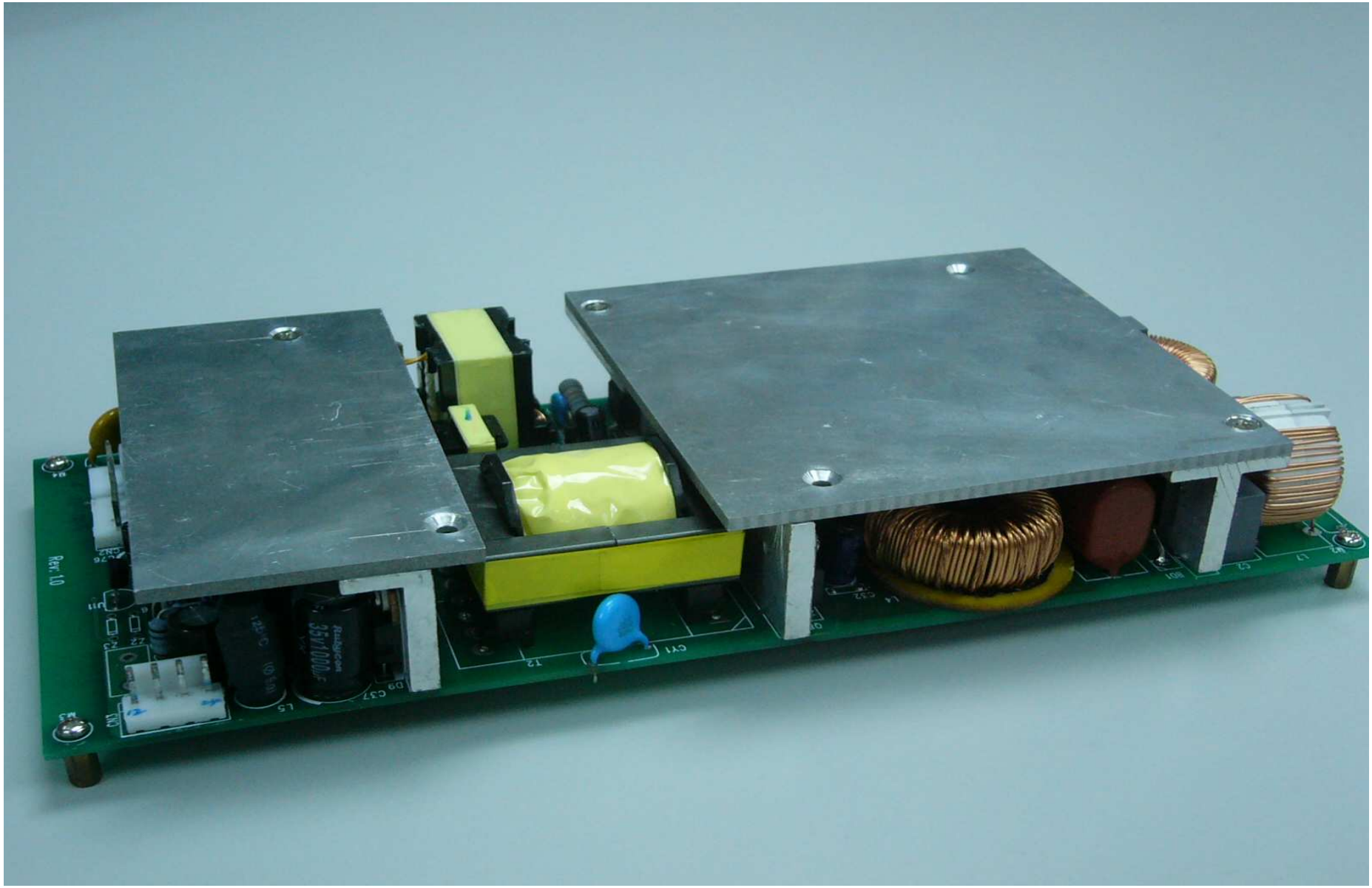
❑ Design Example and Test Result

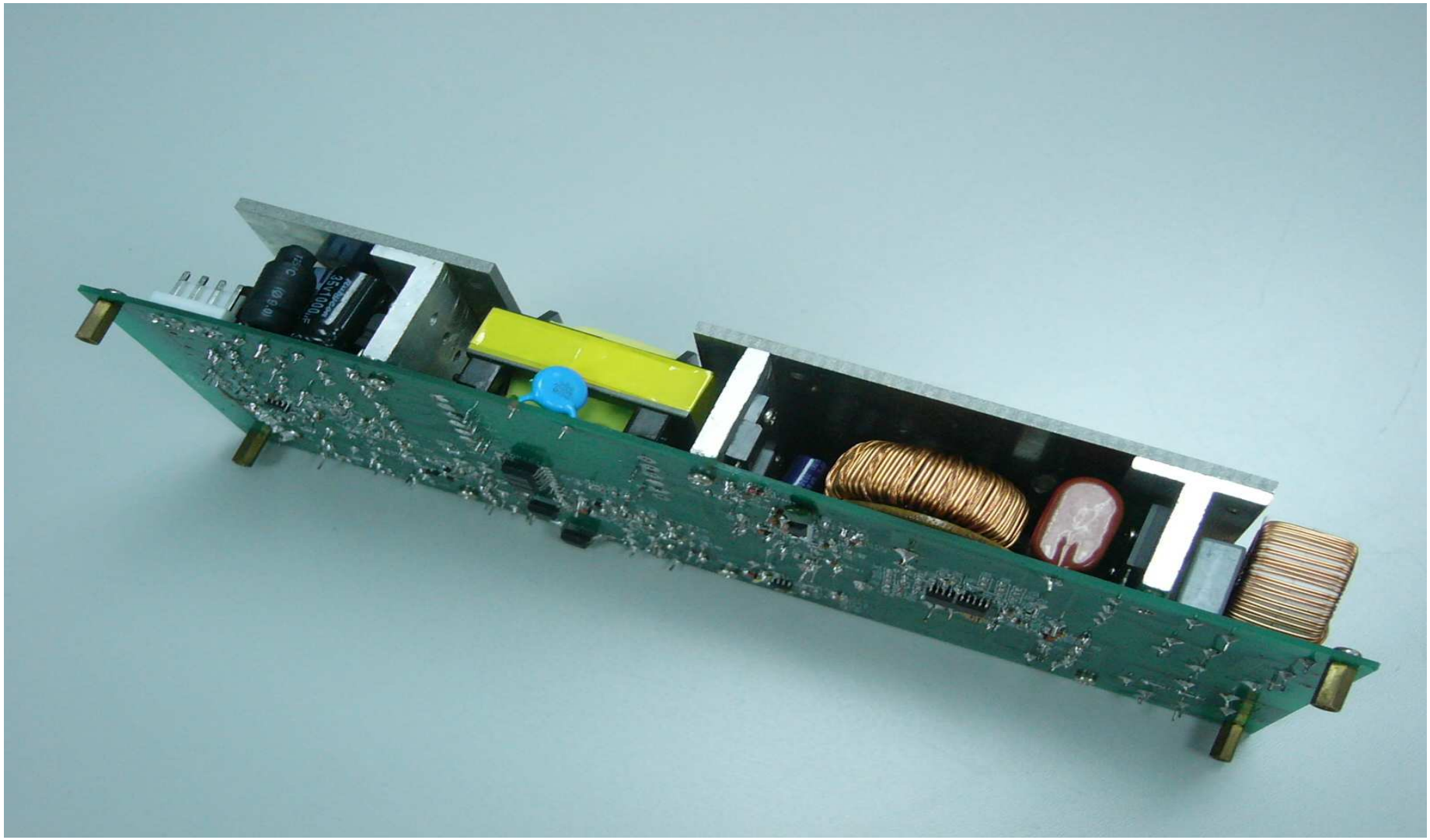
❖ Specification:

Input Voltage: 90VAc~264VAc
Output Voltage: 24V/6A 12V/3A 18V/3A
Resonant Frequency: 75kHz

❖ Resonant Component Rating:

L101: 200uH
C101/C102: 0.022uF/630V
Lm: 1mH
Np: 54T; Ns1:6T; Ns2:3T

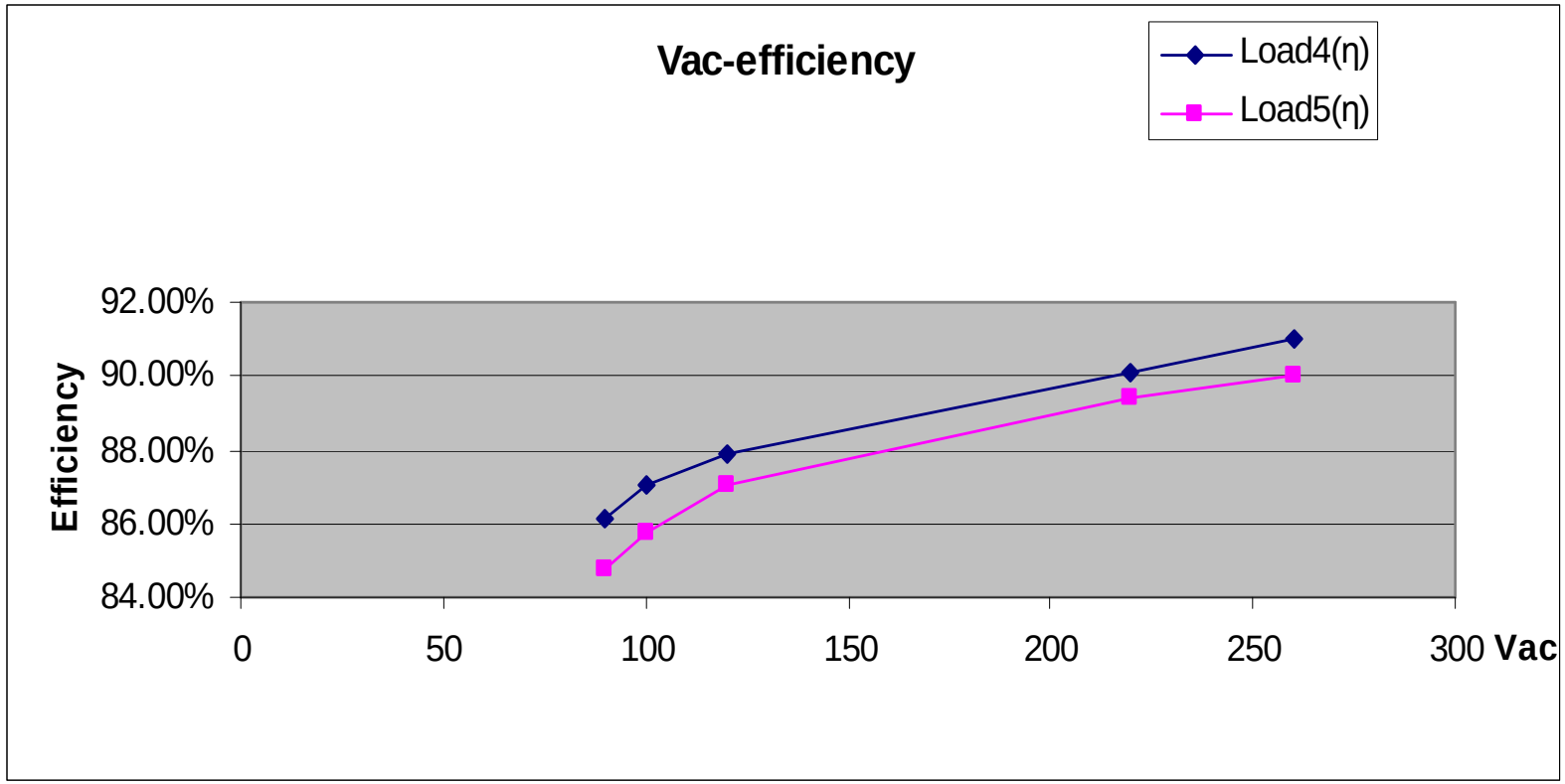

Rev.1.0
35V1000µF
CY1



Load setting

Unit: A				
	+24V	+12V	+5Vs	+18V
Load1	0.2	3	0.05	1
Load2	6	0.2	0.2	1
Load3	3	1.5	0.5	2
Load4	6	3	0.2	0
Load5	6	3	0.2	3

Efficiency


Vac-efficiency
Load4(η)
Load5(η)
Efficiency
92.00%
90.00%
88.00%
86.00%
84.00%
0
50
100
150
200
250
300
Vac

Regulation1

Vin=90Vac							Unit:V
	+24V	+12V	+5Vs	+18V	Pin	Pout	Efficiency
Load1	24.43	11.60	4.95	18.24	72.20	58.17	80.57%
Load2	23.73	12.25	4.95	18.22	192.50	164.04	85.22%
Load3	24.05	11.93	4.95	18.22	152.10	128.96	84.79%
Load4	24.08	11.91	4.96	18.25	210.30	181.20	86.16%
Load5	24.06	11.91	4.96	18.24	278.20	235.80	84.76%

Regulation2

Vin=100Vac							Unit:V
	+24V	+12V	+5Vs	+18V	Pin	Pout	Efficiency
Load1	24.43	11.60	4.95	18.24	72.00	58.17	80.80%
Load2	23.73	12.25	4.95	18.22	191.10	164.04	85.84%
Load3	24.05	11.93	4.95	18.22	151.20	128.96	85.29%
Load4	24.08	11.91	4.95	18.24	208.20	181.20	87.03%
Load5	24.06	11.91	4.96	18.25	275.00	235.83	85.76%

Regulation3

Vin=220VAC							
	+24V	+12V	+5Vs	+18V	Pin	Pout	Efficiency
Load1	24.43	11.60	4.95	18.23	69.50	58.16	83.69%
Load2	23.73	12.25	4.95	18.22	184.40	164.04	88.96%
Load3	24.05	11.93	4.95	18.22	146.60	128.96	87.97%
Load4	24.08	11.91	4.96	18.23	201.10	181.20	90.11%
Load5	24.06	11.91	4.95	18.22	263.60	235.74	89.43%

Regulation4

Vin=260VAC							
	+24V	+12V	+5Vs	+18V	Pin	Pout	Efficiency
Load1	24.43	11.60	4.95	18.24	69.40	58.17	83.82%
Load2	23.73	12.24	4.95	18.22	183.50	164.04	89.39%
Load3	24.05	11.60	4.95	18.22	145.60	128.47	88.23%
Load4	24.08	11.92	4.95	18.24	199.20	181.23	90.98%
Load5	24.06	11.91	4.95	18.22	261.80	235.74	90.05%


Q&A