# PSpice Applications for Power Electronics

이 상 우

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㈜오닉스 테크놀로지스

# Magnetic Core Modeling

- The parameters in the model library(magnetics.lib) were derived from the data sheets for each core.

The Jiles-Atherton magnetics model is described in:

Theory of Ferromagnetic Hysteresis, by D C Jiles and D L Atherton,

Journal of Magnetism and Magnetic Materials, vol 61 (1986) pp 48-60

- Model parameters for ferrite material (Philips 3C8) were obtained by trial simulations, using the B-H curves from the manufacturer's catalog.

  Then, the library was compiled from the data sheets for each core geometry.

  Notice that only the geometric values change once a material is characterized.

# Magnetic Core Modeling

- Notes:

  1) Using a K device (formerly only for mutual coupling) with a model reference changes the meaning of the L device: the inductance value becomes the number of turns for the winding.

  2) K devices can "get away" with specifying only one inductor, as in the example above, to simulate power inductors.

- Demonstration of power inductor B-H curve To view results with Probe (B-H curve):

  1) Add Trace for B(K1)

  2) set X-axis variable to H(K1)

  Probe x-axis unit is Oersted

  Probe y-axis unit is Gauss

# Magnetic Core Modeling

| Name | Meaning | Unit | Default |
|---|---|---|---|
| AREA | Mean magnetic cross section | $cm^2$ | 0.1 |
| PATH | Mean magnetic path length | cm | 1.0 |
| GAP | Effective air-gap length | cm | 0 |
| PACK | Pack(stacking) | | 1.0 |
| MS | Magnetic saturation | A/m | 1E+6 |
| ALPHA | Mean field parameter | | 1E-3 |
| A | Shape parameter | | 1E+3 |
| C | Domain wall-flexing constant | | 0.2 |
| K | Domain wall-pinning constant | | 500 |

## Method I

1. K=0 : Anhysteric Curve Setup
2. $B_{max}$ 결정 : $B_{max}$=MS*0.01257
3. A조정 : Get a Curve
4. K조정 : Create Hysteresis
5. C결정 : Initial Permeability

## Method II

1. MS ; $B_{max}$/0.01257
2. 100A/m=1.25 oersted
3. MS, A, C, K ← B-H Loop에서 추출
4. Core Size에 따라 Area와 Path결정

# Magnetic Core Modeling

```
* 3C81_LSW CORE model
* updated using Model Editor release 9.2.2 on 11/15/01 at 11:16
* The Model Editor is a PSpice product.
.MODEL 3C81_LSW CORE
+ GAP=0
+ MS=384.61E3
+ A=27.747
+ C=.2418
+ K=18.396
+ AREA=2.7900
+ PATH=14.400
*$
```

- Ferroxcube 3C81 Core: www.Ferroxcube.com

# Magnetic Core Modeling

## Example(Ferroxcube사 참조)

**3C81**

| H(Oersted) | B(Gauss) |
|---|---|
| 0 | 1100 |
| 0.176 | 0 |
| 3.125 | 4250 |
| 0.625 | 2560 |
| 0.625 | 3400 |

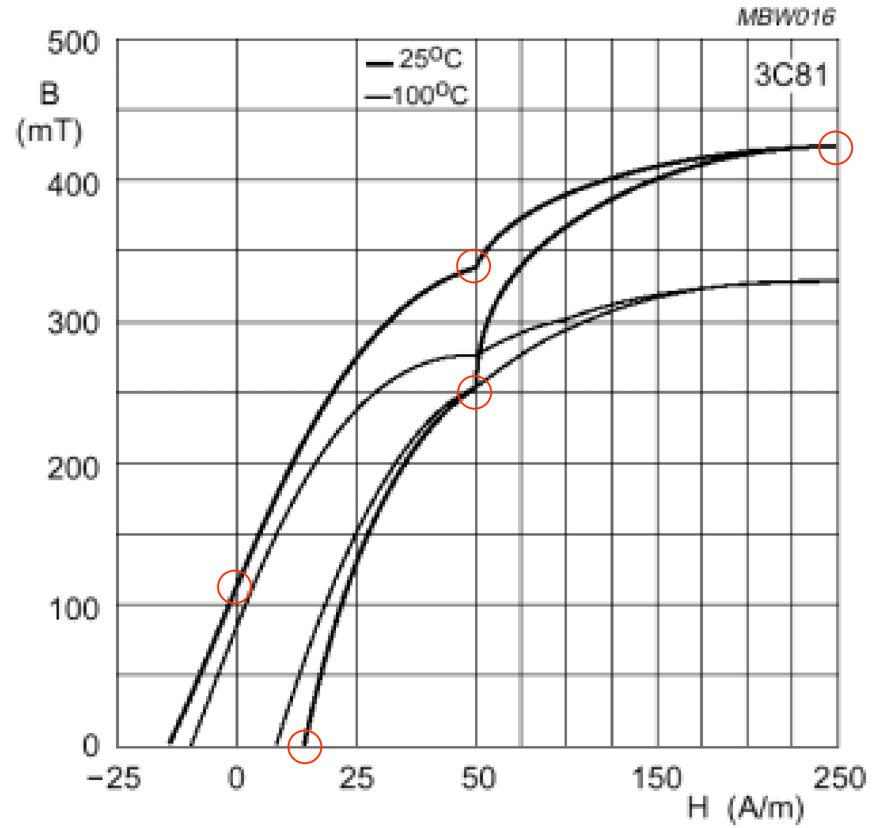



**FIG. 1.**

# Magnetic Core Modeling

## Example(Ferroxcube사 참조)

| H(Oersted) | B(Gauss) |
|---|---|
| 0 | 1100 |
| 0.176 | 0 |
| 3.125 | 4250 |
| 0.625 | 2560 |
| 0.625 | 3400 |

| Active Parameters<br>Initial Perm : 2700 | |
|---|---|
| **Name** | **Value** |
| MS | 384610 |
| A | 27.747 |
| C | 0.2418 |
| K | 18.396 |

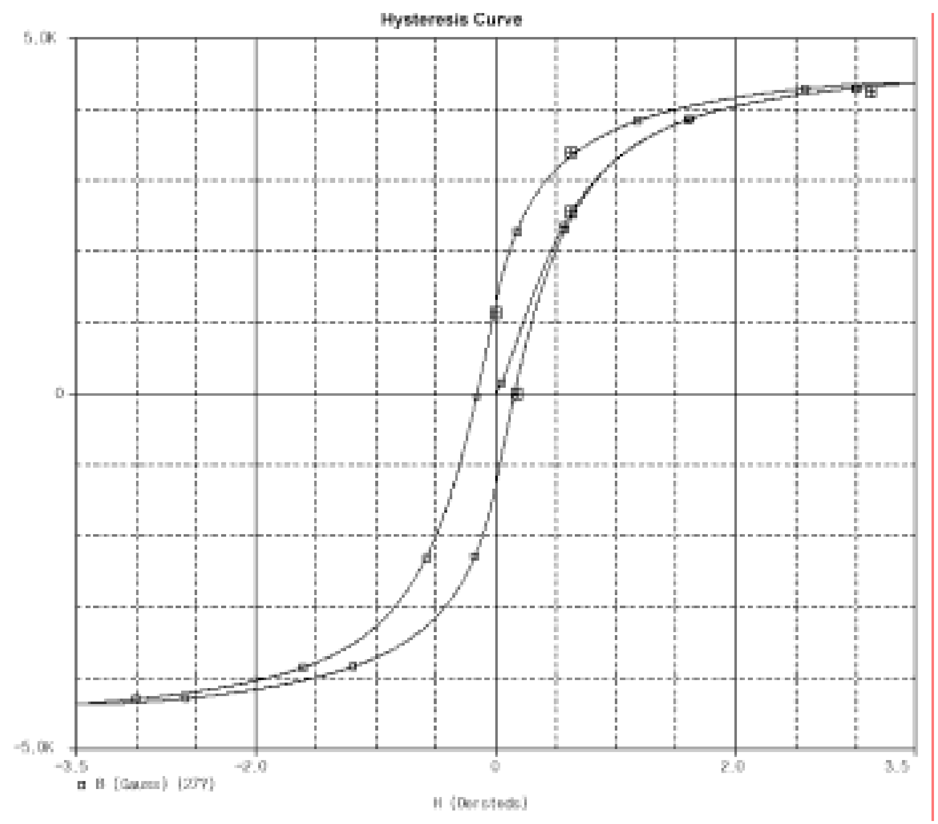



**FIG. 2.**

# Magnetic Core Modeling

## B-H Curve

1. 3C81_LSW
2. EC70_3C81

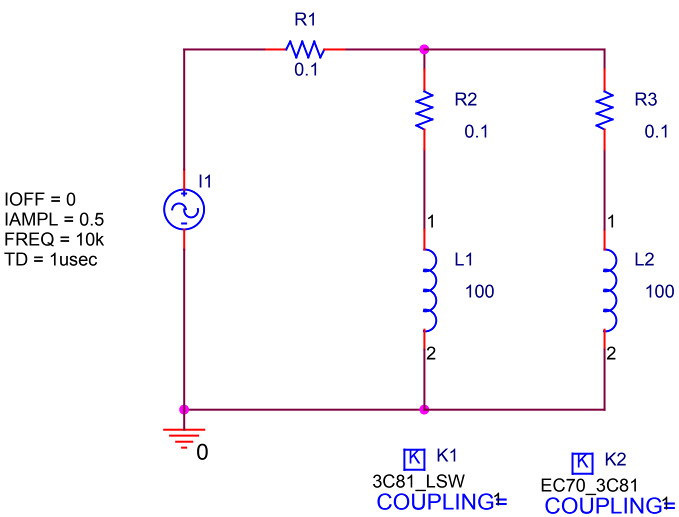



FIG. 3

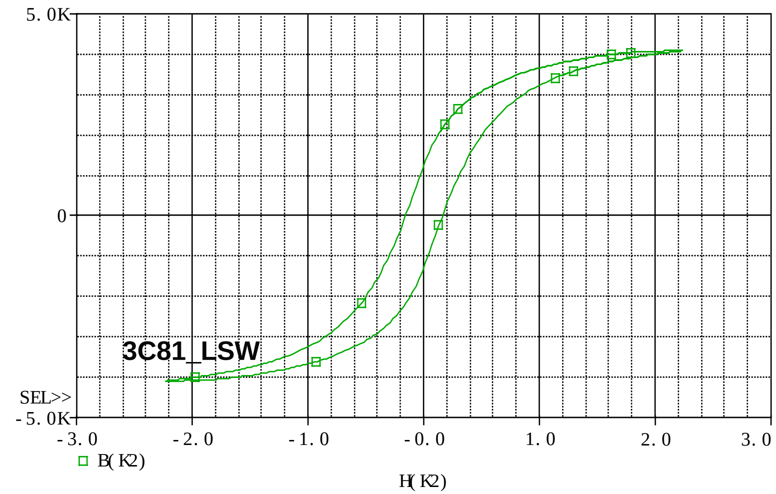



FIG. 4

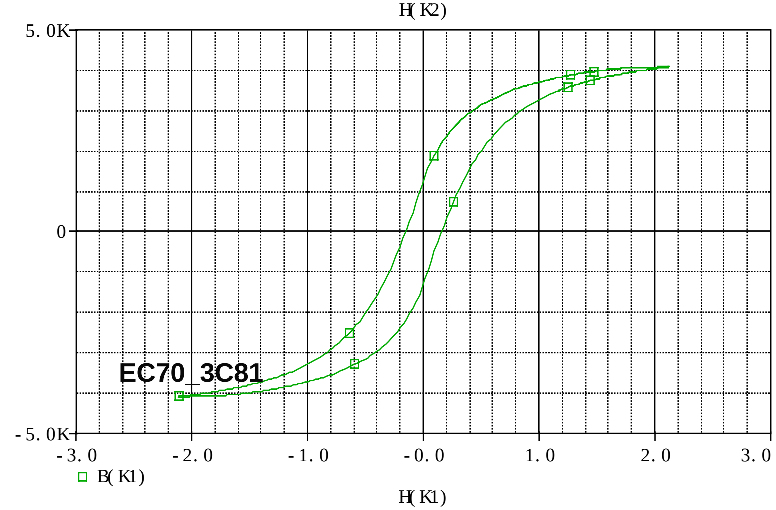



FIG. 5

# Magnetic Core Modeling

## ■ 전류와 턴수에 따른 B-H Curve

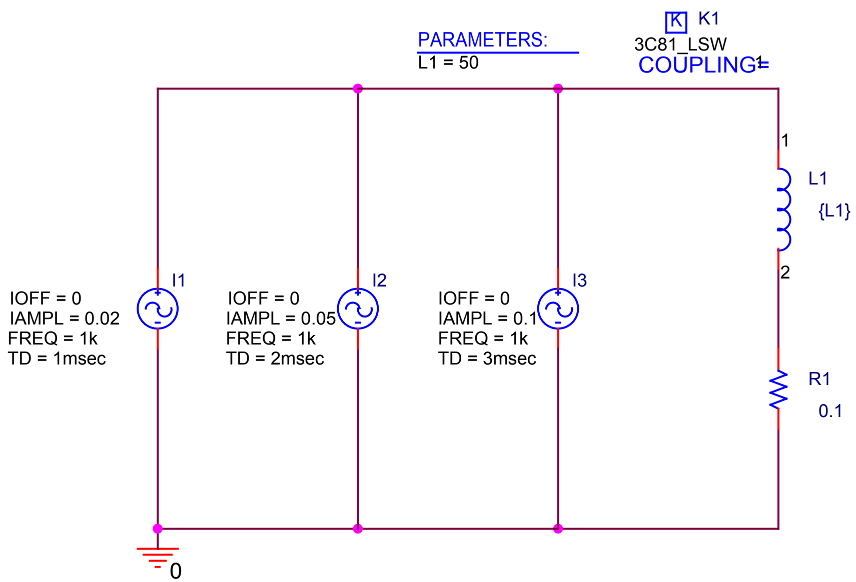



**FIG. 6**

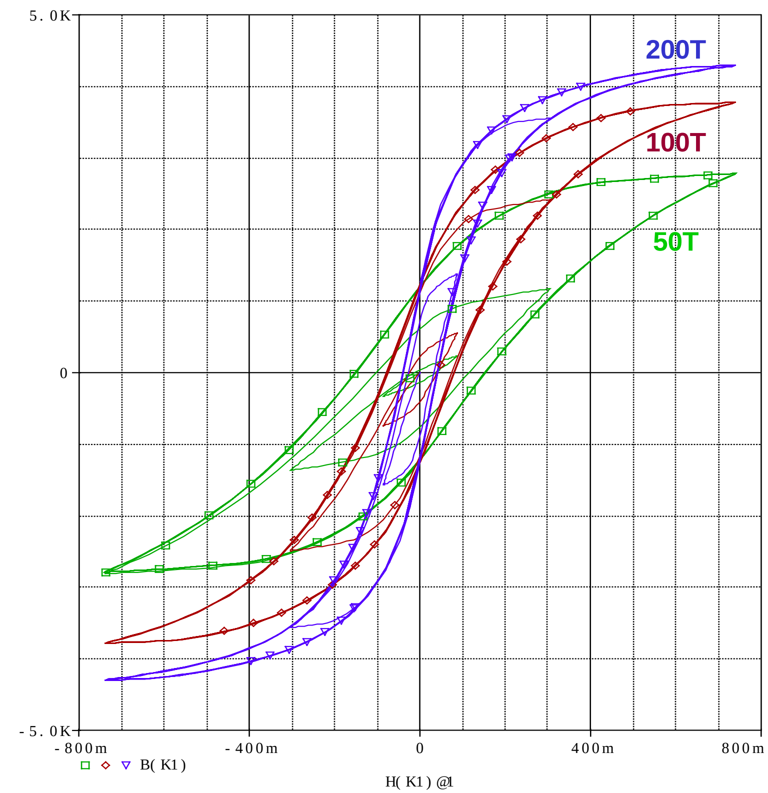



**FIG. 7.**

# Modeling of Transformer

**Equivalent Circuit : ABM 이용**

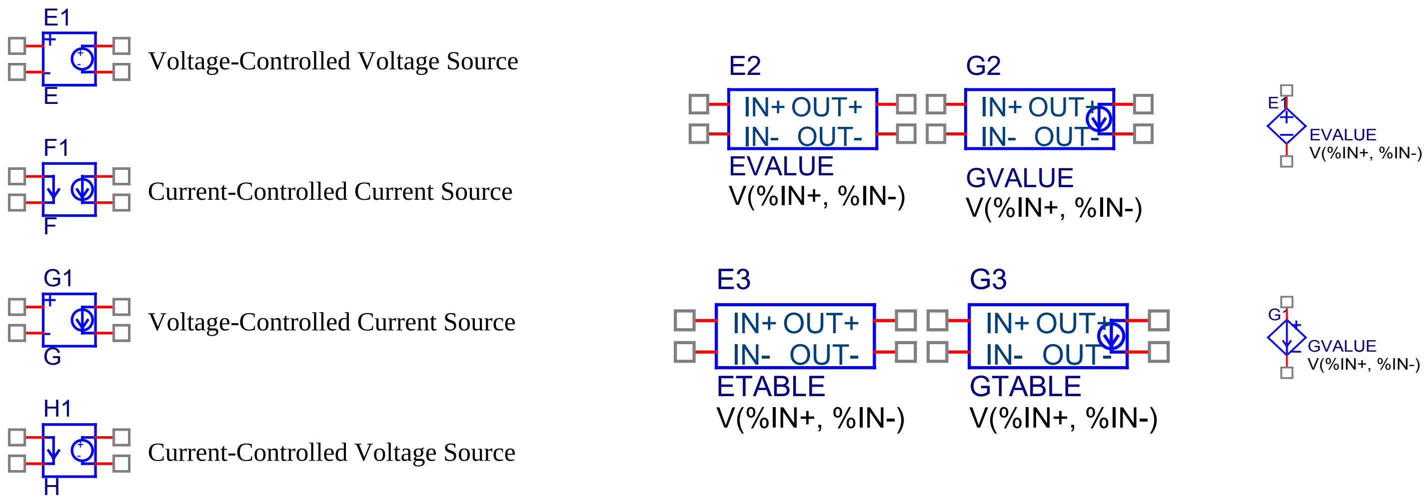
1. **K_Linear 사용**
2. **PSpice Template Properties수정**

# What's ABM(Analog Behavioral Modeling)?

Behavioral Modeling is the process of developing a model for a device or system component from the viewpoint of externally observed behavior rather than from a microscopic description

Two important application of Behavioral Modeling in the domain of analog simulation are : modeling new device types : and block-box modeling of complex systems.

Applications ➔ Averaged-PWM Switch, Transformer, PWM IC



# Transformer Equivalent Circuit

이상적인 트랜스포머와 기생성분 고려

1. 이상적인 트랜스포머 : ABM으로 구성
2. 기생성분 : R, L 및 C로 구성

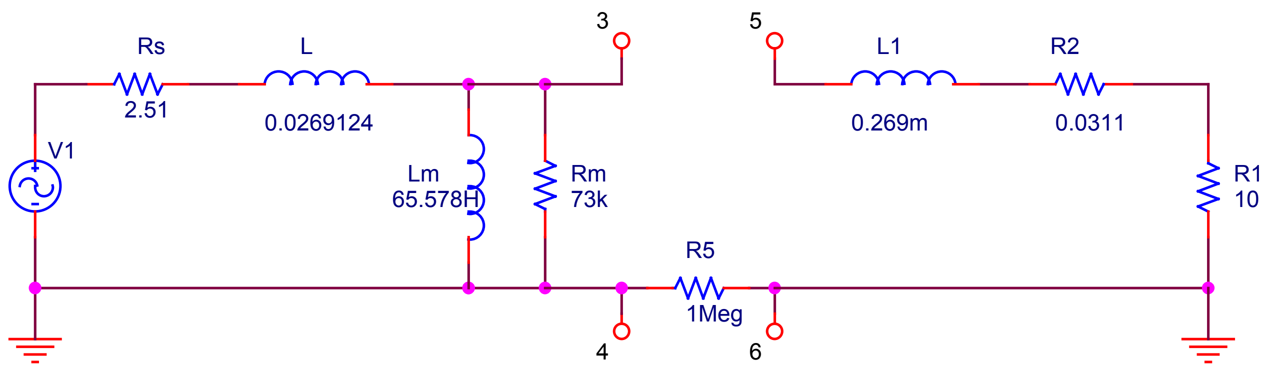



FIG. 8

**Ideal Transformer**

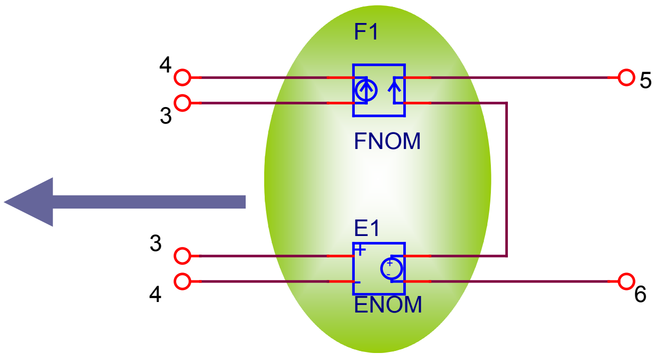



FIG. 9

# K_Linear 이용

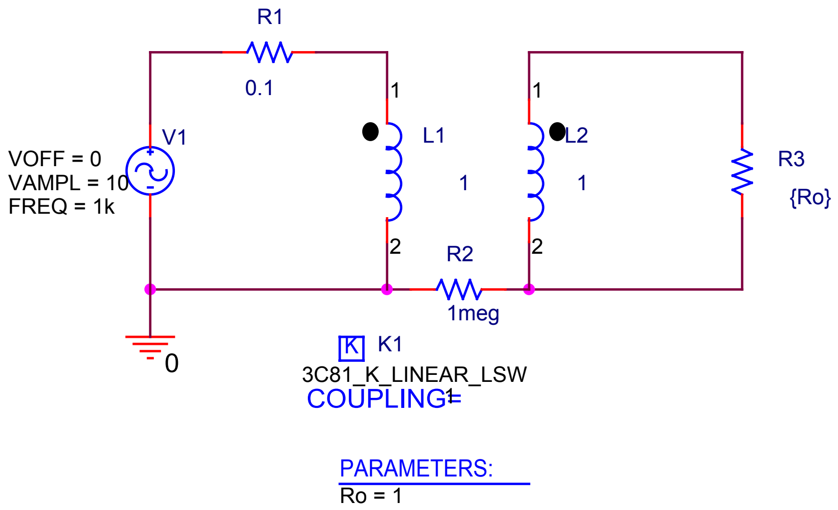



**FIG. 10**

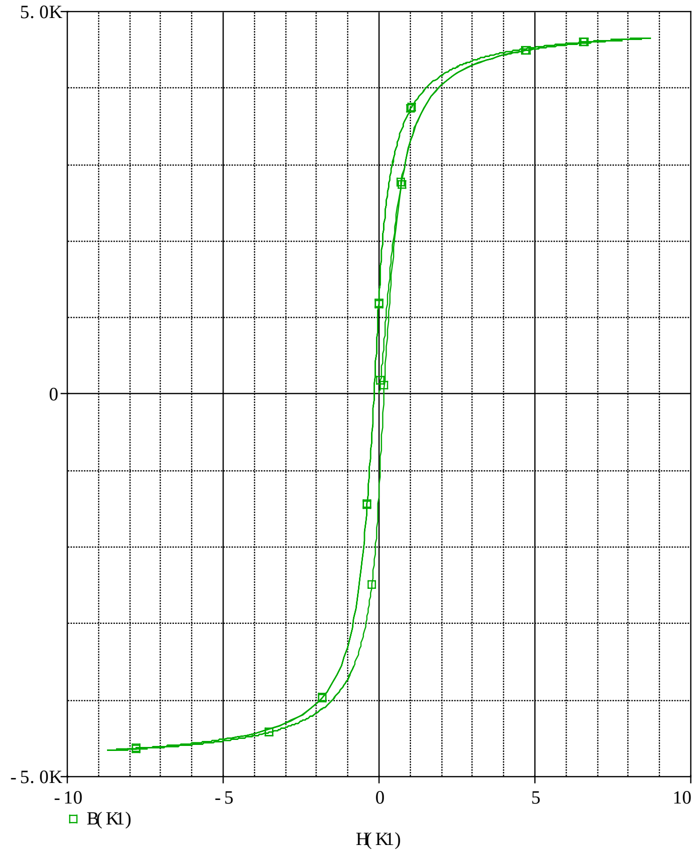
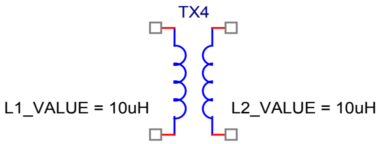



**FIG. 11**

# XFRM_LINEAR or XFRM_NONLINEAR Editing
## ➔ Transformer의 Template Properties 수정

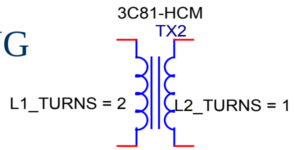
**XFRM_LINEAR**

K^@REFDES L1^@REFDES L2^@REFDES @COUPLING\nL1^@REFDES %1 %2 @L1_VALUE\nL2^@REFDES %3 %4 @L2_VALUE

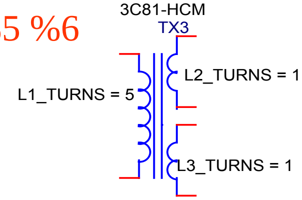



**XFRM_NONLINEAR**

K^@REFDES L1^@REFDES L2^@REFDES @COUPLING @MODEL\nL1^@REFDES %1 %2 @L1_TURNS \nL2^@REFDES %3 %4 @L2_TURNS




K^@REFDES L1^@REFDES L2^@REFDES L3^@REFDES @COUPLING @MODEL\nL1^@REFDES %1 %2 @L1_TURNS \nL2^@REFDES %3 %4 @L2_TURNS \nL3^@REFDES %5 %6 @L3_TURNS



# Waveforms with Nonlinear Transformer

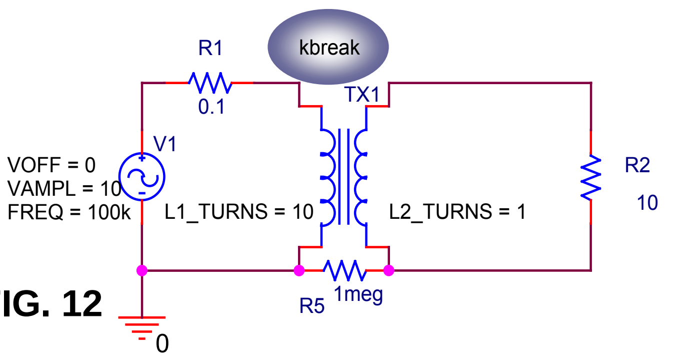



**FIG. 12**

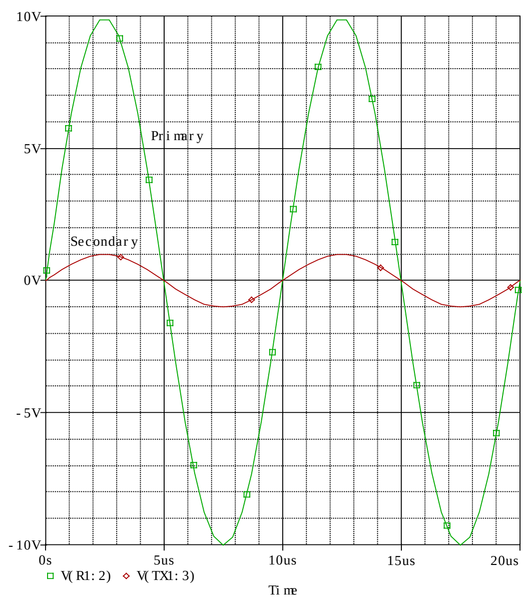



**FIG. 13**

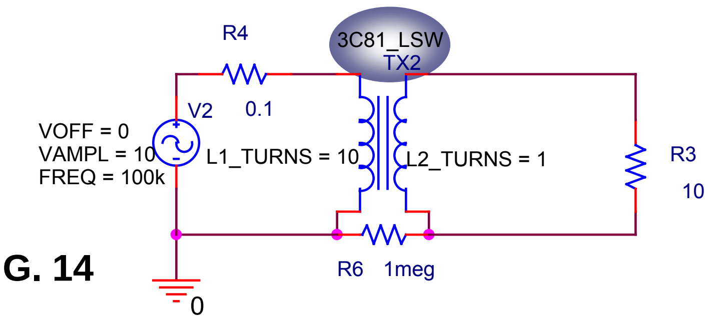



**FIG. 14**

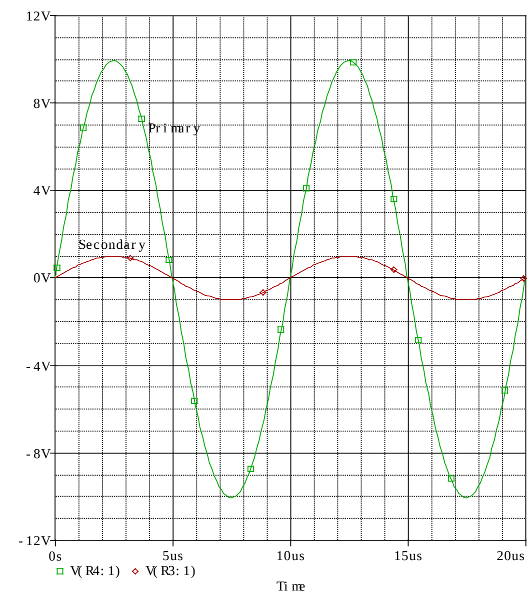



**FIG. 15**

# XFRM_Nonlinear 소자에서 Template 변경

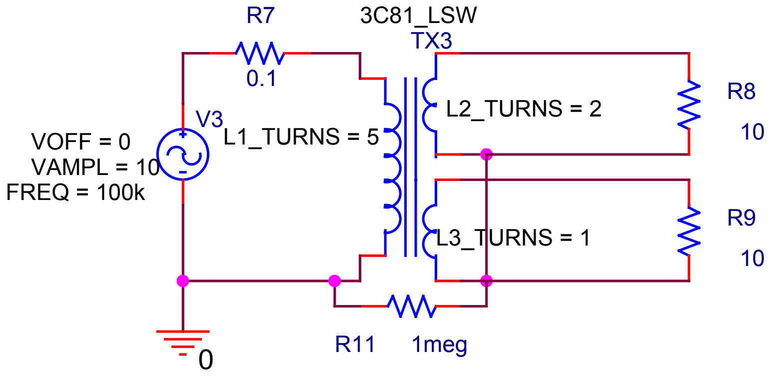



**FIG. 16**

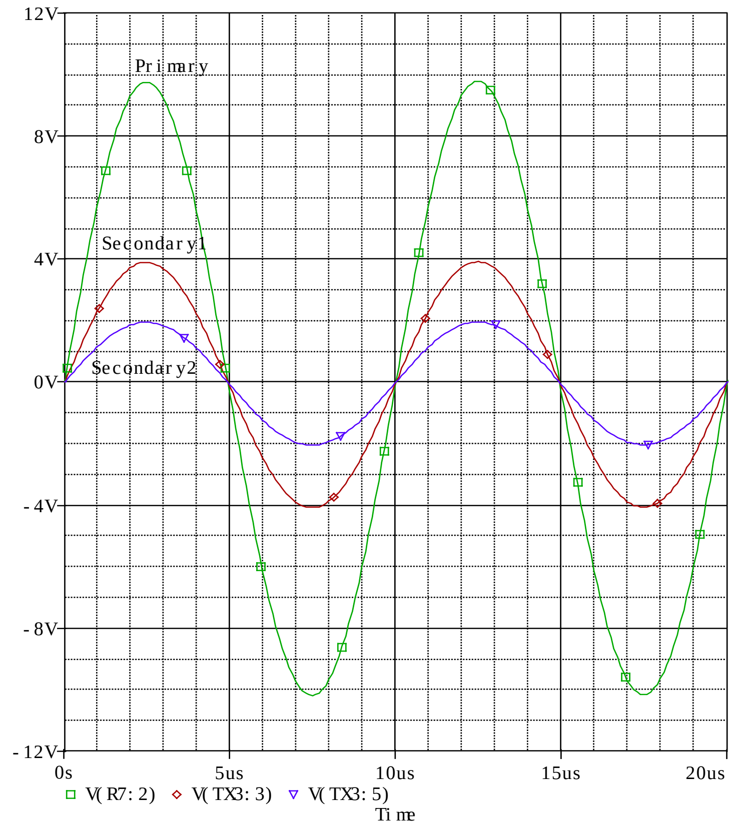



**FIG. 17**

# Switching Mode Power Supply 의 분류

## 절연형과 비절연형에 의한 분류

- Isolation Type
  - Flyback
  - Forward
  - Half Bridge
  - Full Bridge
  - Push Pull
- Non-Isolation Type
  - Buck (Step Down)
  - Boost (Step Up)
  - Buck-Boost

# Switching Mode Power Supply 의 분류

## 에너지 축적 Type에 의한 분류

- Inductor 축적형
    - Buck (Step Down)
    - Boost (Step Up)
    - Buck-Boost
    - Flyback
    - Forward
    - Half Bridge
    - Full Bridge
    - Push Pull

- Capacitor 축적형
    - Cuk
    - Sepic
    - Zeta

# Buck Converter

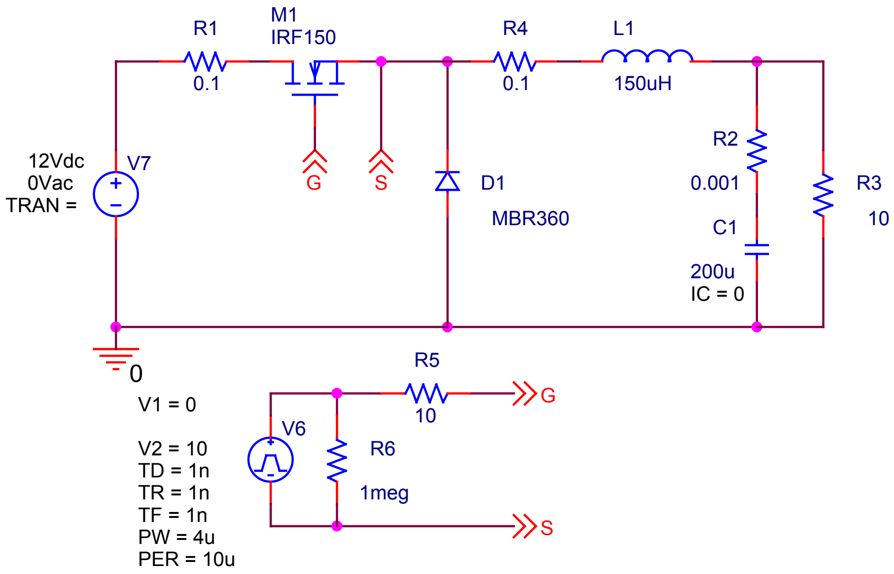



FIG. 18

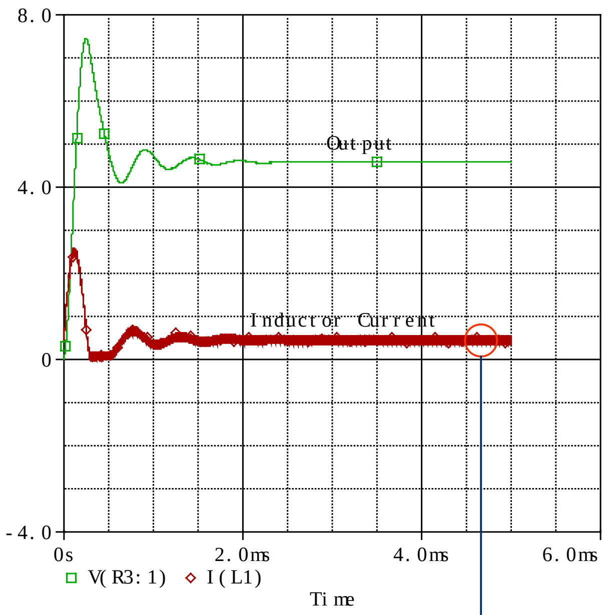



FIG. 19

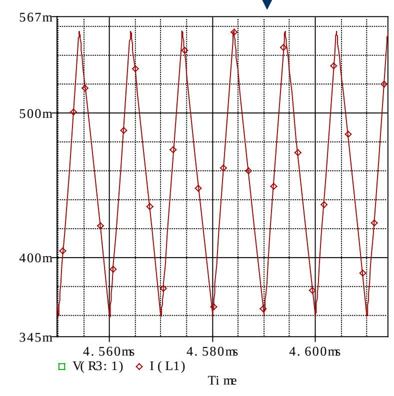



FIG. 20

# Design of Buck Converter

Input Voltage : 12V
Output Voltage : 4.8V
Output Current : 0.1 ~ 3A
Frequency : 100kHz

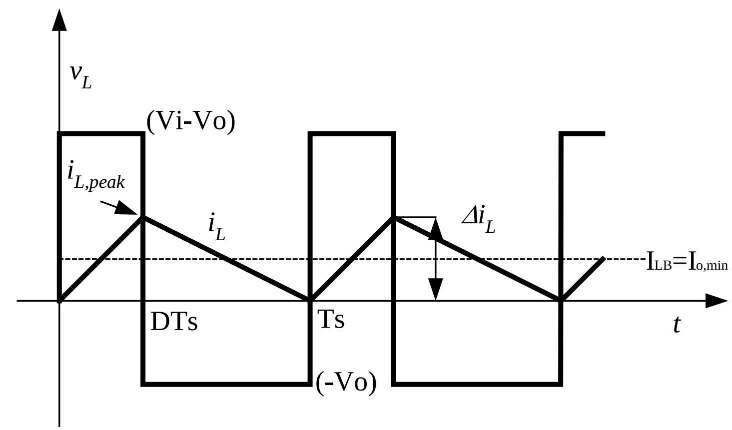



**FIG. 21**

## 입출력 관계식

$$v_L = L\frac{di}{dt} \qquad (1)$$

$$(V_i - V_o)DT_S = V_o(1-D)T_S \qquad (2)$$

$$V_o = DV_{in} \qquad (3)$$

==> $D = 0.4$

## 인덕터 값 설정

$$\Delta i_L = \frac{V_{in}-V_o}{L}T_{on} = \frac{V_{in}-V_o}{L}DT_S \qquad (4)$$

$$I_{LB} = \frac{1}{2}\Delta i_L = \frac{DT_S}{2L}(V_i - V_o) = I_{o,\min} \qquad (5)$$

$$L = \frac{V_o(1-D)T_S}{2I_{o,\min}} \qquad (6)$$

## 커패시터 값 설정

$$\Delta v_o = \frac{1}{C}\int i_c dt + i_c R_c \cong i_c R_c = \Delta i_L R_c \qquad (7)$$

$$\frac{\Delta v_o}{V_o} = \frac{T_S^2(1-D)}{8LC} \qquad (8)$$

$$C = \frac{T_S^2(1-D)}{8L} \bullet \frac{V_o}{\Delta v_o} \qquad (9)$$

# Simulation Waveforms

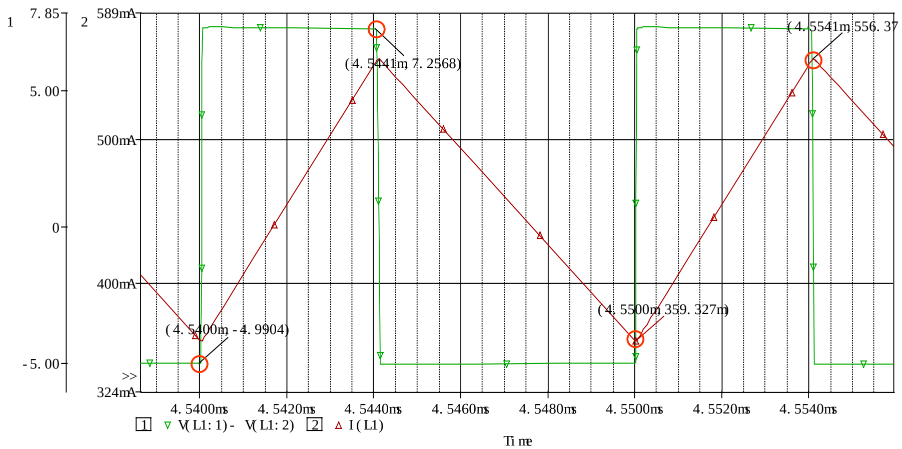



**FIG. 22**

On time : 4.551ms-4.54ms=4.1us
Off time : 10us-4.1us=5.9us
$\Delta i_L$ : 556.3mA-359.2mA=197.1mA
(Vi-Vo) : 7.26
(-Vo) : 4.99

Inductor Voltage(1)
Inductor Current(2)

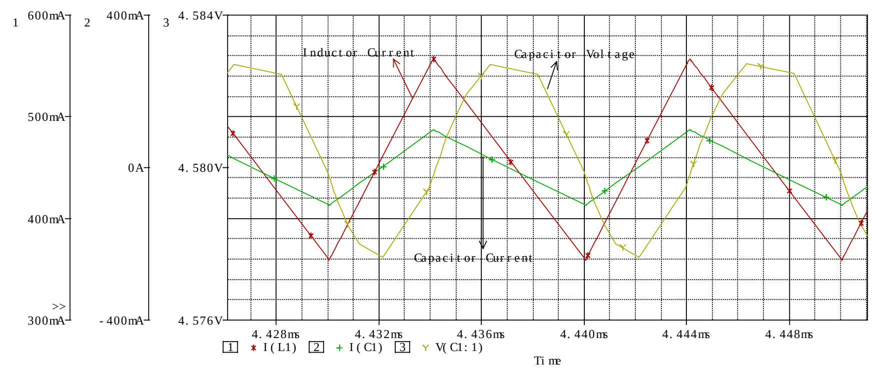



**FIG. 23**

Inductor Current(1)
Capacitor Current(2)
Capacitor Voltage(3)

# Boost Converter

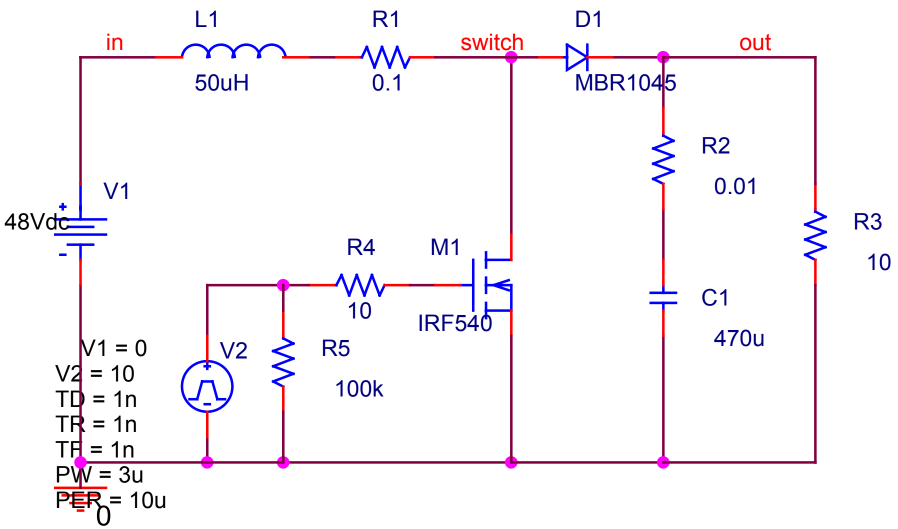



**FIG. 24**

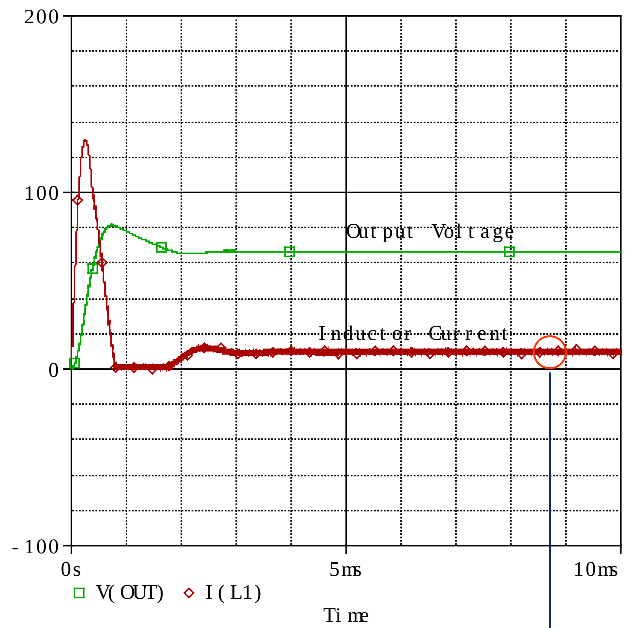



**FIG. 25**

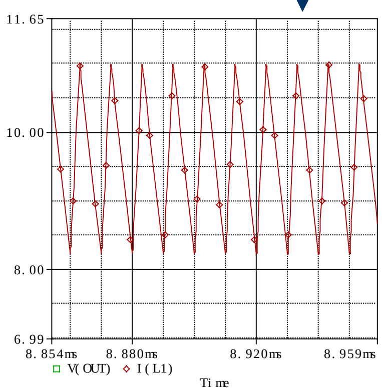



**FIG. 26**

# Design of Boost Converter

Input Voltage : 12V
Output Voltage : 4.8V
Output Current : 0.1 ~ 3A
Frequency : 100kHz

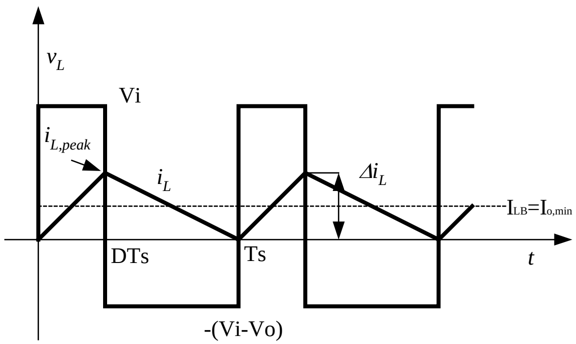



FIG. 27

## 입출력 관계식

$$v_L = L\frac{di}{dt} \quad (10)$$

$$V_i DT_S = V_o(1-D)T_S \quad (11)$$

$$V_o = \frac{1}{1-D}V_{in} \quad (12)$$

$$==> D = 0.33$$

## 인덕터 값 설정

$$\Delta i_L = \frac{V_{in}-V_o}{L}T_{on} = \frac{V_{in}-V_o}{L}DT_S \quad (13)$$

$$I_{LB} = \frac{1}{2}\Delta i_L = \frac{DT_S}{2L}V_i \quad (14)$$

$$I_{OB} = \int_{DT_S}^{T_S} I_{LB}dt = I_{LB}(1-D)T_S = I_{LB}D'$$

$$= \frac{V_i}{2L}DD'T_S = \frac{V_o}{2L}DD'^2T_S = I_{o,\min} \quad (15)$$

$$L = \frac{V_o DD'^2 T_S}{2I_{o,\min}} \quad (16)$$

## 커패시터 값 설정

$$\Delta v_o = \frac{1}{C}\int i_c dt + i_c R_c \cong i_c R_c = \Delta i_L R_c \quad (17)$$

$$\Delta v_o = \frac{\Delta Q}{C} = \frac{I_o DT_S}{C} = \frac{Vo}{R} \bullet \frac{DT_S}{C} \quad (18)$$

$$C = \frac{DT_S}{R} \bullet \frac{V_o}{\Delta v_o} \quad (19)$$

# Boost Converter

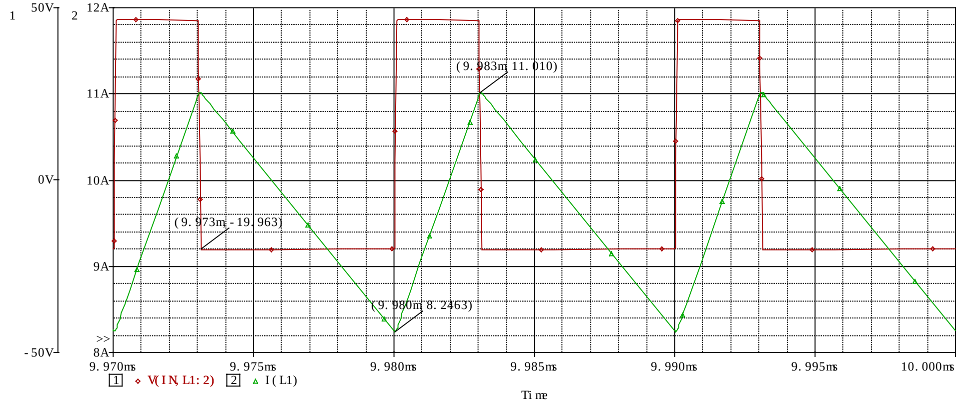



FIG. 28

On time : 4.551ms-4.54ms=4.1us
Off time : 10us-4.1us=5.9us
$\Delta i_L$ : 556.3mA-359.2mA=197.1mA
(Vi-Vo) : 7.26
(-Vo) : 4.99

Inductor Voltage(1)
Inductor Current(2)

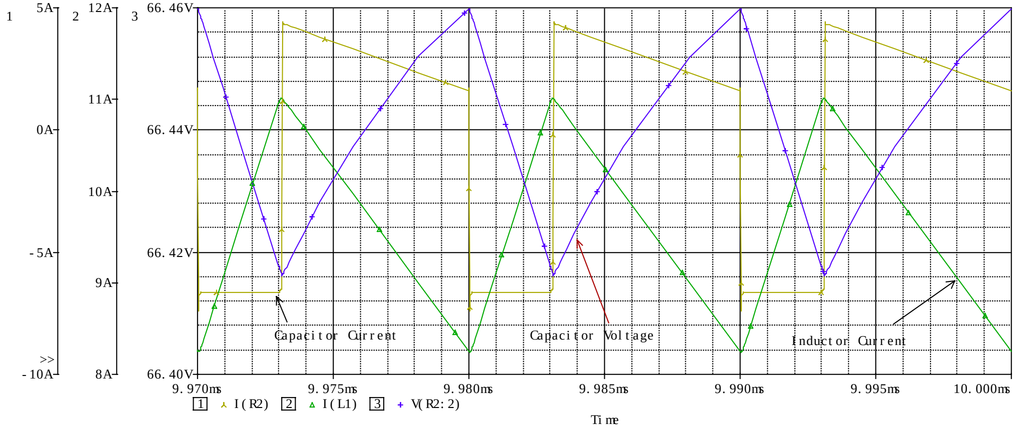



FIG. 29

Inductor Current(2)
Capacitor Current(1)
Capacitor Voltage(3)

# Flyback Converter

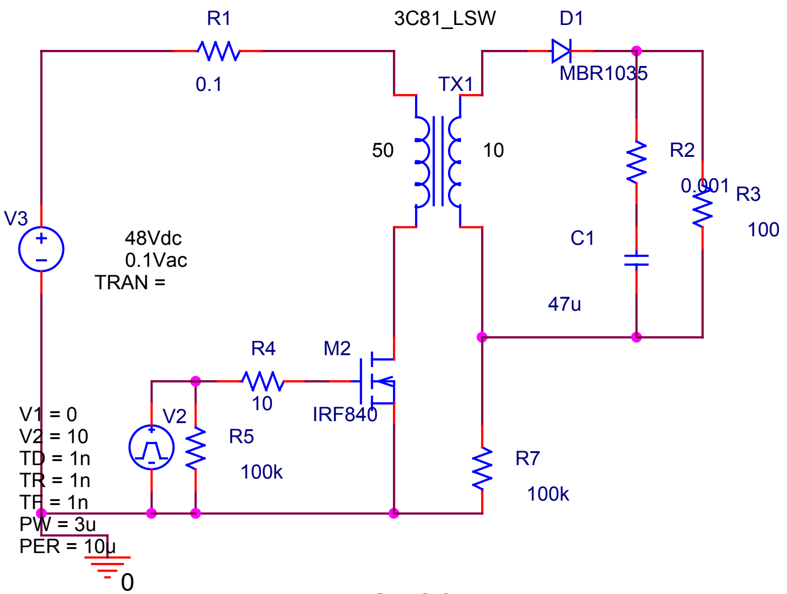



**FIG. 30**

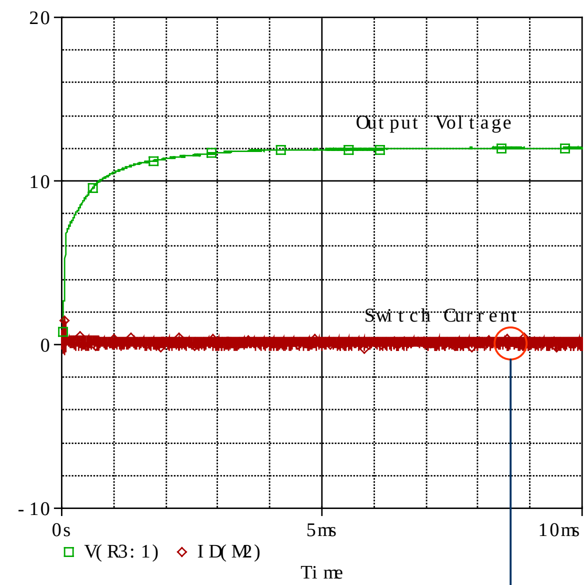



**FIG. 31**

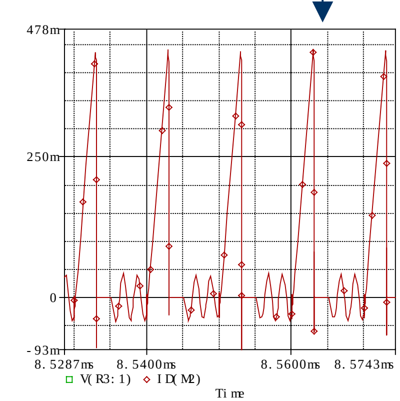



**FIG. 32**

# Forward Converter

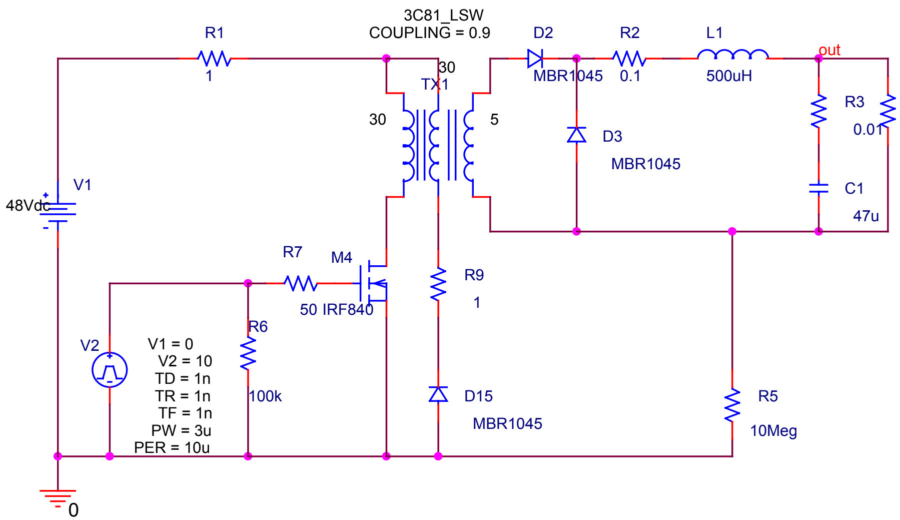



FIG. 33

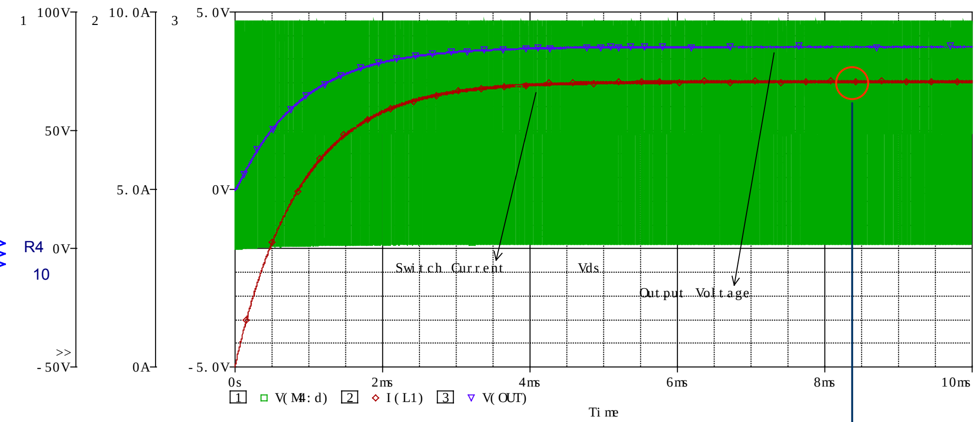



FIG. 34

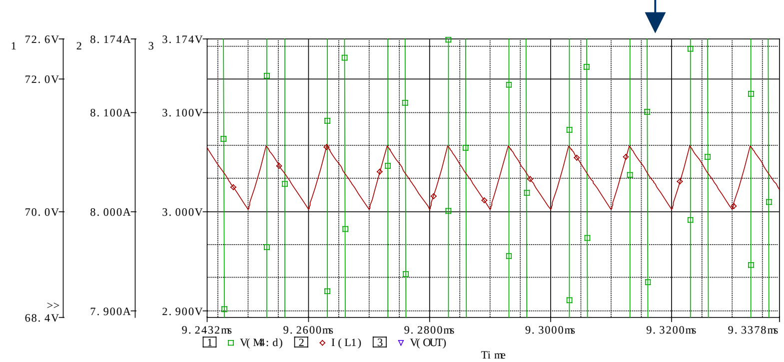



FIG. 35

# Buck Converter

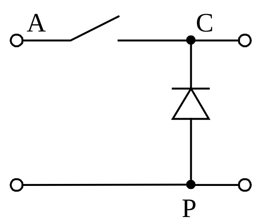



FIG. 36

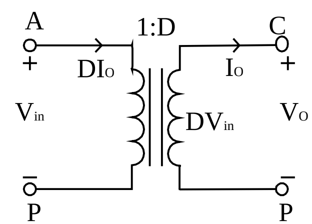



FIG. 37

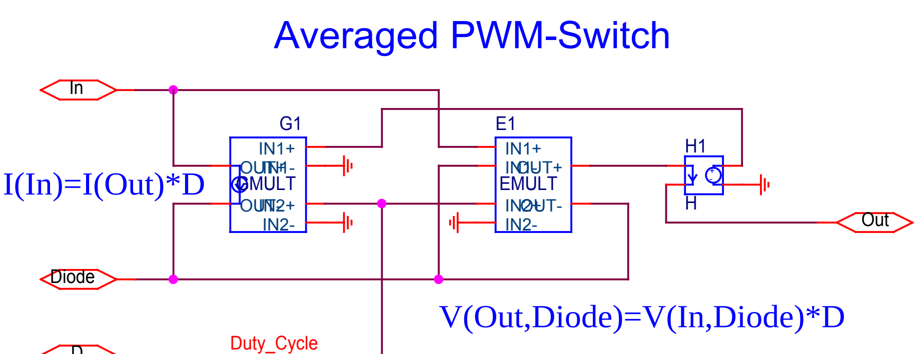



FIG. 38

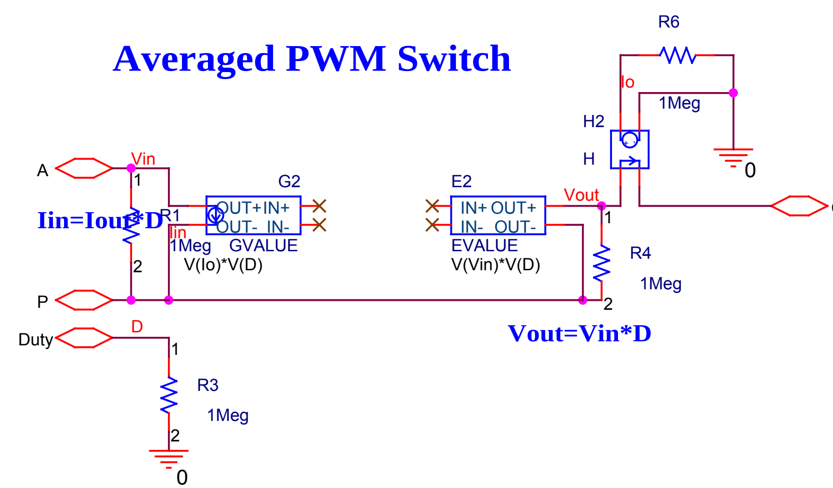



FIG. 39

# Boost Converter

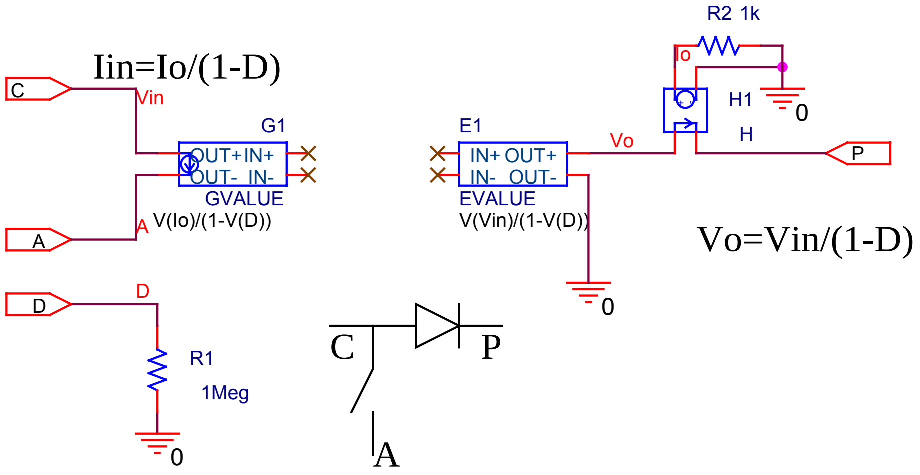



FIG. 40

# Average PWM Buck Converter

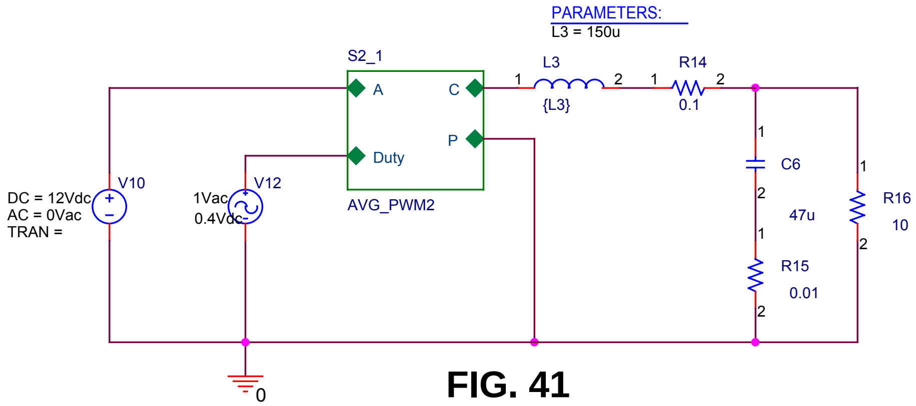



FIG. 41

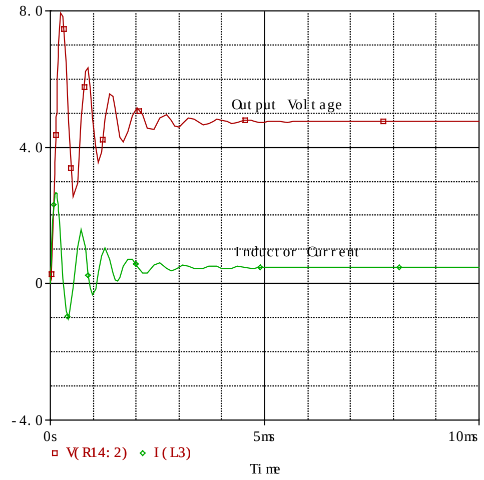



FIG. 42

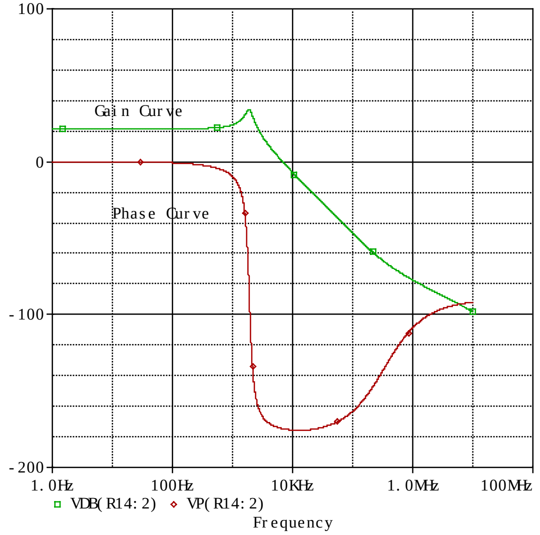



FIG. 43

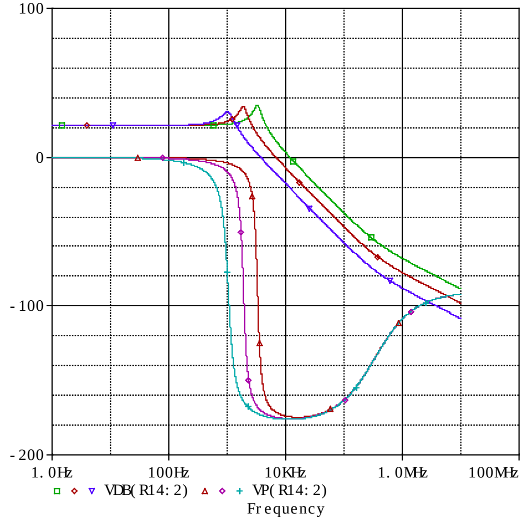



FIG. 44

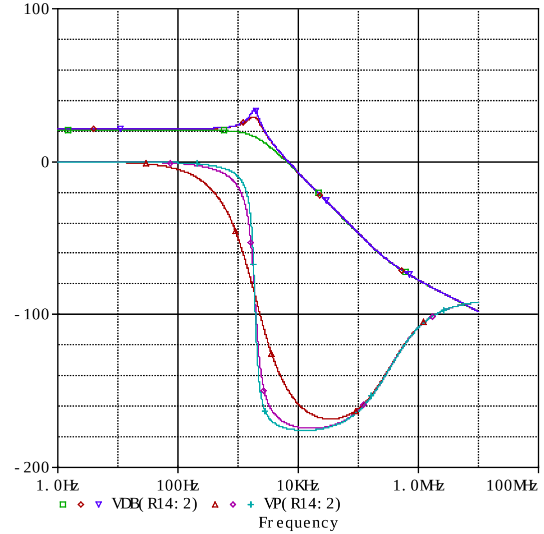



FIG. 45

# Average PWM Boost Converter

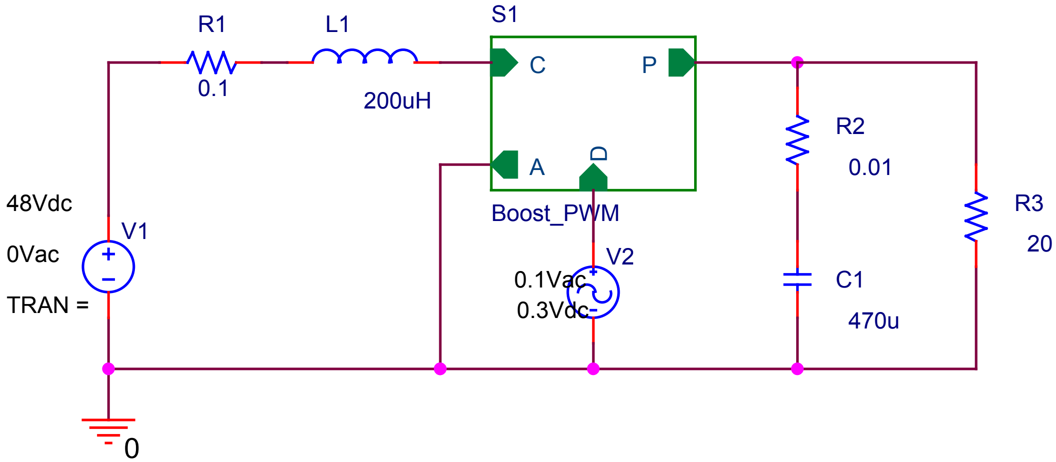



**FIG. 46**

# Compensation

## Type I.

$$f_C = \frac{1}{2\pi RC} \qquad (20)$$

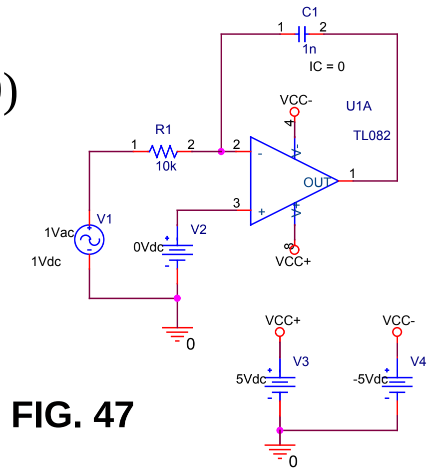



FIG. 47

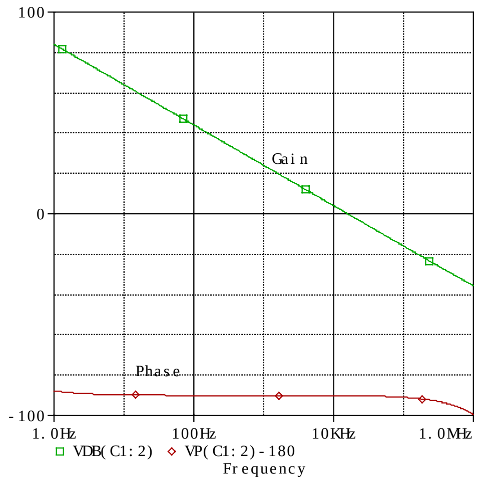



FIG. 49

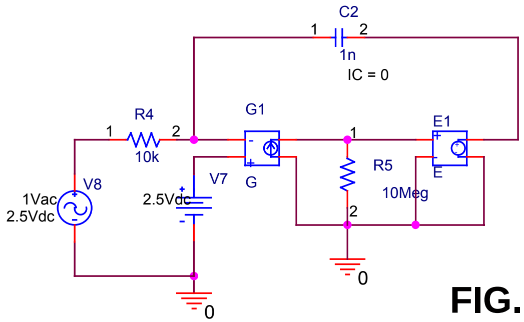



FIG. 48

# Type II.

$$\frac{v_c}{v_o} = \frac{(1+sC_1R_2)}{s(C_1+C_2)R_1\left\{1+s\dfrac{C_1C_2}{(C_1+C_2)}R_2\right\}} \qquad (21)$$

$$f_Z = \frac{1}{2\pi C_1R_2} \qquad (22)$$

$$f_P = \frac{C_1+C_2}{2\pi C_1C_2R_2} \cong \frac{1}{2\pi C_2R_2}(\because C_1 >> C_2) \qquad (23)$$

$$A_{V1} = \frac{R_2}{R_1} \qquad (24)$$

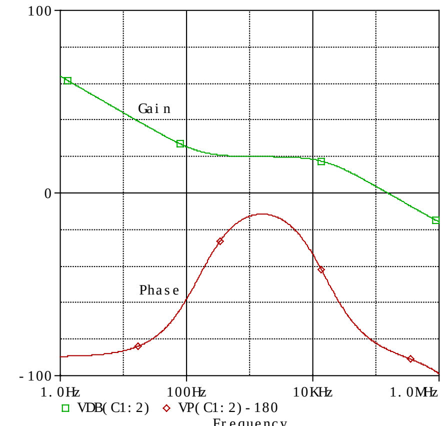



**FIG. 50**

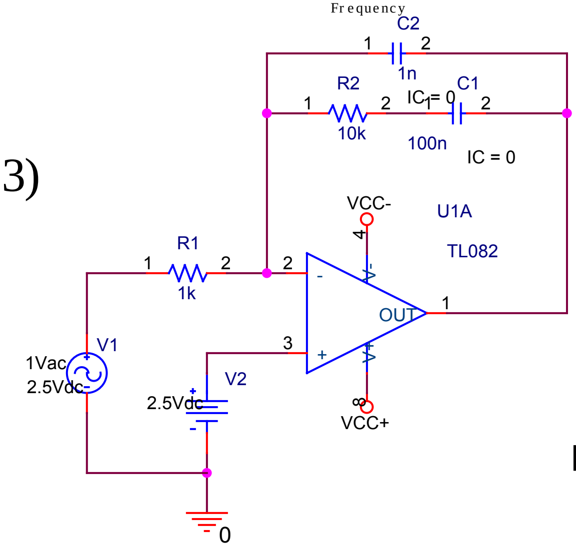



**FIG. 51**

# Type III.

$$\frac{v_c}{v_o} = \frac{(1+sC_1R_1)(1+sC_2R_3)}{sC_2R_1(1+sC_1R_2)} \qquad (25)$$

$$f_{Z1} = \frac{1}{2\pi C_1R_1} \qquad (26)$$

$$f_{Z2} = \frac{1}{2\pi C_2R_3} \qquad (27)$$

$$f_P = \frac{1}{2\pi C_1R_2} \qquad (28)$$

$$A_{V1} = \frac{R_3}{R_1+R_2} \qquad (29)$$

$$A_{V2} = \frac{R_3}{R_2} \qquad (30)$$

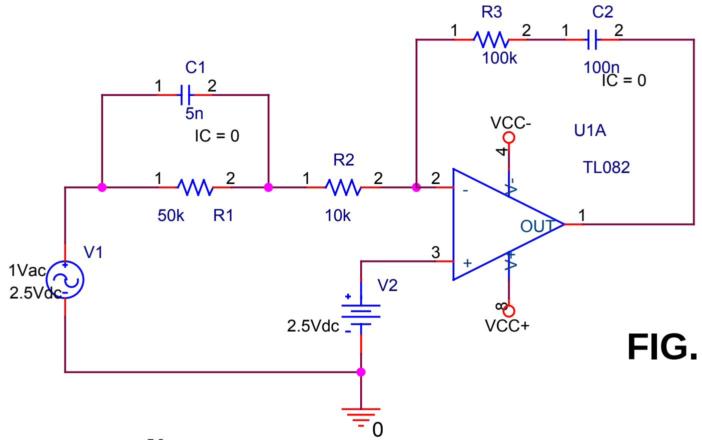



FIG. 52

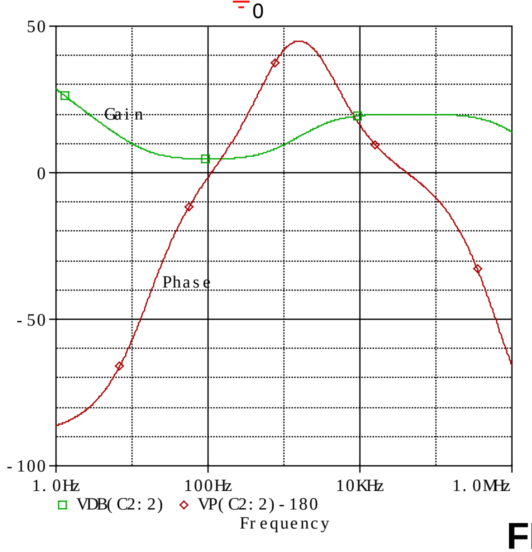



FIG. 53

# Type IV.

$$\frac{v_c}{v_o} = \frac{(1+sC_1R_2)\{1+sC_3(R_1+R_3)\}}{s(C_1+C_2)R_1(1+sC_3R_3)\left(1+s\frac{C_1C_2R_2}{C_1+C_2}\right)} \quad (31)$$

$$f_{Z1} = \frac{1}{2\pi C_1R_2} \quad (32)$$

$$f_{Z2} = \frac{1}{2\pi C_3(R_1+R_3)} \cong \frac{1}{2\pi C_3R_1} \quad (33)$$

$$f_{P1} = \frac{1}{2\pi C_3R_3} \quad (34)$$

$$f_{P1} = \frac{C_1+C_2}{2\pi C_1C_2R_2} \cong \frac{1}{2\pi C_2R_2} (\because C_1 >> C_2) \quad (35)$$

$$A_{V1} = \frac{R_2}{R_1} \quad (36)$$

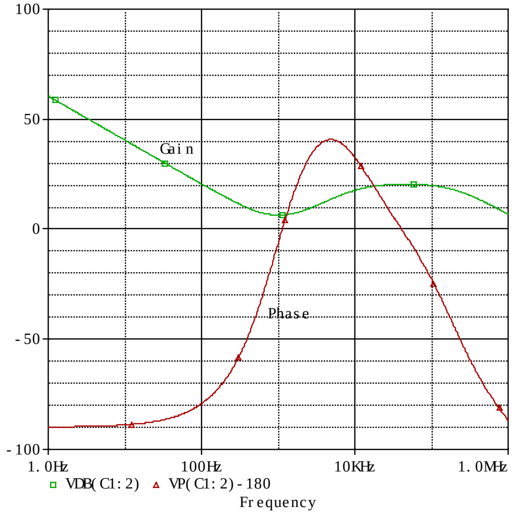



**FIG. 54**

$$A_{V2} = \frac{R_2(R_1+R_3)}{R_1R_3} \cong \frac{R_2}{R_3} \quad (37)$$

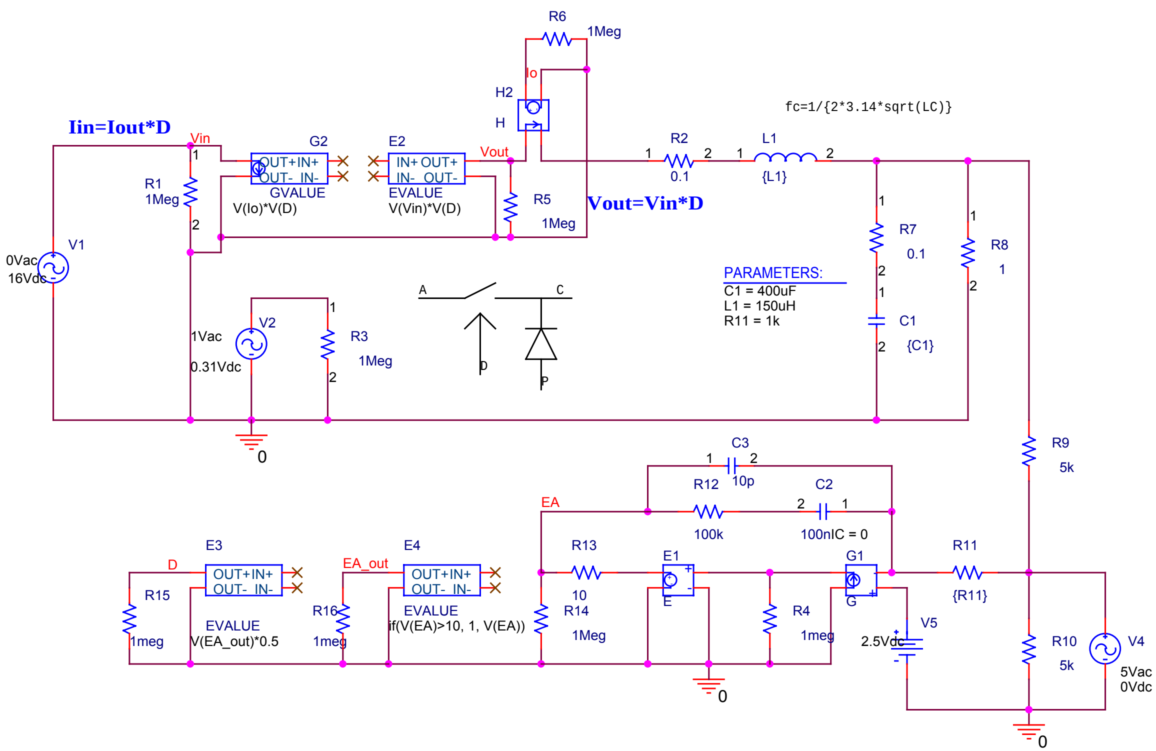

R6
1Meg
Io
H2
H
fc=1/{2*3.14*sqrt(LC)}
Iin=Iout*D
Vin
G2
E2
Vout
R2
L1
1
2
0.1
{L1}
OUT+IN+
OUT- IN-
GVALUE
V(Io)*V(D)
IN+ OUT+
IN- OUT-
EVALUE
V(Vin)*V(D)
R1
1Meg
R5
1Meg
Vout=Vin*D
R7
0.1
R8
1
V1
0Vac
16Vdc
PARAMETERS:
C1 = 400uF
L1 = 150uH
R11 = 1k
A
C
C1
{C1}
V2
1Vac
0.31Vdc
R3
1Meg
P
0
R9
5k
C3
10p
R12
100k
C2
100nIC = 0
EA
E3
E4
D
EA_out
OUT+IN+
OUT- IN-
R13
10
R14
1Meg
E1
G1
R11
{R11}
R15
1meg
EVALUE
V(EA_out)*0.5
R16
1meg
EVALUE
if(V(EA)>10, 1, V(EA))
E
G
R4
1meg
V5
2.5Vdc
R10
5k
V4
5Vac
0Vdc

**FIG. 55**

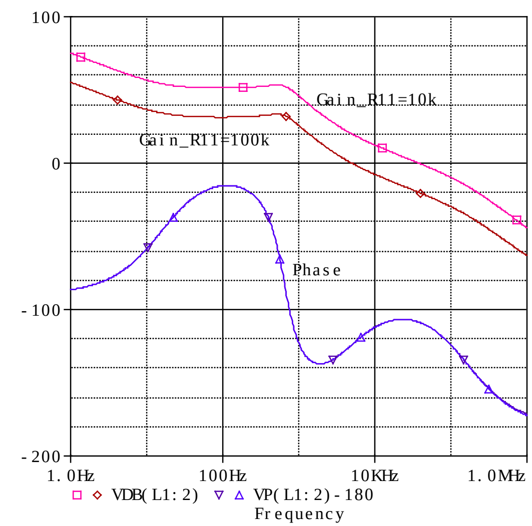

100
0
-100
-200
1.0Hz
100Hz
10KHz
1.0MHz
Gain_R11=10k
Gain_R11=100k
Phase
VDB(L1:2)
VP(L1:2)-180
Frequency

**FIG. 56**

# PF / THD

## Power Factor

– What Is It and Why Must It Be Corrected?

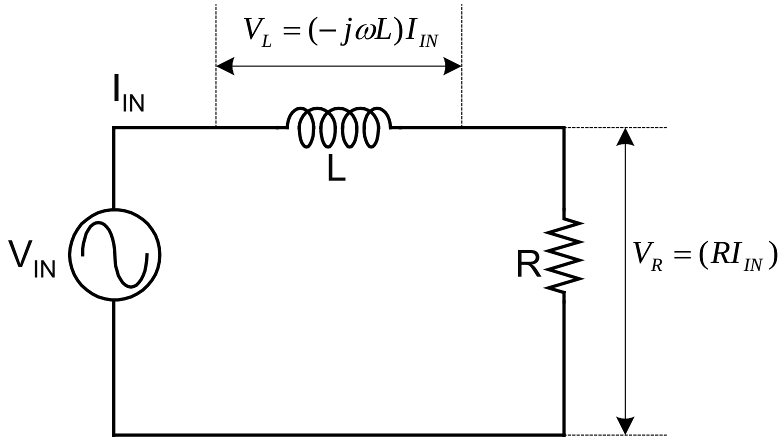



FIG. 57

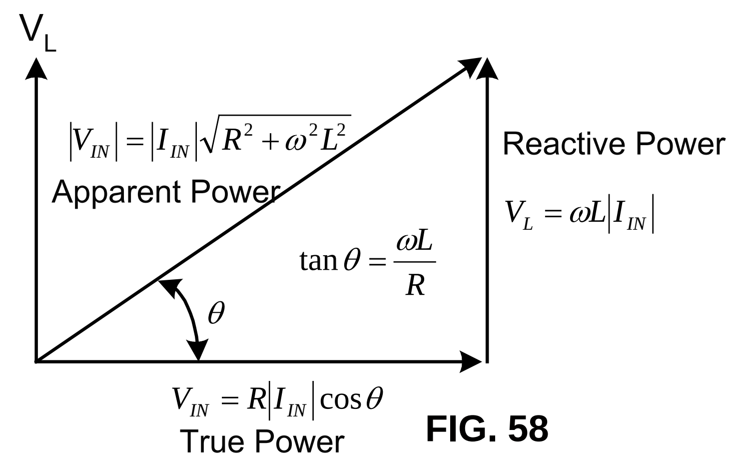



FIG. 58

Apparent Power = $V_{IN}I_{IN}$

Actual Power = $V_{IN}I_{IN}\cos\theta$

# PF / THD

$$PF = \frac{\text{Average Power}}{\text{Apparent Power}} = \frac{avg[v(t) * i(t)]}{Vrms * Irms}$$

If v(t) has form of sine wave, power factor can be expressed as following.

$$PF = \frac{Vrms * Irms(1) * \cos\theta}{Vrms * Irms} = \frac{Irms(1)}{Irms}\cos\theta = Kd * K\theta$$

$$THD = \frac{Irms(DIST)}{Irms(1)} * 100$$

$$THD = \frac{\sqrt{I^2 rms - I^2 rms(1)}}{Irms(1)} * 100$$

Where, $Irms(DIST) = \sqrt{I^2 rms - I^2 rms(1)}$

# PF / THD

$$THD = \sqrt{\left(\frac{Irms}{Irms(1)}\right)^2 - 1} * 100$$

$$THD = \sqrt{\frac{1}{K^2 d} - 1} * 100$$

$$Kd = \frac{1}{\sqrt{1 + \left(\frac{THD}{100}\right)^2}}$$

$$PF = \frac{Irms(1)}{Irms} \cos\theta = Kd * K\theta = Kd$$

$$\therefore PF = \frac{1}{\sqrt{1 + \left(\frac{THD}{100}\right)^2}}$$

# Relationship Between PF and THD

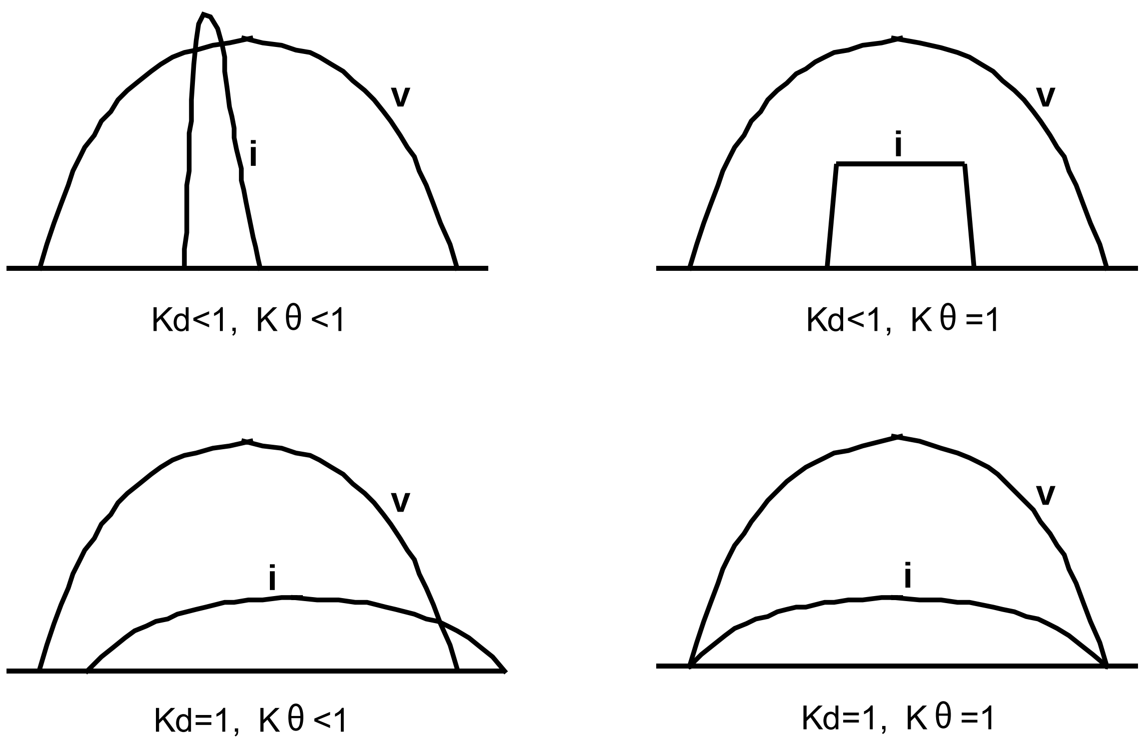



**FIG. 59**

# Equipment Classification

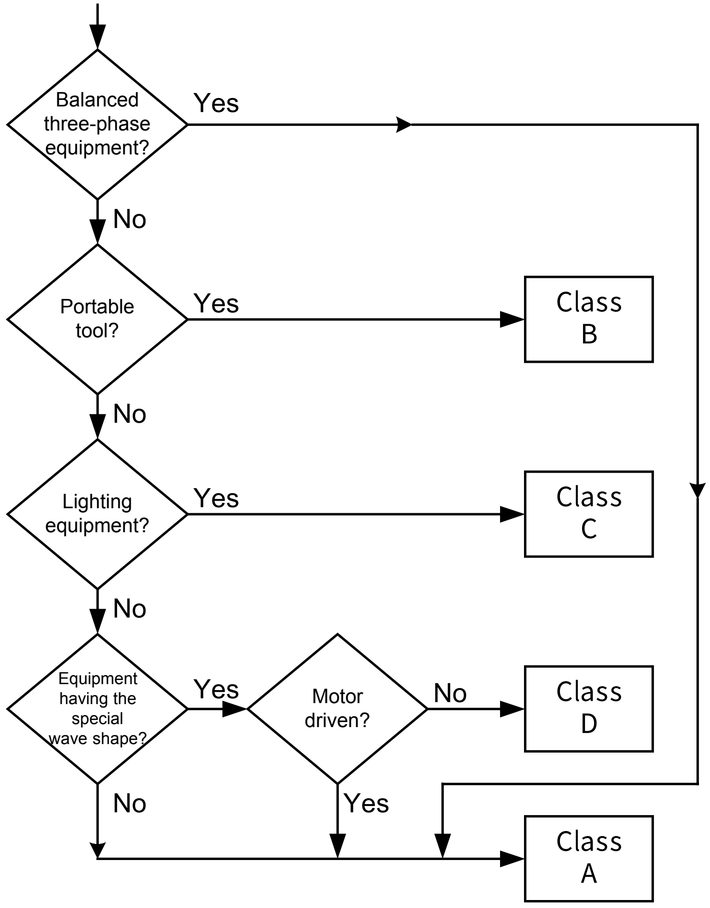
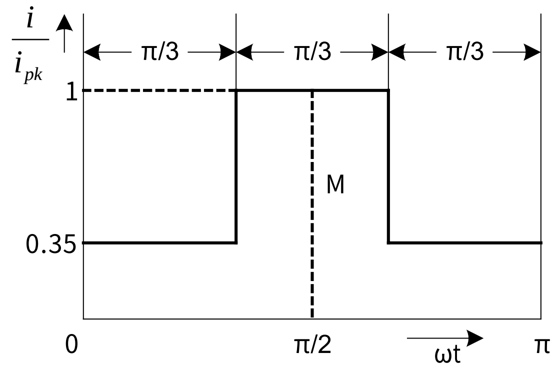



FIG. 60




Class D Wave Shape Definition

FIG. 61

# IEC 555-2 Absolute Limits

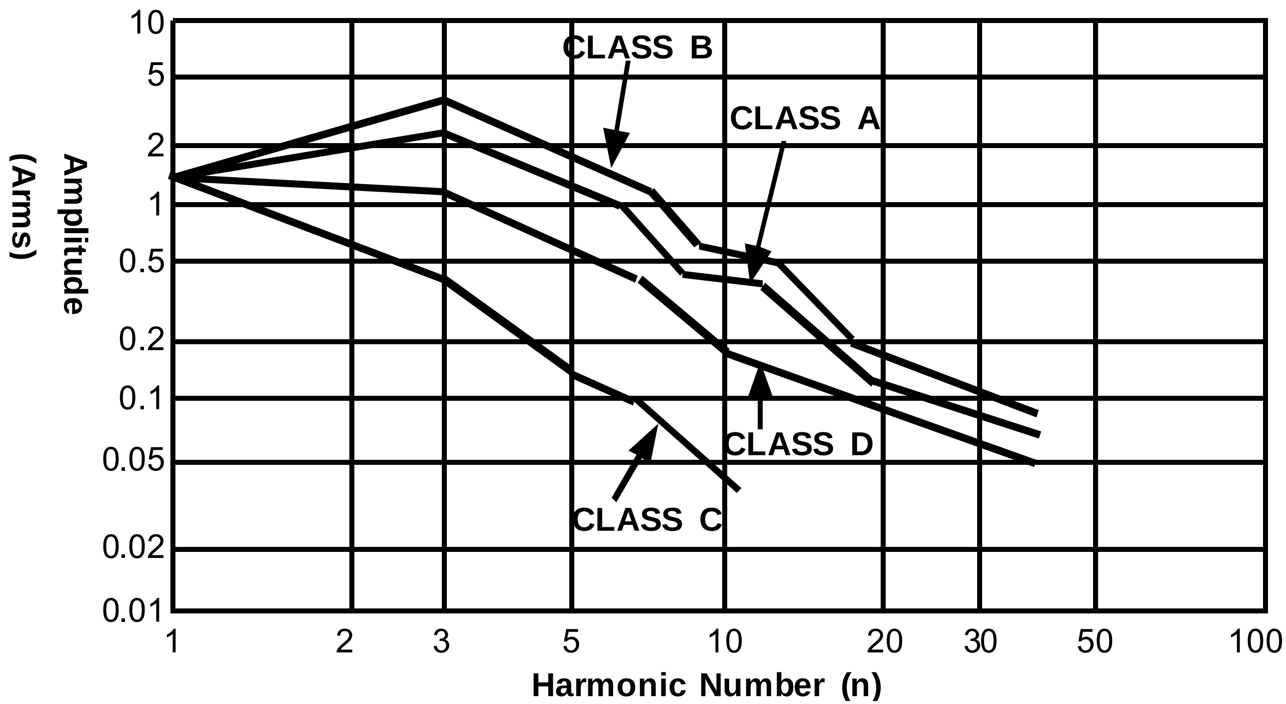



FIG. 62

# IEC 555-2 Class D Specification

| Harmonic Order | mA/W | Maximum Permissible Harmonic Current |
|---|---|---|
| 3 | 3.4 | 2.30 |
| 5 | 1.9 | 1.14 |
| 7 | 1.0 | 0.77 |
| 9 | 0.5 | 0.40 |
| 11 | 0.35 | 0.33 |
| 13 and on | Linear Extrapolation 3.85/n | See Limits for Class A Equipment |

Notes:

1. Class-D specifications apply to equipment operating from a single-phase 220V ac line with a waveshape such as that exhibited by the input current to a rectifier with a apacitive input filter.
2. Current IEC documentation suggests that the above Class D limits will be applicable from 1st January 1995 to all equipment having an input power from 75W to 600W.

# PFC Specification Information

EMi Soft

## Summary

- Harmonics+flicker required under 89/336
- Commission has re-listed both EN61000-3-2 and [-3-3] effectively delaying implementation until 1/1/2001
- 4 year transition for the limits for low power [75W>50W] of class D equipment, Start date not defined.
- Do I need to test ?

http://www.emisoft.co.uk

# Comparison

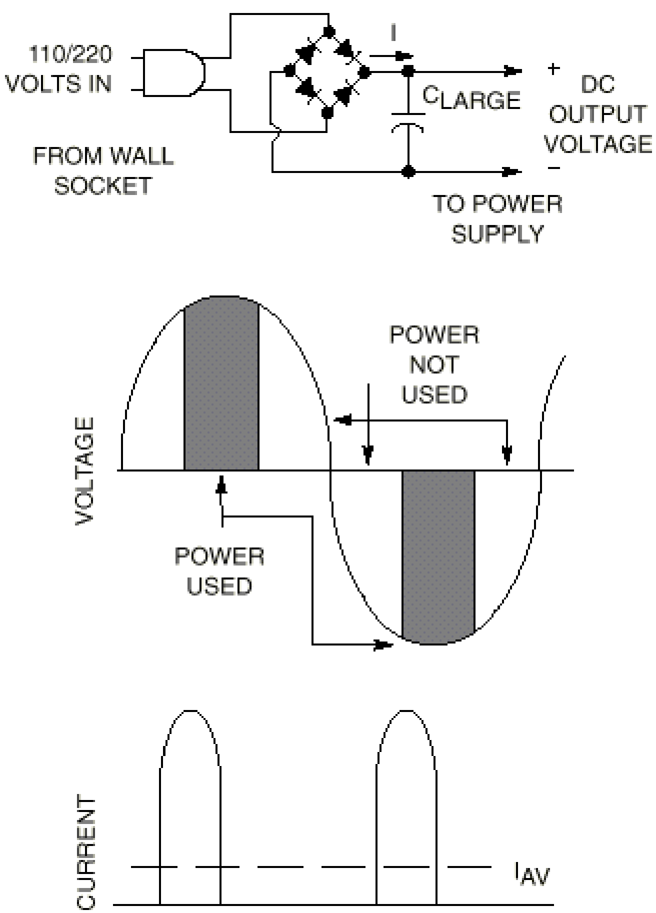



**FIG. 63**

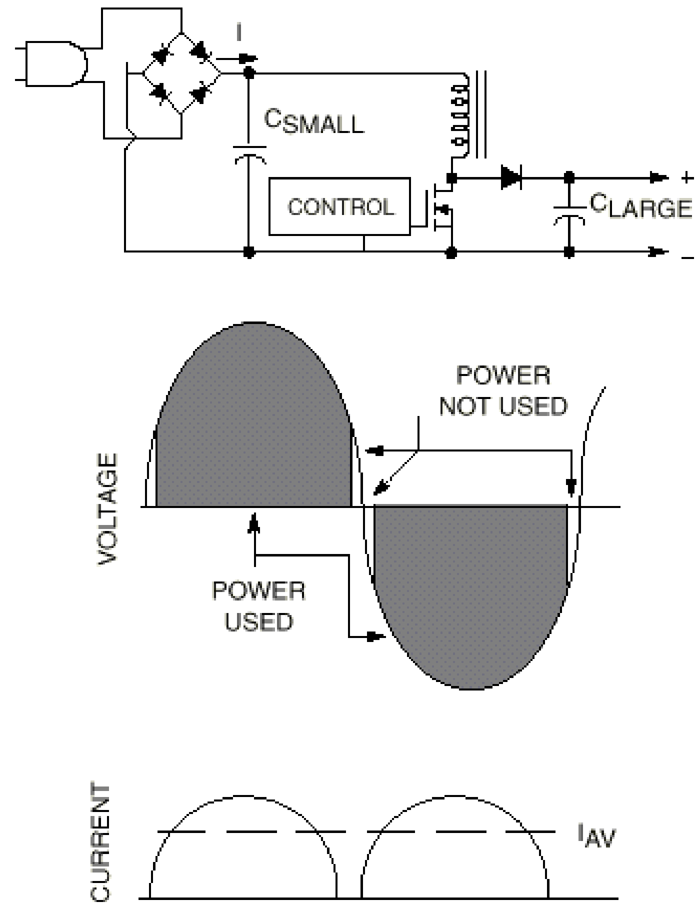
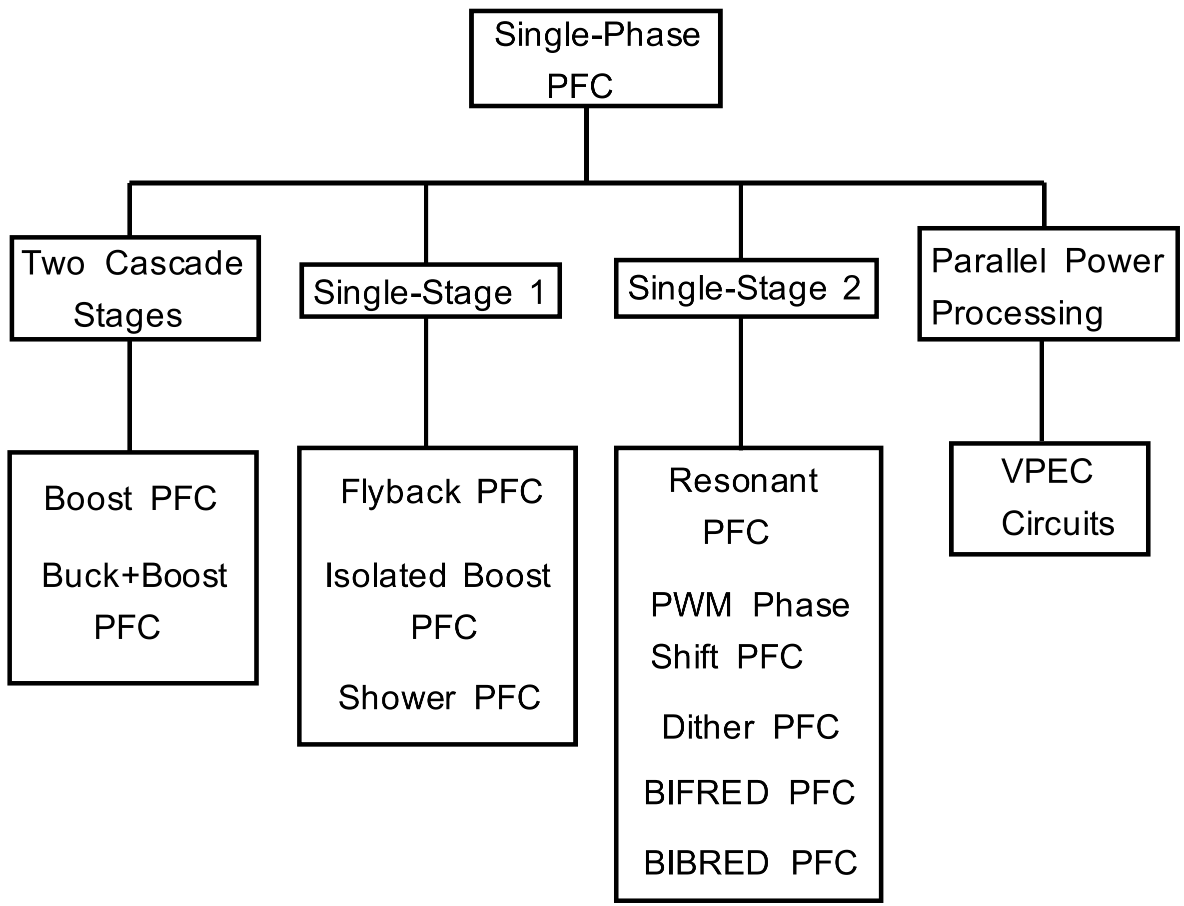



**FIG. 64**

# Single Phase PFC Topologies



# Basic Topology & Control Method

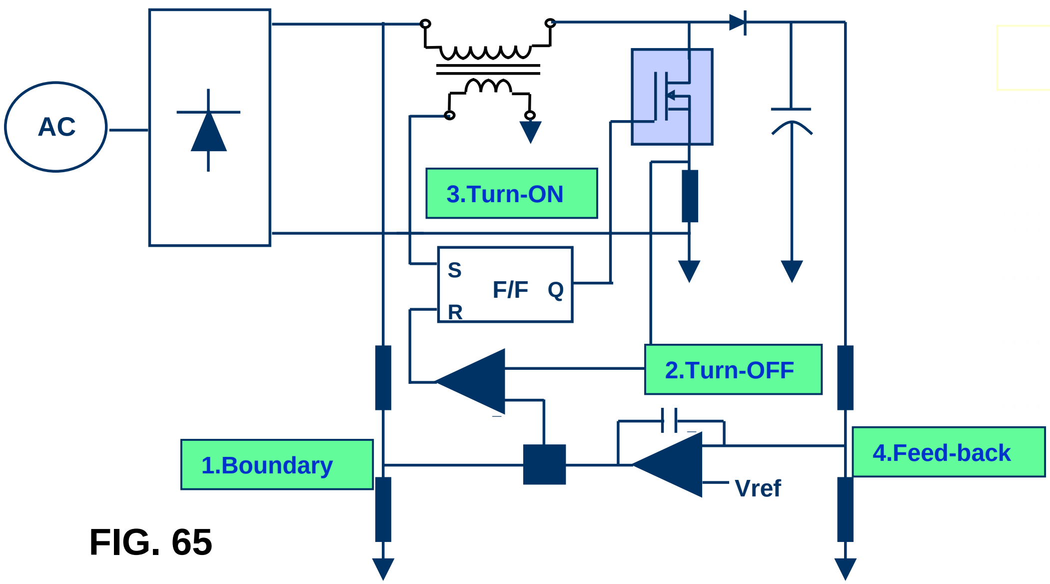



FIG. 65

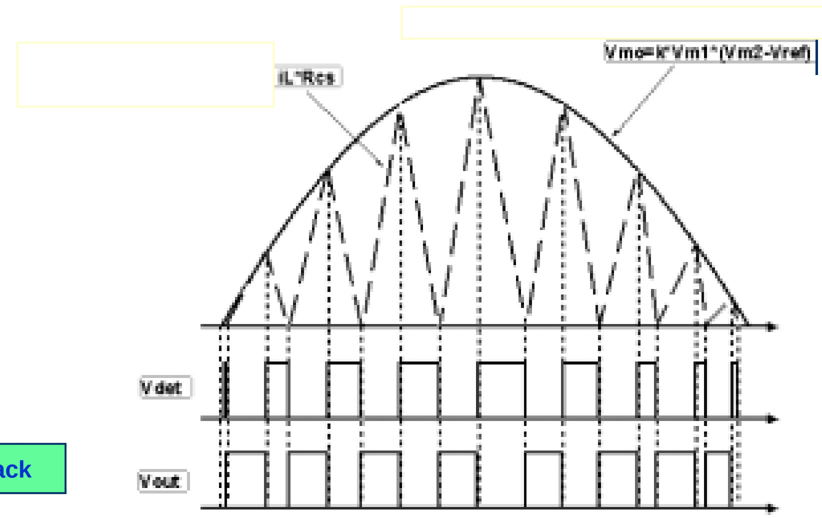


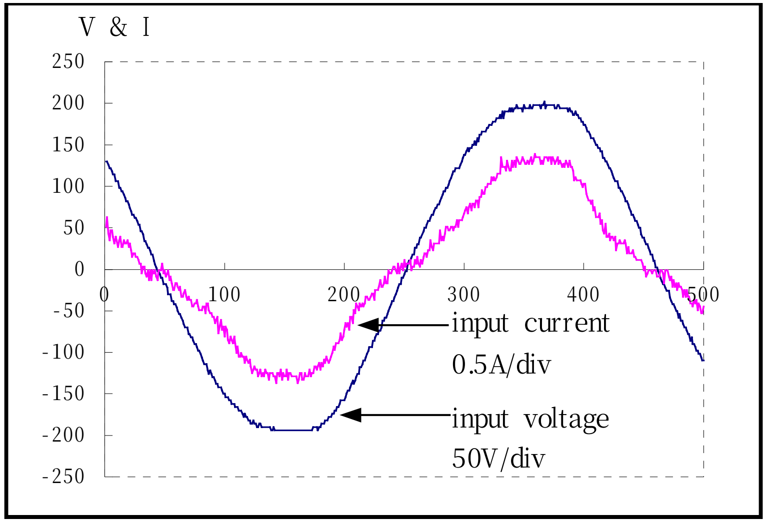

FIG. 66

- **Power Factor :** $P.F. = \frac{P}{S} = \frac{P}{V_{rms} I_{rms}} = \frac{V_{1,rms} I_{1,rms}}{V_{1,rms} I_{T,rms}} \cos\theta_1 = \frac{I_{1,rms}}{I_{T,rms}} \cos\theta_1$
- **Target : Ballast, High Efficiency SMPS**
- **Switch turns on when iL reduces to zero**
- **Switch turns off when the switch current exceeds K*IVil*Vc**



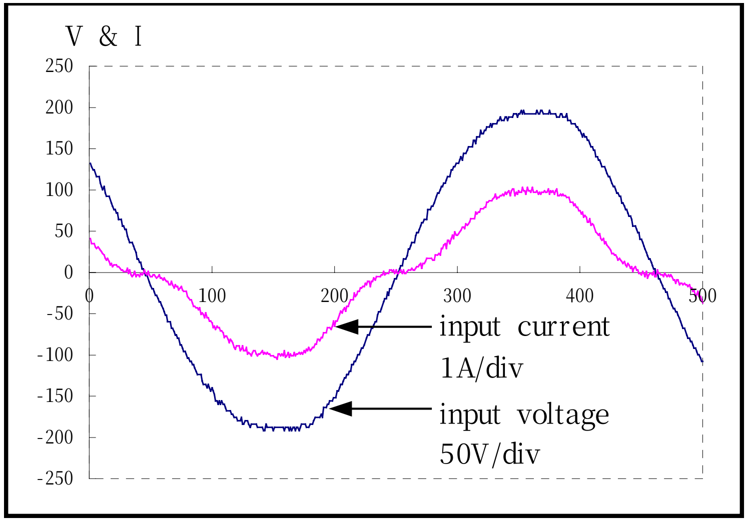
Technologies nyx

# Experimental Results




Output Power = 60W

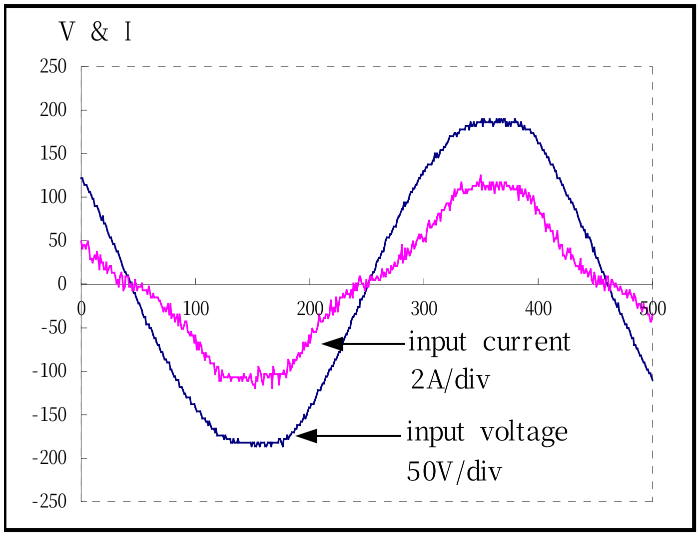
**FIG. 67**




Output Power = 125W

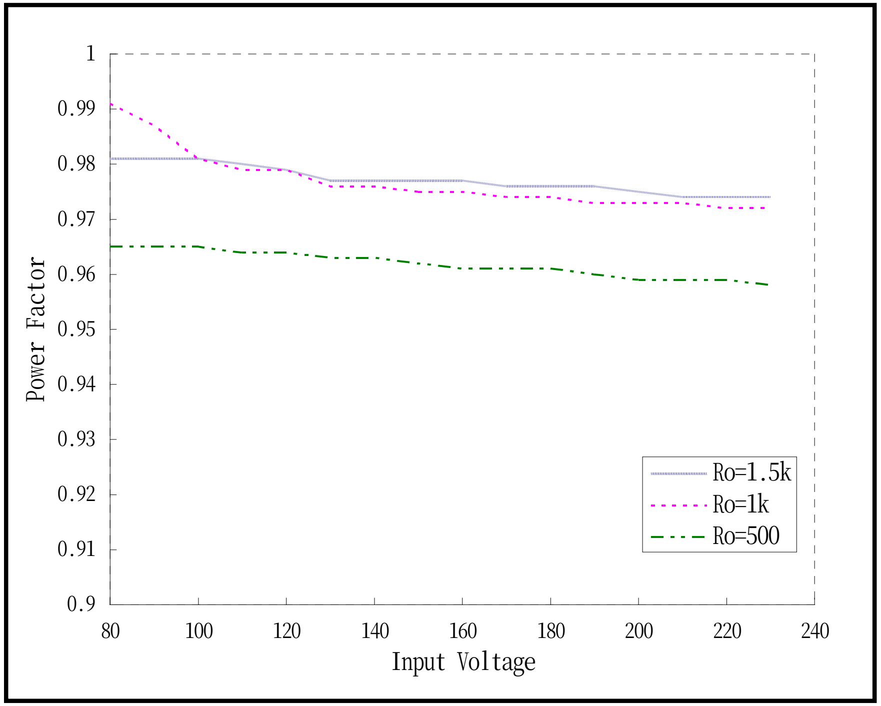
**FIG. 68**

# Experimental Results




Output Power = 250W

**FIG. 69**




Power Factor Versus the Input Voltage Variation

**FIG. 70**

# Two Stage Topology

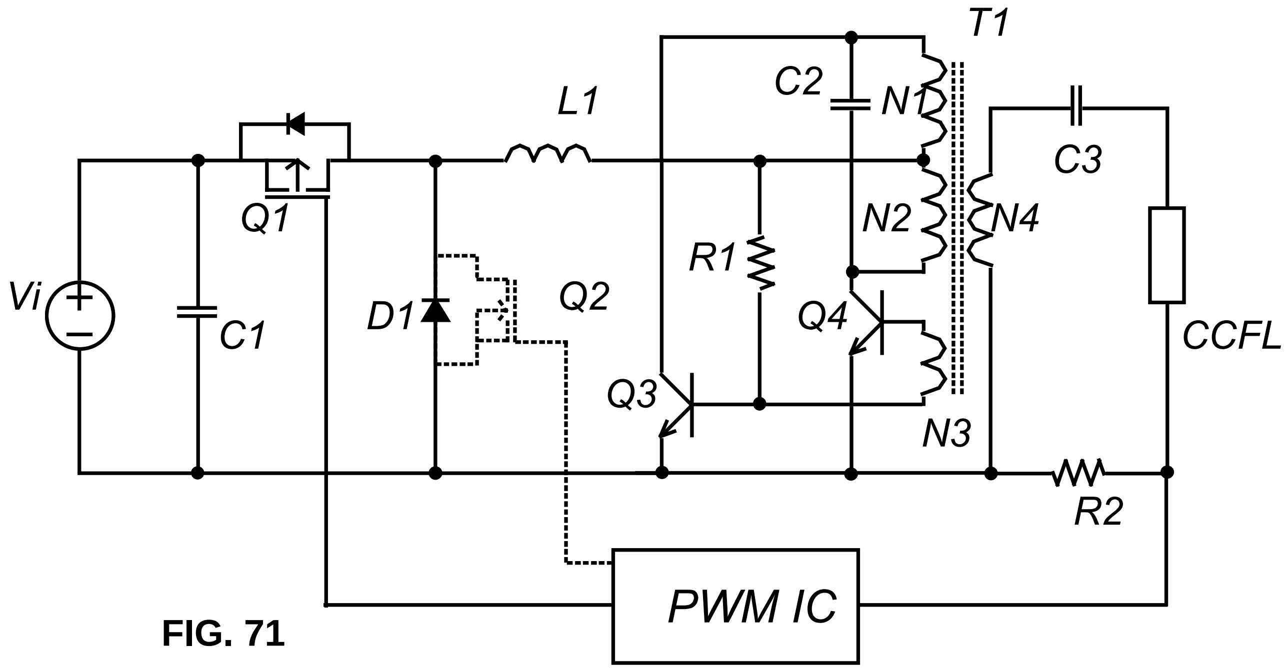



FIG. 71

- Buck + Royer Inverter
- Low System Efficiency
- Self Oscillation
- High Cost

# Simulation Circuit of Buck + Royer Topology

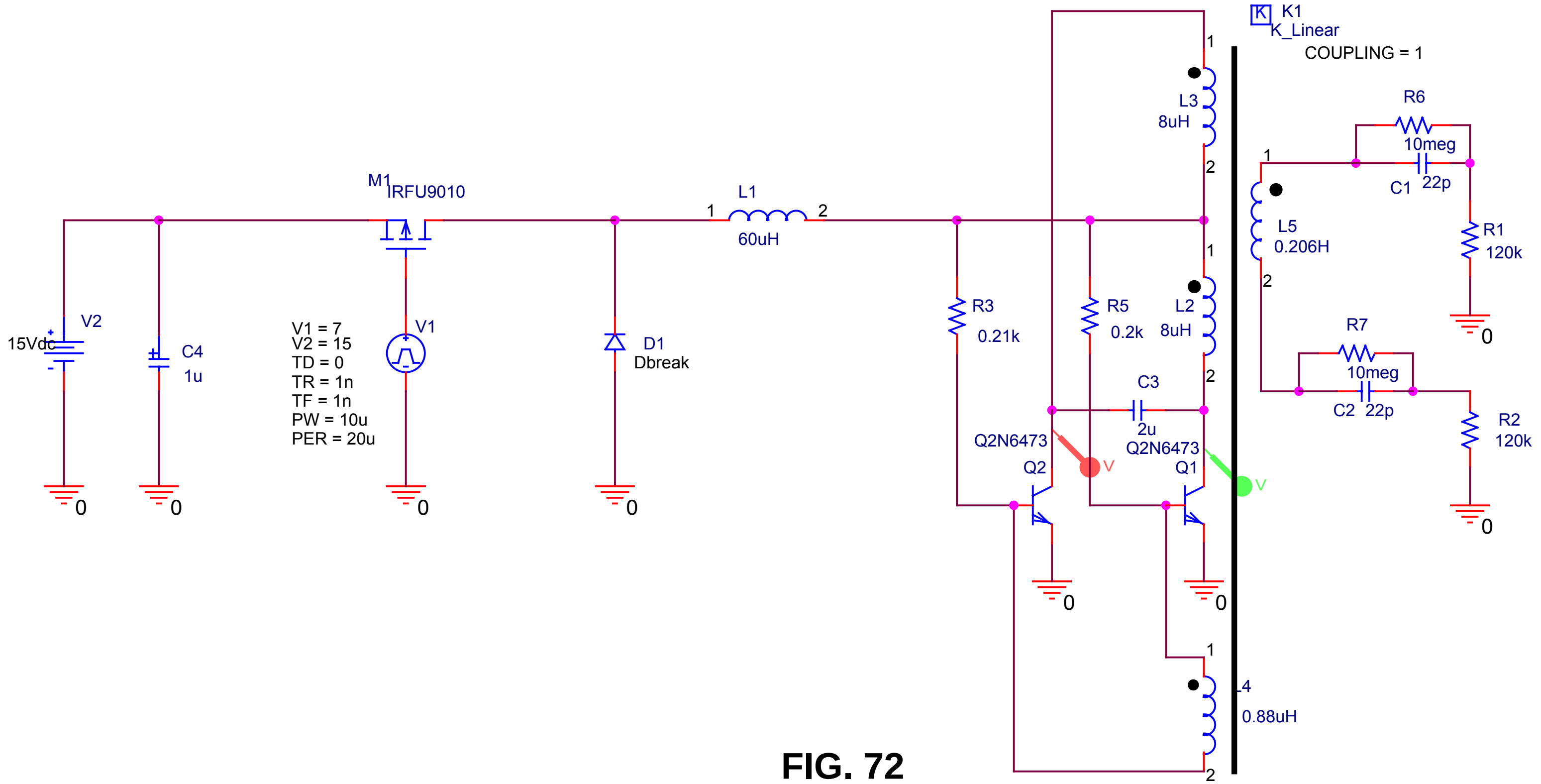



FIG. 72

# Simulation Result

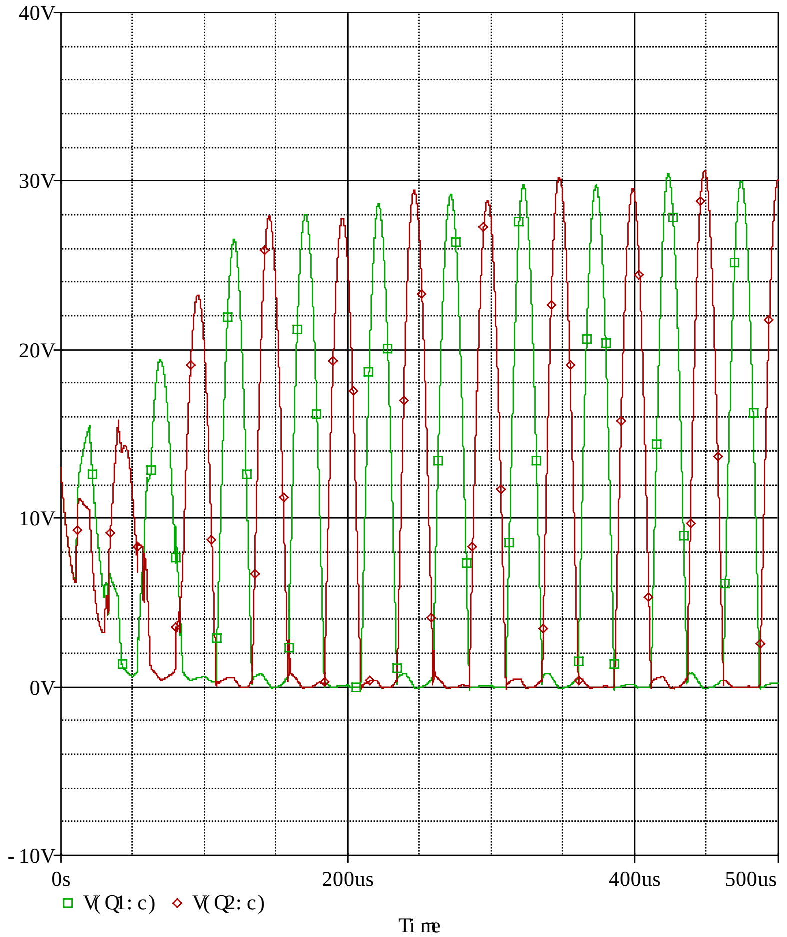



FIG. 73

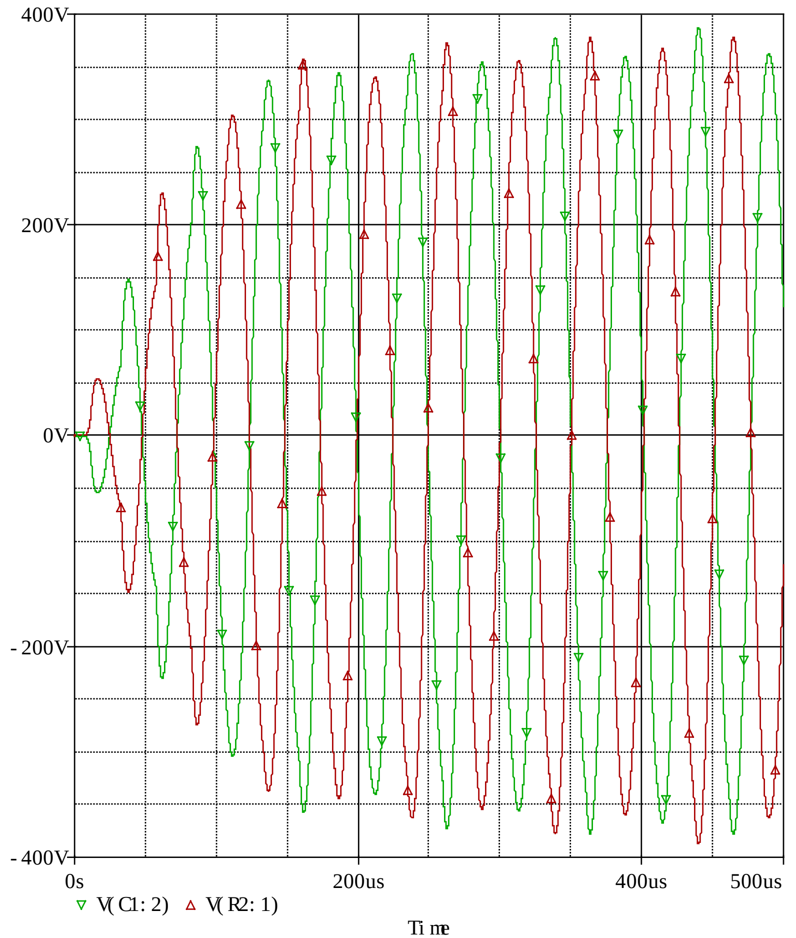



FIG. 74

# Single Stage Topology

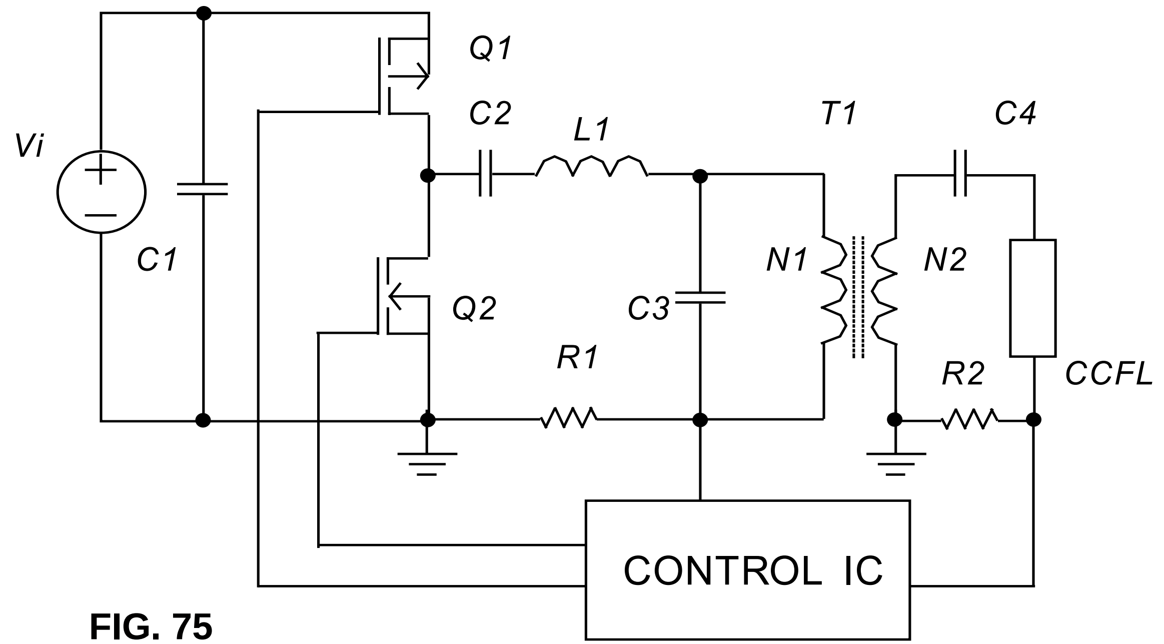



**FIG. 75**

- Half Bridge Converter
- High System Efficiency
- PWM / PFM Control Method
- Low Cost

# Freq. Characteristic of Power Stage

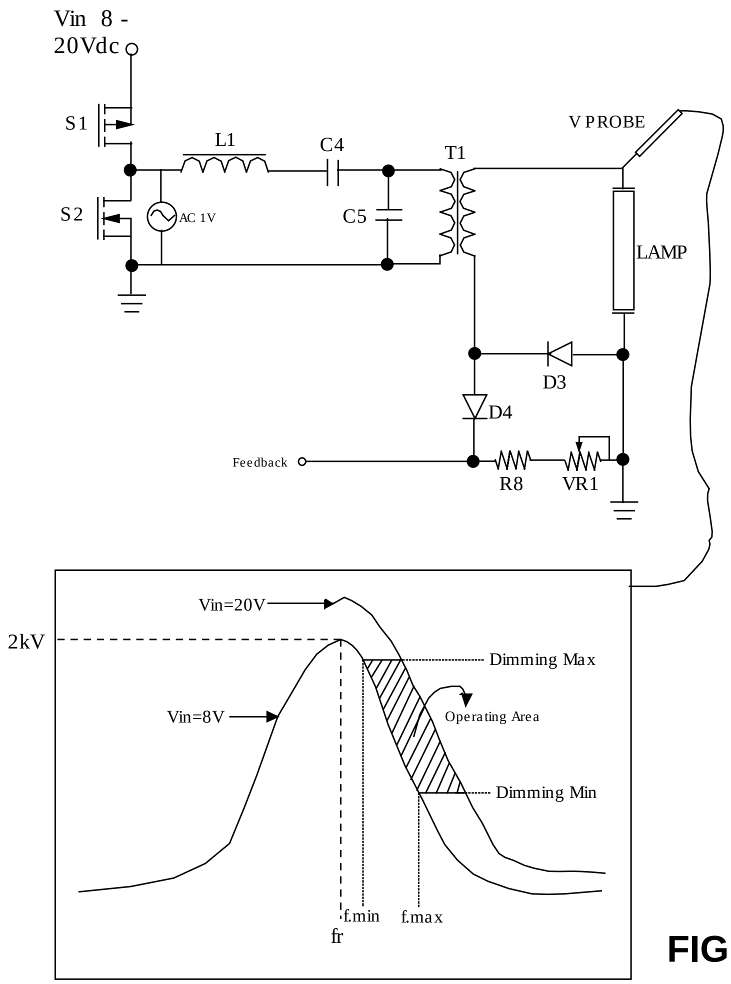



FIG. 76

- Pulse Frequency Modulation
- High Side Gate Drive
- Charge Pump Technique (NMOS)
- High System Efficiency
- Class D Type CCFL Inverter
- Low Cost

# Power Stage AC Simulation

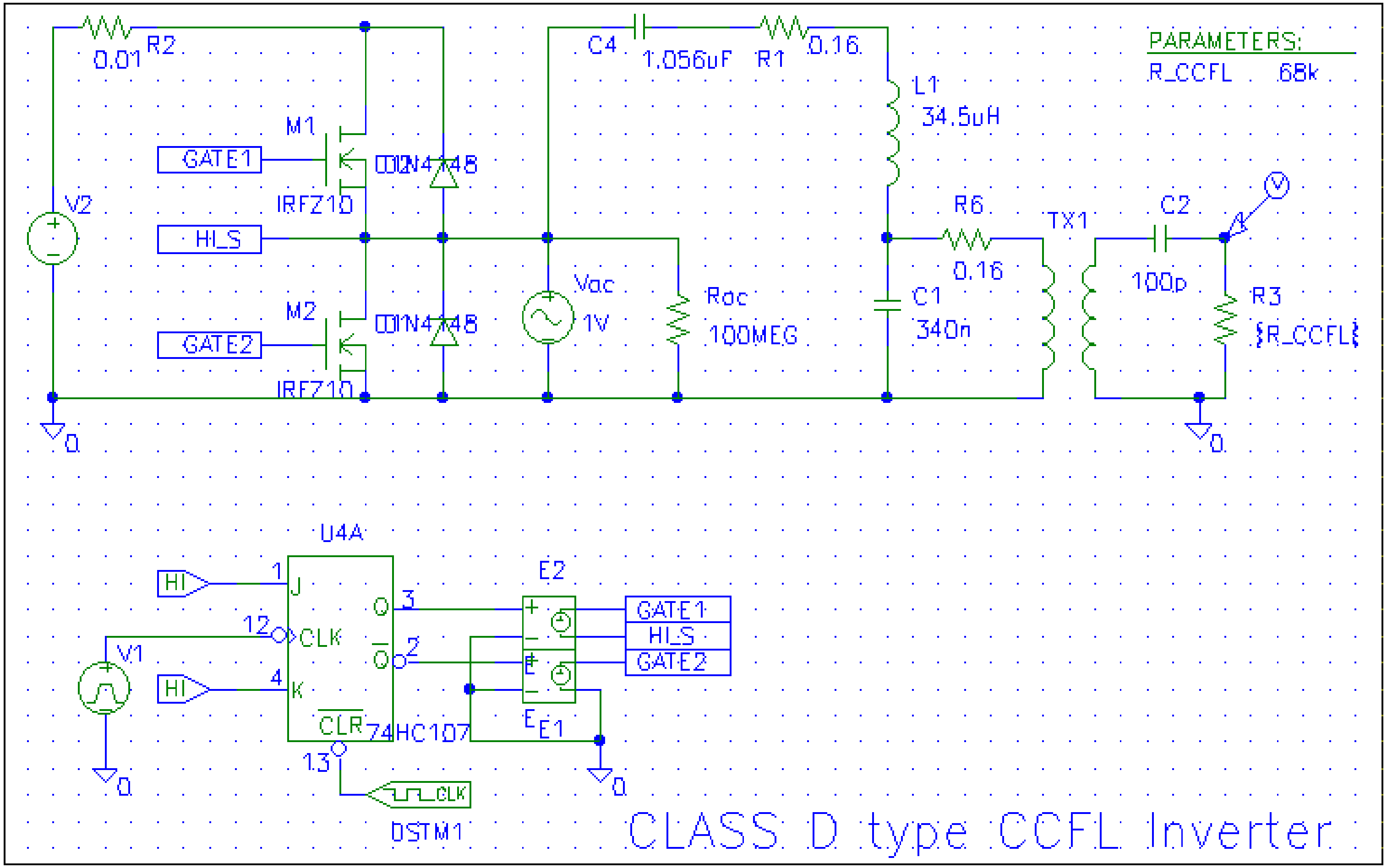



FIG. 77

# AC Simulation Result

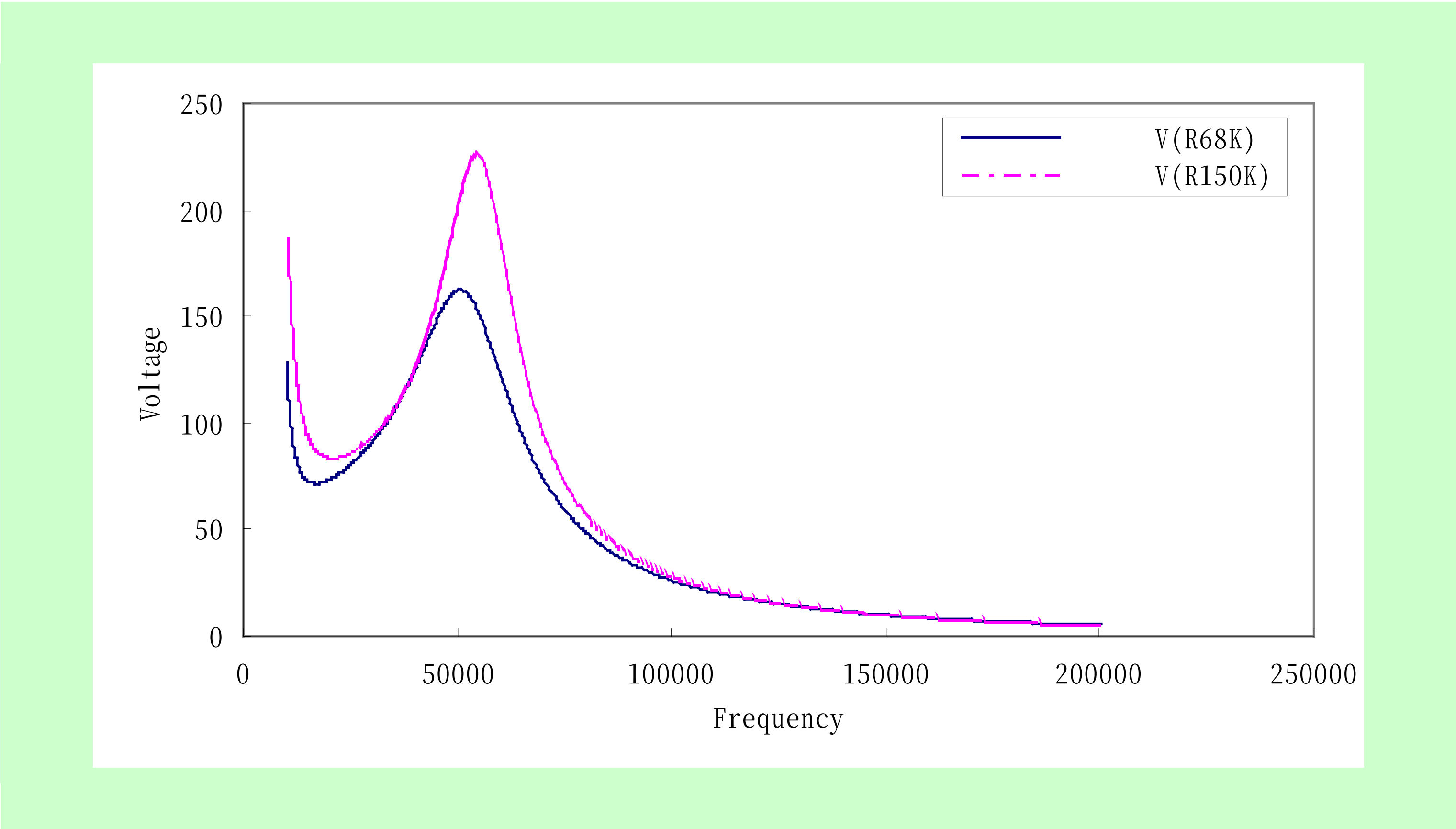



**FIG. 78**

# AC Simulation that Consider Actual Parameters

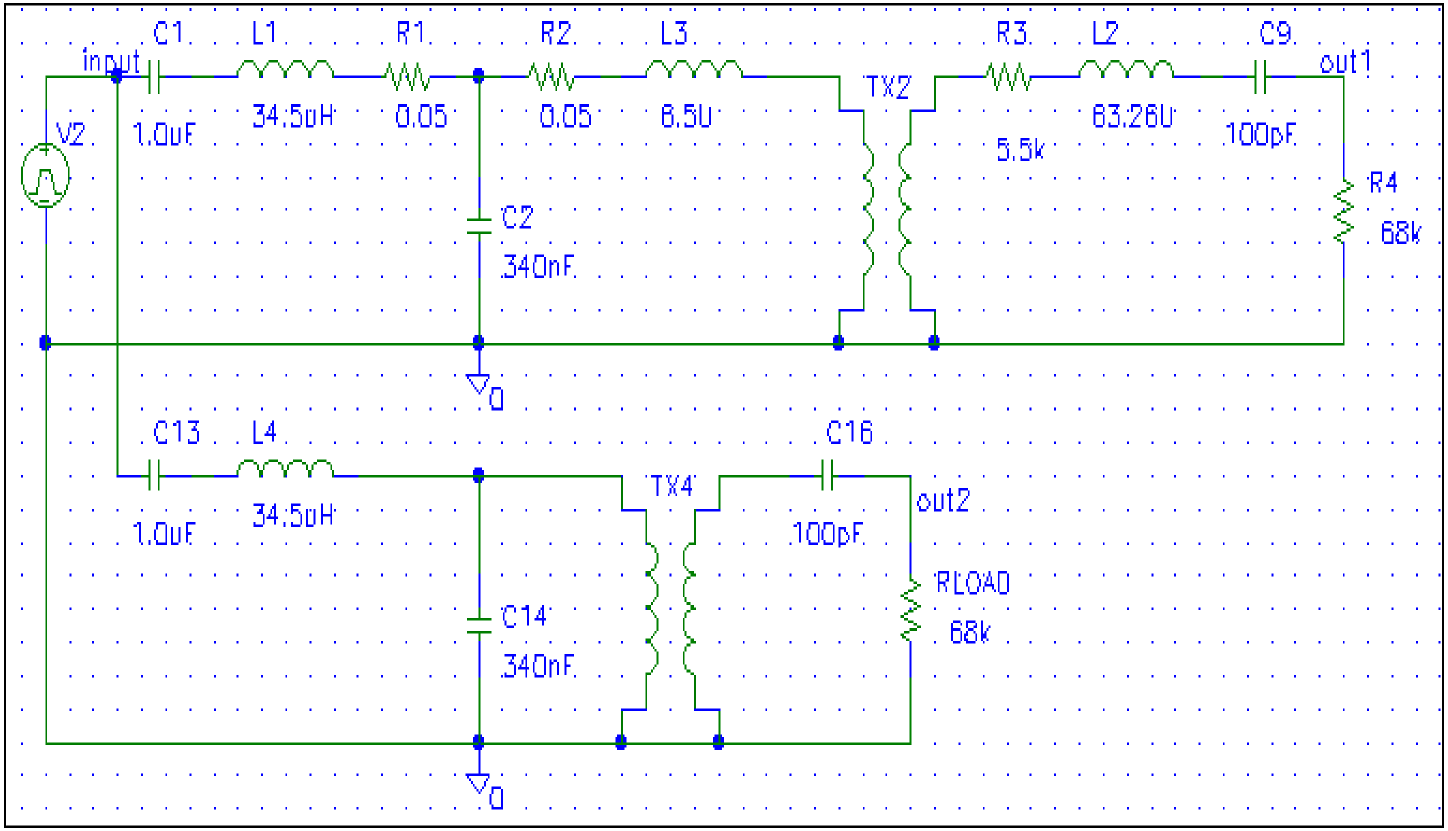



**FIG. 79**

# Simulation Results(Ideal / Actual Case)

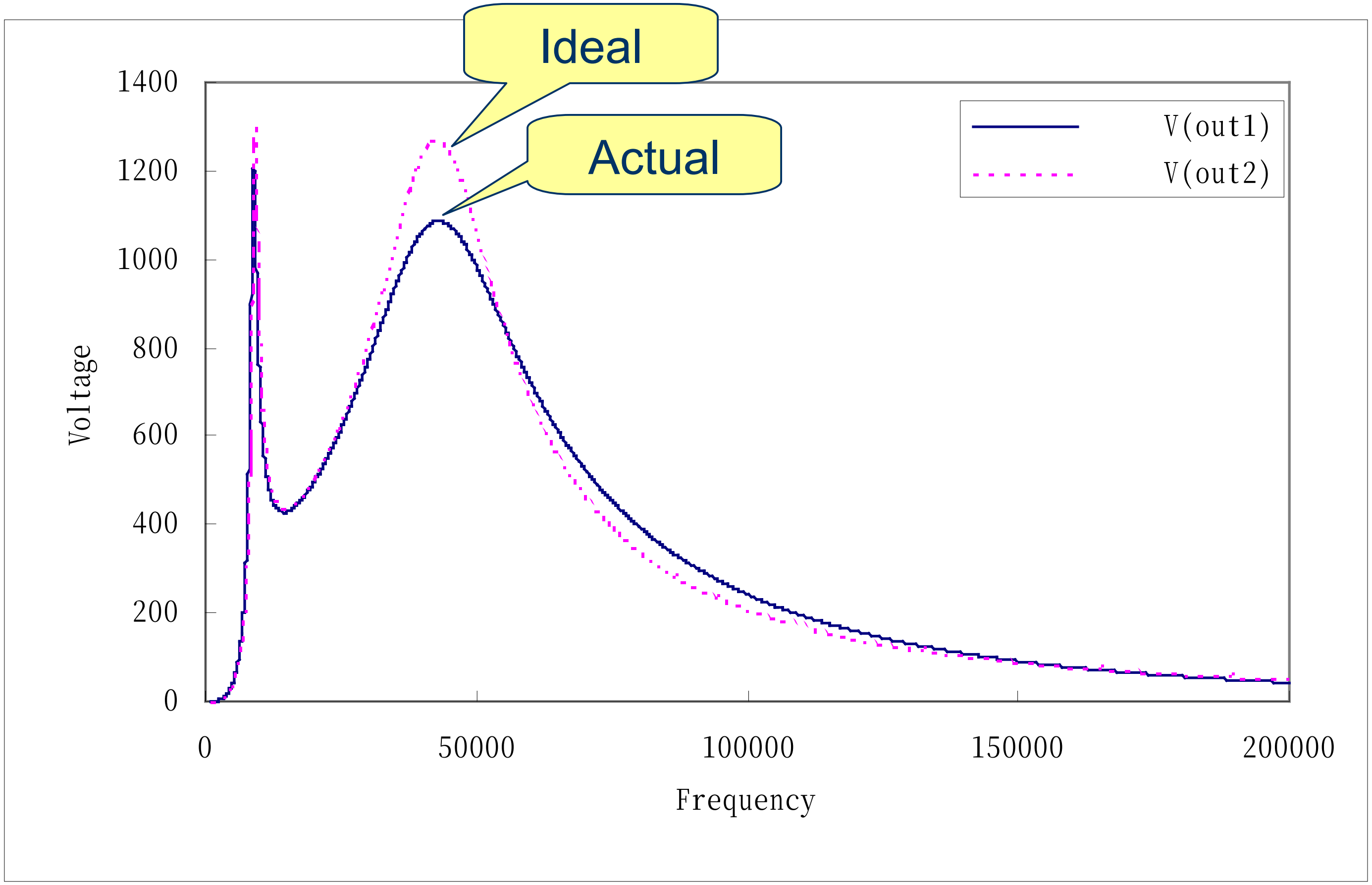



**FIG. 80**

# Power Stage Design Guideline

## Program of Design guideline

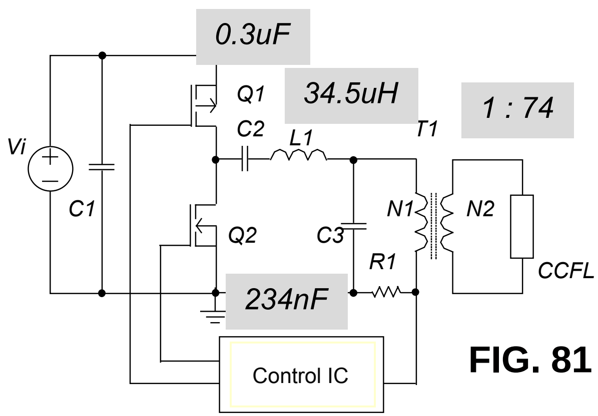



**FIG. 81**

| Parameter | Description | Typical Value | Units |
|---|---|---|---|
| VLrms | Nominal Lamp Operating Voltage at full brightness | 420 | V |
| ILrms | Nominal Lamp Operating Current at full brightness | 5 | mA |
| fo | Minimum Operating Locked Frequency | 53 | kHz |
| Lm | Primary side Magnetizing Inductance | 143 | μ H |
| Cout | Output Ballasting Capacitor | 100 | pF |
| Vin | Power circuit DC voltage | 7 | V |
| | | | |
| | | | |
| Cs | Input DC Decoupling Capacitor | 0.8 | μ H |
| N | Turns ratio of Transformer | 74 | none |

| | | | |
|---|---|---|---|
| 1. The vertual resistance of the lamp at the operating point | Rout = | 84.0 | kΩ |
| 2. The RMS value of the equivalent sinewave source voltage | Vrms = | 3.15 | V |
| 3. The input impedance | Rs = | 4.73 | Ω |
| 4. The impedance of the converted secondary capacitance | Xcop = | 48.5 | Ω |
| 5. The parallel equivalent load resistance | Rop = | 17.4 | Ω |
| 6. The total parallel net capacitance | Xctot = | 10.6 | Ω |
| 7. The net value of the required series inductor | XLs = | 11.5 | Ω |
| 8. The impedance of the primary side magnetizing inductance | XLm = | 47.6 | Ω |
| 9. The actual capacitive impedance that must be used | Xcp = | 10.6 | Ω |
| 10. The parallel capacitor value | Cp = | 284 | nF |
| 11. The series inductance value | Ls = | 34.5 | μ H |
| | | | |
| | | | |

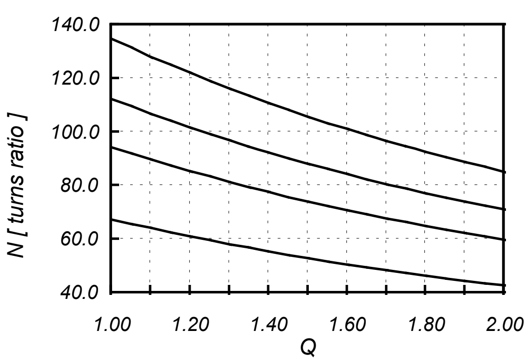



**FIG. 82**

Frequency response of output voltage

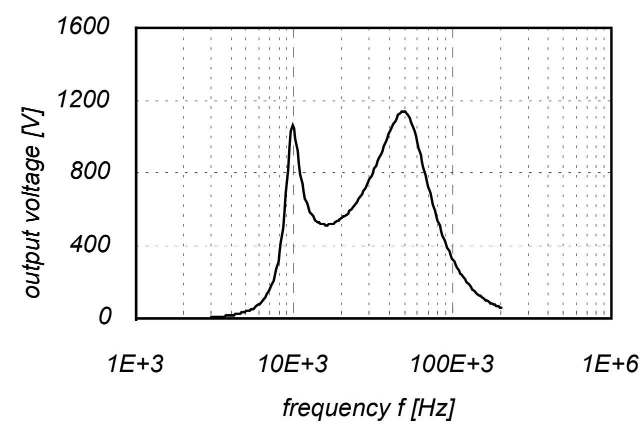
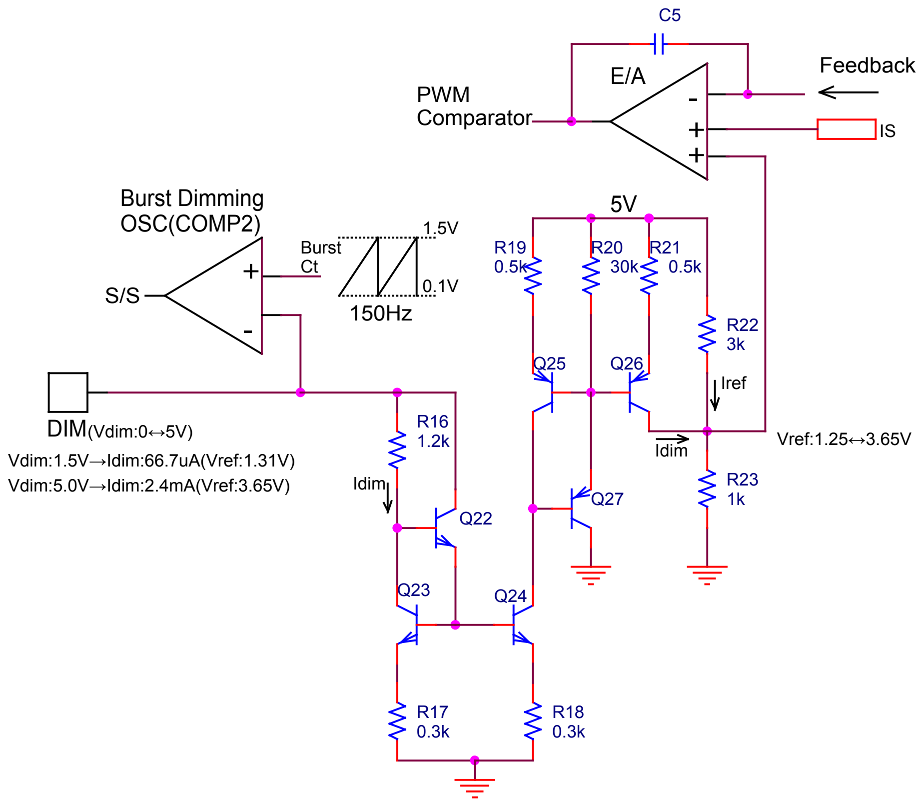



**FIG. 83**

# Mixed Dimming Control Method




Functional Block Diagram of Mixed Dimming Method

**FIG. 84**

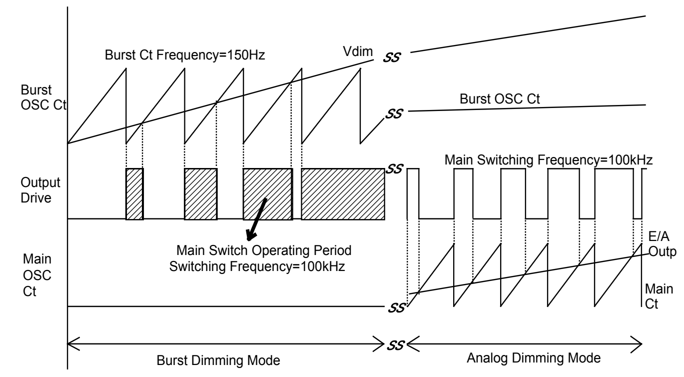



**FIG. 85** Timing Waveforms of the Control Circuit

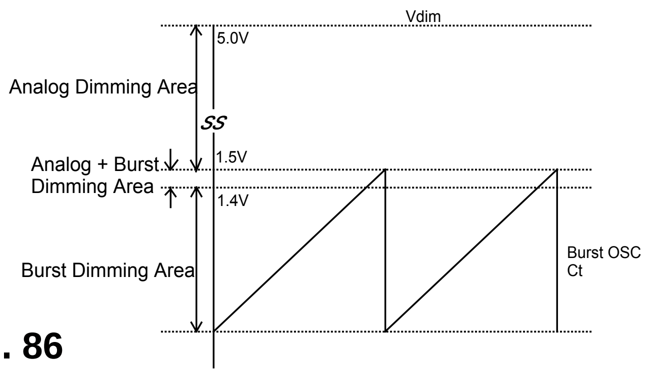
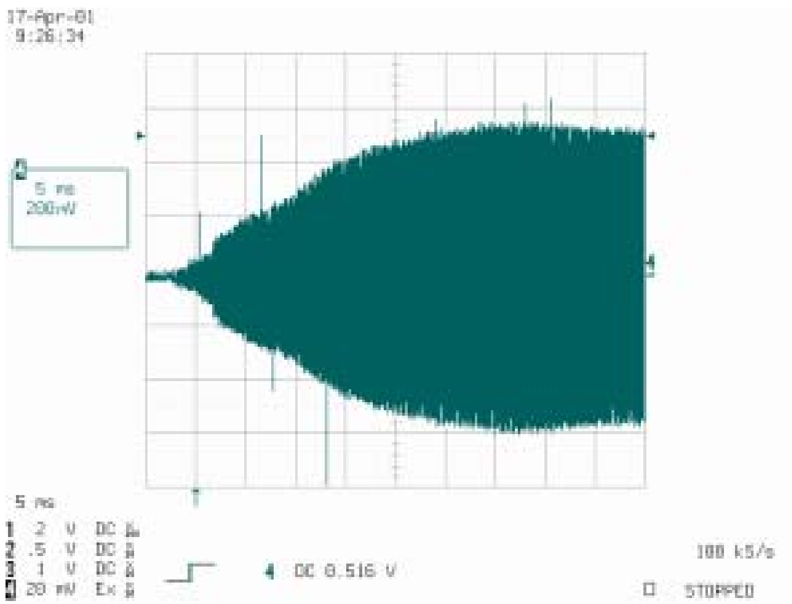



**FIG. 86**

Operating Area by the Dimming Voltage

# Experimental Results

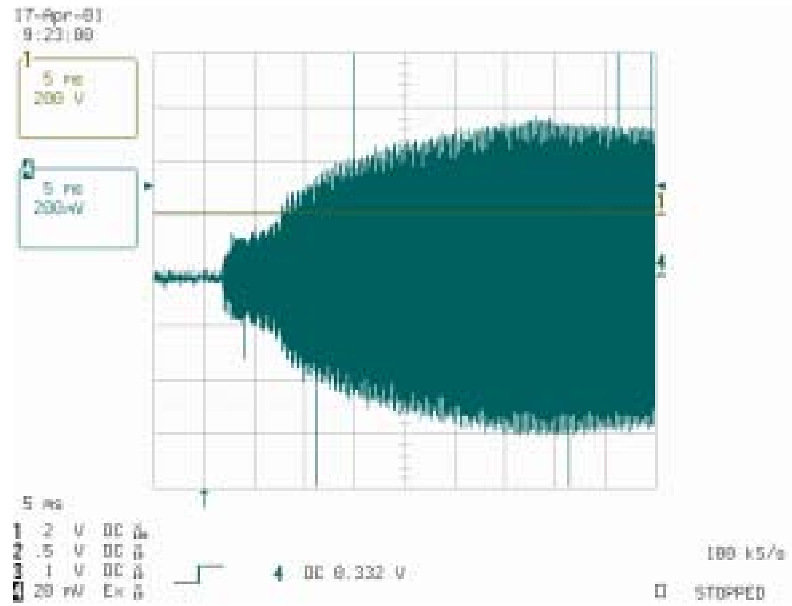
## Soft Start




- Lamp Current

Vin: 8V

**FIG. 87**




- Lamp Current

Vin: 20V

**FIG. 88**

# *Experimental Results*

## Burst Dimming Function

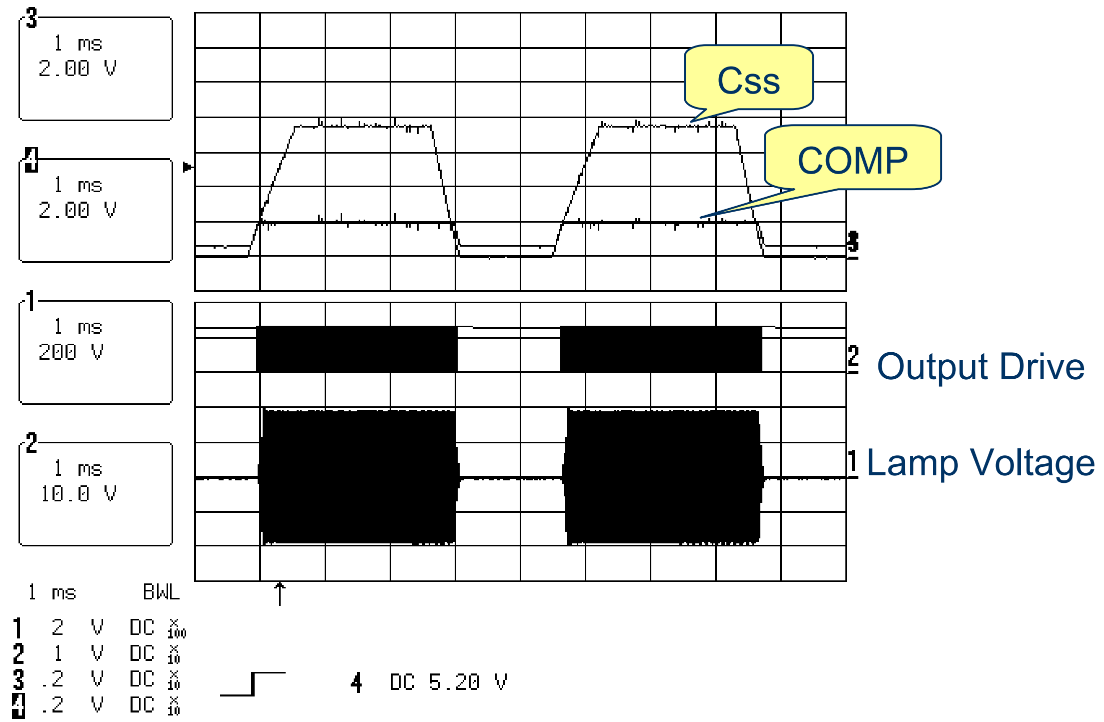



**FIG. 89**

# *Experimental Results*

## Open Lamp Regulation

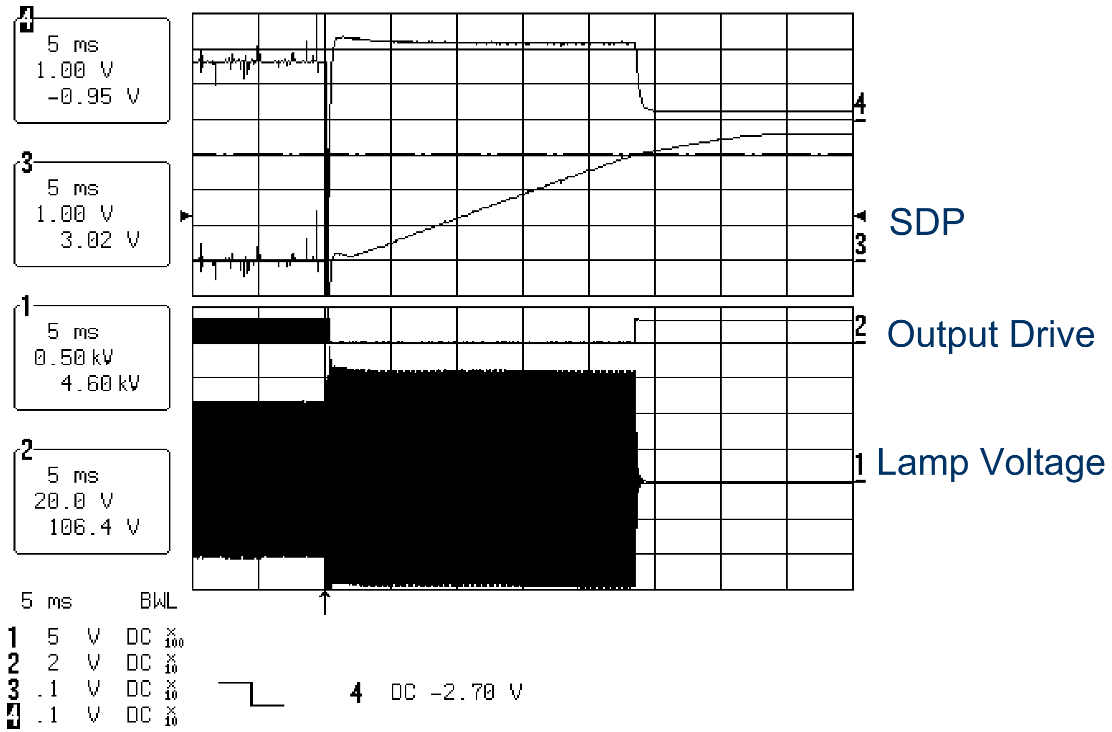



**FIG. 90**