Current resonant control IC
FA6A30/31N

Datasheet

1. Overview

FA6A30/31N is a switching power supply control IC for LLC current resonant converter.

This IC enables a LLC current resonant converter for wide input voltage range without PFC. It incorporates a 600V start up circuit, downsizing the circuit and enabling low-power consumption. It also incorporates a 600V high-side driver and low side driver, which can drive directly both high-side and low-side MOSFETs with 50% duty cycle alternatively.

To ensure high reliability of the power supply, the arm-short prevention function, high-accuracy overload protection function, and overcurrent protection function with adjustable delay time are provided.

In addition, low standby power is achieved with low standby mode selected by external signal, therefore auxiliary power supply for standby can be removed.

Since a small package of 16 pins is used and the number of exterior parts is substantially reduced, space- and cost-saving power supply can be obtained.

2. Features

・ For wide input voltage range, LLC current resonant power supply system can be configured without PFC.
・ Integrated high-side and low-side drive circuits, which can be directly connected to the power MOSFET and operates with 50% duty cycle.
・ The integrated startup circuit achieves downsized power supply and lower power consumption.
・ Operating mode can be selected from normal operation mode, low standby mode, and ultralow standby mode (STB pin)
・ During the low standby mode, standby power is lowered by the burst mode operation.
・ Integrated input filter X-capacitor discharge function decreases loss due to discharge resistance.
・ Low consumption current, 0.65mA (Vcc quiescent current).
・ Since the dead time is set automatically within the IC, switch-through and hard switching are prevented.
・ Various protection functions: overcurrent (IS pin), overload (VW,FB pin), overvoltage (VH,VCC pin) and overheat.
・ Integrated level-fixed brown-in/out function (VH pin)
・ Level-adjustable brown-in/out function (BO pin)
・ Various condition settings, including external latch-off function, overcurrent protection (detection by IS pin) delay time setting, operation setting in standby mode, and PFC with/without setting, can be made (MODE pin).
・ Built-in circuit for prevention of low-voltage malfunction (VCC,VB pin)
・ Package: SOP-16 (compliant with JEDEC)

Pacge：SOP-16
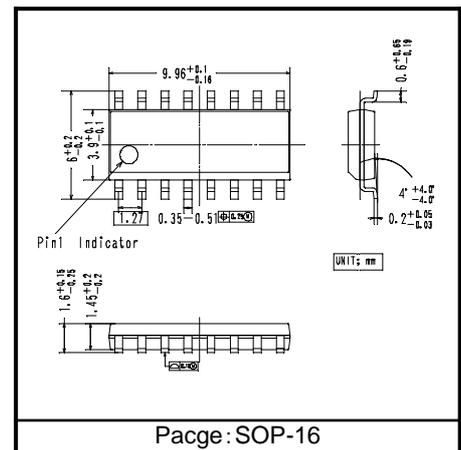
Protection functions

Type name	Overload (VW,FB pin)	Overcurrent (IS pin)	Overvoltage (VCC pin)	Protection by external signal (MODE pin)	VCC voltage drop (VCC pin)
FA6A30N	Auto recovery	Auto recovery	Latch	Latch	Auto recovery
FA6A31N	Latch	Latch	Latch	Latch	Auto recovery

3. Application circuit example
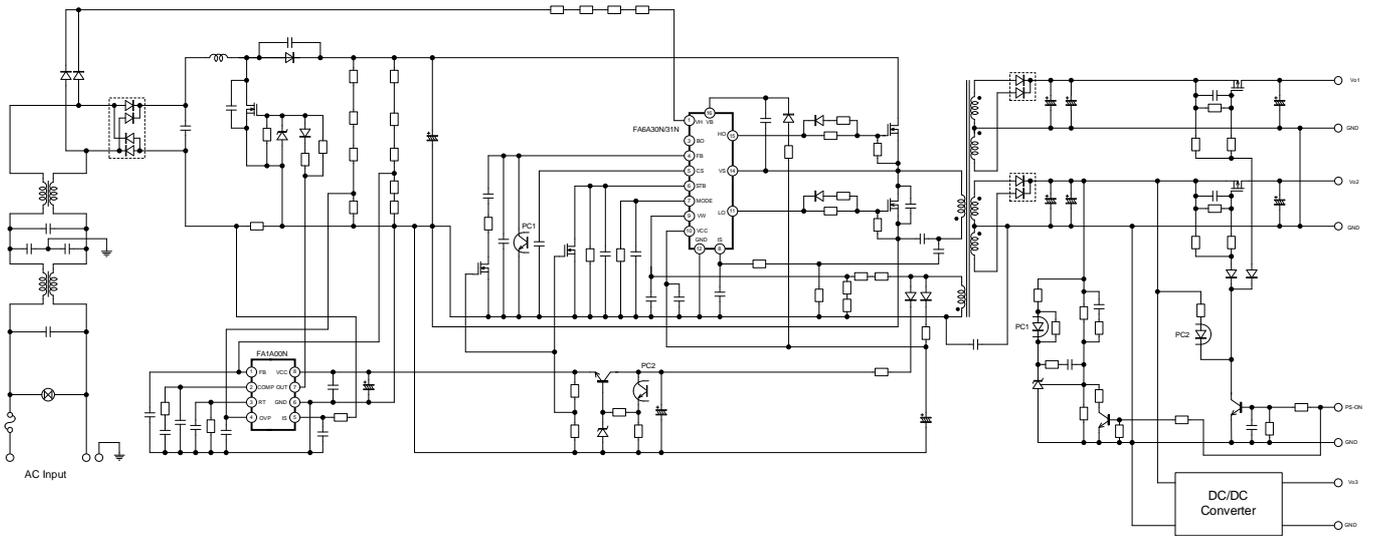


4. Block diagram

FA6A30/31N

Innovating Energy Technology
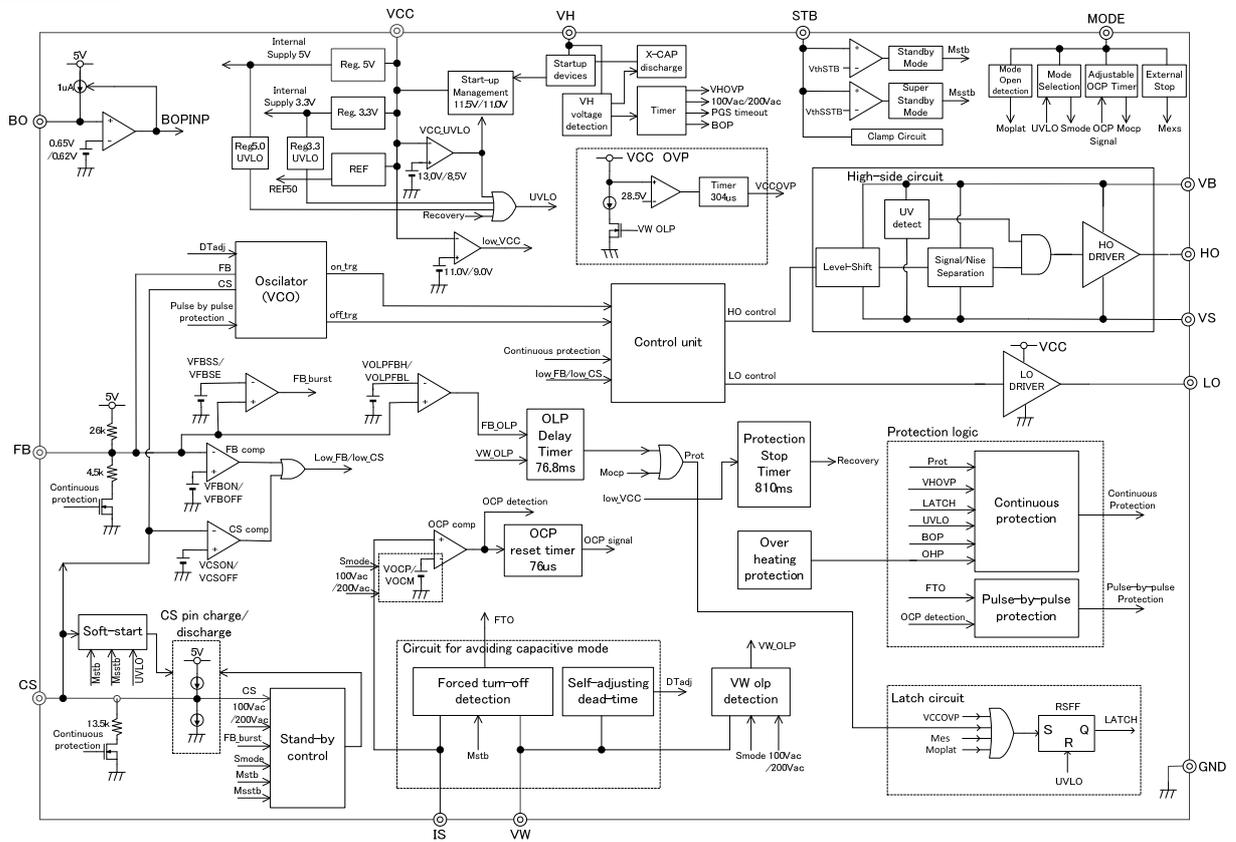
5. Functional description of pins

Pin No.	Pin name	I/O	Description	Note
1	VH	I	High voltage input	*2
2	(NC)	-	(No connection)	*3
3	BO	I/O	Brown-in/out setting	*1,*2
4	FB	I/O	Feedback input	*1,*2
5	CS	I/O	Soft start and soft end	*1
6	STB	I/O	Standby signal input	*1,*2
7	MODE	I/O	Operating mode setting and Delay time for over current protection	*1,*2
8	IS	I	Current detection	*1,*2
9	VW	I	Winding voltage detection	*2
10	VCC	I	Low side power supply	*1
11	LO	O	Low-side gate drive output	*2
12	GND	-	Ground	-
13	(NC)	-	(No connection)	*3
14	VS	I	High-side floating ground	-
15	HO	O	High-side gate drive output	*2
16	VB	I	High-side floating power supply	*1
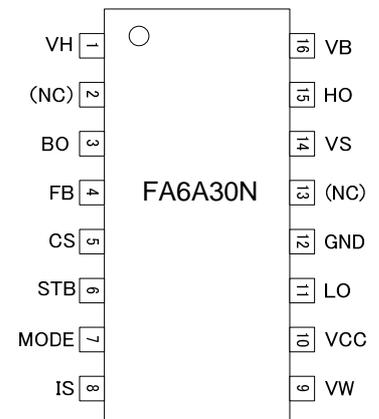
I: Input pin, O: Output pin, I/O: Input and output pin

Pin diagram (FA6A30N):
- 1 VH
- 2 (NC)
- 3 BO
- 4 FB
- 5 CS
- 6 STB
- 7 MODE
- 8 IS
- 16 VB
- 15 HO
- 14 VS
- 13 (NC)
- 12 GND
- 11 LO
- 10 VCC
- 9 VW

Notes)
*1 Connect the capacitor
*2 Connect the resistance
*3 Pin 2 and 13 are high voltage spacer and these pins are not internally connected.

6. Ratings & characteristics

(1) Absolute maximum ratings

*Stress exceeding absolute maximum ratings may malfunction or damage the device.
*"-" shows source and "+" shows sink in current descriptions.

Item	Symbol	Value	Unit
High side floating absolute voltage	V_B	-0.3 to 630	V
High side floating absolute current in no switching	I_{VB}	0.05	mA
High side floating supply offset voltage	V_S	V_B-30 to V_B+0.3	V
High side floating supply offset current in no switching	I_{VS}	0.05	mA
High side floating supply voltage ($V_{BS}=V_B-V_S$)	V_{BS}	-0.3 to 30	V
High side floating supply current in no switching	I_{BS}	1.5	mA
High side floating output voltage	V_{HO}	V_S-0.3 to V_B+0.3	V
High side floating output current *1 (V_B-V_S=30V, Pulse Width < 1us, 1pulse)	I_{HO}	-1.1/ 2.5	A
Low side supply voltage	V_{CC}	-0.3 to 30	V
Low side supply voltage in no switching	I_{CC}	3.0	mA
Low side output voltage	V_{LO}	-0.3 to V_{CC}+0.3	V
Low side output current *1 (V_{CC}=30V, Pulse Width < 1us, 1pulse)	I_{LO}	-1.1/ 1.7	A
Allowable offset supply voltage transient dv/dt	dV_S/dt	-50 to +50	kV/us
VH pin input voltage	V_H	-0.3 to 600	V
VH pin input current	I_{VH}	12	mA
IS pin input voltage	V_{IS}	-5.3 to +5.3	V
IS pin input current	I_{IS}	-100 to +100	uA
VW pin input voltage	V_{VW}	-5.3 to +5.3	V
VW pin input current	I_{VW}	-150 to +150	uA
PGS/BO/FB/MODE/CS pin input voltages	V_{IL}	-0.3 to +5.3	V
PGS/BO/FB/MODE/CS pin input currents	I_{IL}	-100 to +100	uA
STB pin input voltage	V_{STB}	-0.3 to +6.0	V
STB pin input current	I_{STB}	-100 to +100	uA
Power dissipation at T_a=25 deg.	P_d	0.83	W
Thermal resistance, junction to ambient *2	R_{thJA}	120	℃/W
Operating junction temperature	T_j	-40 to +150	℃
Storage temperature	T_{stg}	-40 to +150	℃

*1 Please consider power supply voltage and load current well and use this IC within maximum power dissipation, operating junction temperature and recommended ambient temperature in operation. The IC may cross over maximum power dissipation at normal operating condition by power supply voltage or load current within peak current absolute maximum rating value.
*2   JEDEC STANDARD test board
*3 The specified value is defined as DC applied voltage. The tolerance of negative voltage serge is defined as follows.

Tj [℃]	Min. serge voltage[V]	Max. serge width[ns]
-40	-0.90	45
25	-0.76	60
125	-0.56	82

Please contact us if the situation exceeded above table happens.

※Maximum dissipation curve

Maximum power Dissipation

Package thermal resistor
θj-a= 120℃／W
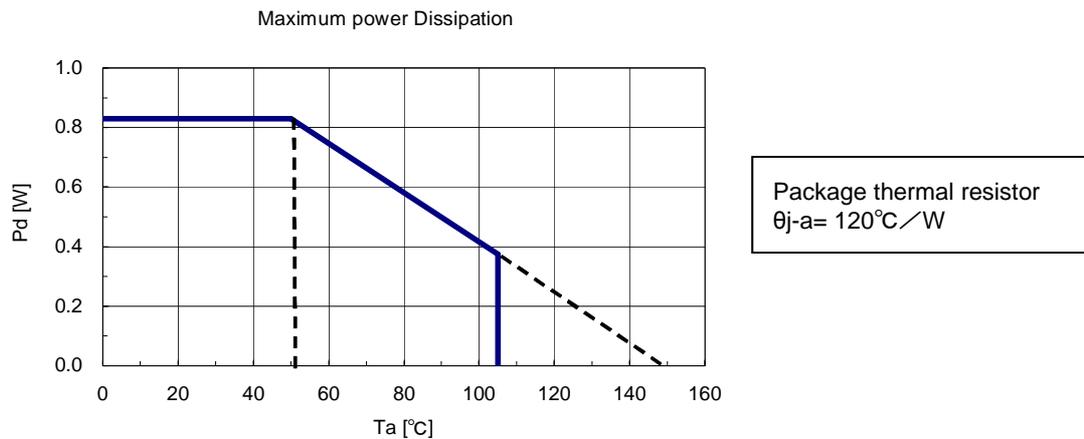
(2) Recommended operating conditions

Item	Symbol	MIN.	TYP.	MAX.	Unit
High side floating absolute voltage	V_B	V_S+14	V_S+19	V_S+27	V
High side floating supply offset voltage *1	V_S	-5	—	500	V
High side floating supply voltage ($V_{BS}=V_B-V_S$)	V_{BS}	14	19	27	V
High side floating output voltage	V_{HO}	V_S	—	V_B	V
High side floating pin capacitance *2	C_{VBS}	0.47	1.0	—	uF
Low side supply voltage	V_{CC}	14	19	27	V
Low side output voltage	V_{LO}	0	—	V_{CC}	V
Low side supply pin capacitance *3	C_{VCC}	22	220	—	uF
Low side supply pin by-pass capacitance *4	C_{VCC2}	0.10	—	—	uF
VH pin input voltage	V_H	80	—	500	V
VH pin input peak current	I_{VH}	—	—	10	mA
VH pin resistance	R_{VH}	2	10	40	kΩ
STB pin resistance *5, *6	R_{STB}	32.67	33.00	33.33	kΩ
STB pin capacitance	C_{STB}	820	1000	1200	pF
FB pin capacitance	C_{FB}	220	1000	—	pF
CS pin capacitance	C_{CS}	0.01	0.022	0.047	uF
VS pin capacitance *7	C_{VS}	220	470	1000	pF
MODE pin state selection resistance	R_{MODEA}	55.44	56	56.56	kΩ
	R_{MODEB}	99	100	101	kΩ
	R_{MODEC}	198	200	202	kΩ
	R_{MODED}	326.7	330	333.3	kΩ
External resonant inductor *8	L_{RX}	—	0	—	uH
Operating ambient temperature	T_a	-40	—	105	℃

*0 Recommended values are conditions for guaranteeing that the product operates normally. If it is used out of this condition, there is a possibility of having a negative influence on operation and reliability. Please use it after confirming enough with your products.

*1 The voltage of the VB pin must be over 10V.

*2 The high side floating pin capacitance consist a boot-strap circuit, and it should be connected between VS and VB pin. If a surge current is worried in the capacitor charge term, limit the current by the resister

*3 Start-up operation and stand-by mode power consumption are changed by the VCC pin capacitance. Please determine the capacitance with the confirmation of the actual power supply board,

*4 By-pass capacitor must be connected to VCC pin and GND pin near each pin.

*5 Remove the resistor at ultra-low standby mode.

*6 Use 33kΩ resistance with an uncertainty of 1 % at standby mode.

*7 VS pin capacitor achieves stable operation, but it causes a hard switching when the capacitance is too large. Please determine the capacitance with the confirmation of the actual power supply board.

*8 The leakage inductance of the transformer is used as the resonance inductor. The Addition of external resonance inductor is not recommended.

(3) DC electrical characteristics

- The characteristics in this section are under the described conditions as follows unless otherwise specified.
  The voltages described in conditions are DC input, not AC input.
  T_j=25℃, V_H=100V, V_{CC}=19V, V_B=19V, V_S=0V, V_{FB}=2.0V, V_{CS}=3.7V, V_{IS}=0V, V_{VW}=0V, V_{STB}=0V, V_{MODE}=0.5V, V_{PGS}=0V,
  LO pin open, HO pin open.
- The columns of '−' have no guaranteed specification.
- The operation described in the table as "switching" means the switching output of HO and LO. The items without
  description of HO or LO in condition shows the switching operation of both HO and LO.

(3)-1. High voltage input (VH pin, VCC pin）

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
VH pin input current	I_{HRUN1}	V_H=100V, V_{CC}>V_{STOFF}	2.0	3.0	4.0	uA
	I_{HRUN2}	V_H=400V, V_{CC}>V_{STOFF}	5	10	15	uA
	I_{VH0}	V_H=100V, V_{CC}=0V	0.7	1.4	2.4	mA
	I_{VH6}	V_H=100V, V_{CC}=6V	2.8	4.2	6.0	mA
Charge current to VCC pin	I_{PRE6}	V_H=100V, V_{CC}=6V	-5.5	-3.8	-2.5	mA
	I_{PRE12}	V_H=100V, V_{CC}=V_{CCON}-0.2V	-6.3	-4.3	-2.8	mA
Minimum start operation voltage on VH pin	V_{VHMIN}	VH increasing, VCC open	12	25	50	V

(3)-2. Low-side power supply (VCC pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Start operation voltage	V_{CCON}	V_{CC} increasing, Switching started point	12.4	13.0	13.6	V
Shutdown voltage	V_{CCOFF}	V_{CC} decreasing, Switching stopped point	8.5	9.0	9.5	V
IC reset voltage	V_{CCRST}	V_{CC} decreasing, IC reset	8.0	8.5	9.0	V
Hysteresis voltage	V_{CCHYS}	V_{CCHYS}=V_{CCON}-V_{CCOFF}	3.5	4.0	4.5	V
Low-side minimum operating voltage	V_{CCMIN}	LO pin sink current 1mA	1.0	2.8	4.0	V
Start-up circuit start voltage	V_{STON}	V_{CC} decreasing,	10.4	11.0	11.6	V
Start-up circuit stop voltage	V_{STOFF}	V_{CC} increasing,	10.9	11.5	12.1	V
Hysteresis voltage	V_{CCH1}	V_{CCH1}=V_{STOFF}-V_{STON}	0.3	0.5	0.7	V
	V_{CCH2}	V_{CCH2}=V_{STON}-V_{CCOFF}	1.0	2.0	3.0	V
VCC quiescent current	I_{CC1}	V_{CC}=19V, FB pin open, V_{CS}=0V, switching stops	0.50	0.65	0.80	mA
VCC operating current	I_{CC2}	V_{CC}=19V, V_{CS}=3V, V_{FB}=3V, in minimum frequency operation	0.60	0.75	0.90	mA
	I_{CC3}	V_{CC}=19V, V_{CS}=3V, V_{FB}=0.3V, in maximum frequency operation	0.75	0.95	1.15	mA
Consumption current In latch mode	I_{CCLAT}	V_{CC}=11V, after latch stops by OVP	0.50	0.65	0.80	mA
VCC quiescent current at ultra standby mode	I_{CC1}	V_{CC}=19V, V_H=0V STB pin open	30	55	80	uA
VCC rapid discharge current	I_{VCCRDC}	V_{CC}=25V , V_{VW}=4V, V_{STB}=0V	2.0	3.0	4.0	mA

(3)-3. High-side power supply (VB pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Switching start voltage	V_{BSON}	V_B increasing, V_{FB}=2V, V_S=0V, HO switching started point	7.8	8.8	9.8	V
Switching stop voltage	V_{BSOFF}	V_B decreasing, V_{FB}=2V, V_S=0V, HO switching stopped point	7.0	7.5	8.1	V
Hysteresis voltage	V_{BSHYS}	V_{BSHYS}=V_{BSON}-V_{BSOFF}	0.5	1.3	2.0	V
High-side minimum operating voltage	V_{BSMIN}	HO pin sink current 1mA	0.6	2.2	3.0	V
High-side quiescent current	I_{BS1}	V_{FB}=0V, HO switching stops	25	50	100	uA
High-side operating current	I_{BS2}	V_{FB}=3V, in minimum frequency operation	0.05	0.10	0.25	mA
	I_{BS3}	V_{FB}=0.3V, in maximum frequency operation	0.05	0.10	0.25	mA

(3)-4. MODE Selection (MODE pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Mode selection source current	I_{MODE}	Mode pin source current	-11.2	-10.0	-8.8	uA
Mode selection time	t_{MODE}		32	40	48	ms
Mode selection resistor Open detection voltage	V_{modeO}	No Switching if Vmode > VmodeO	4.10	4.40	4.70	V
VCC charge resume voltage	V_{modeF}	Decreasing Vmode	0.54	0.60	0.66	V

Mode selection list

MODE	MODE pin resistor	Burst setting	With/Without PFC setting
A	56kΩ	High frequency mode	With
B	100kΩ	High frequency mode	Without
C	200kΩ	Low frequency mode	With
D	330kΩ	Low frequency mode	Without

(3)-5. External-fault latch stop function (MODE pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Source current	I_{LATS}	V_{mode} = 0V	-33	-25	-17	uA
Threshold voltage for external-fault stop	V_{THLAT}	V_{mode} decreasing	0.30	0.35	0.40	V
Clamp voltage	V_{CLPLAT}	I_{mode}= -10uA	0.43	0.48	0.53	V
Delay time to external-fault stop	$t_{MODEDLY}$	V_{mode} = 0.5V to 0V, The term of switching	244	304	364	us

(3)-6. Input voltage mode setting (VH pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Threshold voltage to change input voltage mode setting	V_{INH}	V_H increasing, High VH mode	214	240	266	V
			(151)	(170)	(188)	(V_{ac})
	V_{INL}	V_H decreasing, Low VH mode	204	226	249	V
			(144)	(160)	(176)	(V_{ac})
Delay time to change mode setting from low VH mode to high VH mode	$t_{DLY1TO2}$	V_H increasing	3	5	7	us
Delay time to change mode setting from high VH mode to low VH mode	$t_{DLY2TO1}$	V_H decreasing	21.0	26.5	32.0	ms

(3)-7. X-CAP Discharge Function (VH pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
VH Amplitude ensured AC detection (Note1)	V_{HACDET}	V_H=20V to 100V	72	—	—	V
		V_H=200V to 350V	100	—	—	V
Delay time of AC cutting Detection	t_{ACDET}		42	56	70	ms
Average discharge current of X-CAP	I_{XCD}	V_H=120V	1	2	4	mA
On Discharge time	t_{ONXCD}		1.2	1.5	1.8	ms
Off discharge time	t_{OFFXCD}		0.4	0.5	0.6	ms

 (Note1) Input the signal of the amplitude more than the rated value.

(3)-8. Oscillator (FB pin, CS pin, HO pin, LO pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Duty cycle	D_{UTY}	V_{CC}=19V, V_B=19V, V_{FB}=2V, (Note 1)	48	50	52	%
Maximum oscillation frequency	f_{MAX}	V_{CC}=19V, V_B=19V, V_{FB}=0.3V, V_{CS}=4V	300	350	400	kHz
Minimum oscillation frequency	f_{MIN}	V_{CC}=19V, V_B=19V, V_{FB}=4V, V_{CS}=4V	32	38	44	kHz

 (Note 2) The duty cycle of high side and low side are same because HO and LO are symmetric at phase difference 180 degrees. If the times are defined as follows, the duty cycle D_{UTY} is shown as following equation.

$$D_{UTY} = (t_{H1}-t_{L1}) / (t_{L2}-t_{L1}) = (t_{L2}-t_{H1}) / (t_{H2}-t_{H1})$$

   $t_{L1:}$ A certain LO turn-on point
   t_{H1}: A HO turn-on point just after LO turn-off after t_{L1}
   t_{L2}: A LO turn-on point just after HO turn-off after t_{H1}
   t_{H2}: A HO turn-on point just after LO turn-off after t_{L2}

Innovating Energy Technology

(3)-9. Feedback section (FB pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
FB pin source current	I_{FB}	V_{FB}=0V	-250	-190	-130	uA
FB pin input resistance	R_{FB}	I_{FB_1V}=I_{FB} at V_{FB}=1V, I_{FB_2V}=I_{FB} at V_{FB}=2V, R_{FB}=1V/(I_{FB_1V} -I_{FB_2V}}	18	26	34	kΩ
Switching start voltage	V_{FBON}	V_{FB} increasing, Switching started point	0.25	0.30	0.35	V
Switching stop voltage	V_{FBOFF}	V_{FB} decreasing, Switching stopped point	0.22	0.26	0.30	V
Hysteresis voltage	V_{FBHYS}	V_{FBHYS}=V_{FBON}-V_{FBOFF}	0.02	0.04	0.06	V
FB pin discharge resistance	R_{FBDCHG}	V_{FB}=1V, protection	3.0	4.5	6.0	kΩ

(3)-10. Soft-start operation (CS pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
CS pin source current	I_{CSSO1}	Startup	-7.2	-5.5	-3.8	uA
	I_{CSSO21}	Standby⇒Normal V_H=100V	-58.0	-44.0	-30.0	uA
	I_{CSSO22}	Standby⇒Normal V_H=300V	-29.0	-22.0	-15.0	uA
Switching start voltage	V_{CSONS}	Startup	0.35	0.40	0.45	V
Switching stop voltage	V_{CSOFFS}	Startup	0.25	0.30	0.35	V
Hysteresis voltage	V_{CSHYSS}	V_{CSHYSS} = V_{CSONS} -V_{CSOFFS}	0.05	0.10	0.15	V
Soft-start remove voltage	V_{CSSF}	V_{CS} increasing	3.6	4.0	4.4	V

(3)-11. Low standby mode and ultra low standby mode (STB pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
STB pin source current	I_{STBSO}	Vstb=0	-35	-30	-25	uA
Standby mode detection Voltage	V_{THSTBH}		0.30	0.35	0.40	V
	V_{THSTBL}		0.25	0.30	0.35	V
Low standby mode detection hysteresis voltage	$V_{THSTBHYS}$	$V_{THSTBHYS}$ =V_{THSTBH} −V_{THSTBL}	0.02	0.05	0.08	V
Standby mode detection Delay time	t_{DLSTB}		85	105	125	ms
Ultra low standby mode detection voltage	$V_{THSSTBH}$		1.35	1.50	1.65	V
	$V_{THSSTBL}$		1.25	1.40	1.55	V
Ultra low standby mode detection hysteresis voltage	$V_{THSSTBHYS}$	$V_{THSSTBHYS}$ =$V_{THSSTBH}$ −$V_{THSSTBL}$	0.05	0.10	0.15	V
STB pin clump voltage	V_{CLPSTB}	STB pin :open	4.5	5.2	5.9	V

(3)-12. Standby operation (CS pin, VCC pin)

Item	Symbol	Conditions		MIN.	TYP.	MAX.	Unit
CS pin charge current	I_{CSCHG1}	V_H=100V as low VH mode, V_{fb} =4.5V, V_{CS}= 0V (Note1)		-58.0	-44.0	-30.0	uA
	I_{CSCHG2}	V_H=300V as high VH mode, V_{fb} = 4.5V, V_{CS}=0V (Note1)		-29.0	-22.0	-15.0	uA
CS pin discharge current	I_{CSDIS1}	V_H=100V as low VH mode, V_{fb} = 3.5V, V_{CS}=3V		60.0	88.0	116.0	uA
	I_{CSDIS2}	V_H=300V as high VH mode, V_{fb} =3.5V , V_{CS}=3V (Note1)		30.0	44.0	58.0	uA
CS pin switching start voltage	V_{CSON1H}	V_H=100V as low VH mode, V_{CS} increasing, Switching started point	HM	1.08	1.20	1.32	V
	V_{CSON1L}		LM	1.08	1.20	1.32	
	V_{CSON2H}	V_H=300V as high VH mode, V_{CS} increasing, Switching started point	HM	0.81	0.90	0.99	V
	V_{CSON2L}		LM	1.08	1.20	1.32	
CS pin switching stop voltage	$V_{CSOFF1H}$	V_H=100V as low VH mode, V_{CS} decreasing, Switching stopped point	HM	0.99	1.10	1.21	V
	$V_{CSOFF1L}$		LM	0.99	1.10	1.21	
	$V_{CSOFF2H}$	V_H=300V as high VH mode, V_{CS} decreasing, Switching stopped point	HM	0.72	0.80	0.88	V
	$V_{CSOFF2L}$		LM	0.99	1.10	1.21	
CS pin hysteresis voltage	V_{CSHYS1}	V_{CSHYS1}=V_{CSON1}-V_{CSOFF1}		0.05	0.10	0.15	V
	V_{CSHYS2}	V_{CSHYS2}=V_{CSON2}-V_{CSOFF2}		0.05	0.10	0.15	V
CS pin fast discharge resistance	R_{CSCHG}	V_{CS}=4V, V_{STB}=1V to 0V		9.5	13.5	17.5	kΩ
FB pin burst soft-start start voltage	V_{FBSS}	FB increasing		4.1	4.3	4.5	V

(Note 3) HM means High frequency Mode, and LM means Low frequency Mode.

(3)-13. Self-adjusting dead time function (VW pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Min. |dV$_{VW}$/dt| of low side turn on (Note4)	-DV$_{VWM}$	(Note5)	0.6	—	—	V/us
Min. |dV$_{VW}$/dt| of high side turn on (Note4)	DV$_{VWP}$	(Note 6)	0.6	—	—	V/us
Delay time for VW pin detection in low side turn on	t$_{DVWONMS}$	V$_{STB}$=1V (Note 7)	350	450	550	ns
	t$_{DVWONMN}$	V$_{STB}$=0V (Note 7)	100	200	300	ns
Delay time for VW pin detection in high side turn on	t$_{DVWONPS}$	V$_{STB}$=1V (Note 8)	350	450	550	ns
	t$_{DVWONPN}$	V$_{STB}$=0V (Note 8)	100	200	300	ns
Minimum dead time	t$_D$	(Note 9)	380	430	480	ns
Maximum dead time	t$_{DMAX}$	(Note 10)	15	20	25	us

(Note 4) Input the signal of the inclination more than the rated value.
(Note 5) After V$_{VW}$ raise to 4V from 0V, fall with the slope of DV$_{VWM}$ (=-dV$_{VW}$/dt) toward -4V, and detect the LO turn-on point.
(Note 6) After V$_{VW}$ fall to -4V from 0V, raise with the slope of DV$_{VWP}$ (=dV$_{VW}$/dt) toward +4V, and detect the HO turn-on point.
(Note 7) The term from step signal input to VW pin (V$_{VW}$=0V to -2V) to LO turn-on.
(Note 8) The term from step signal input to VW pin (V$_{VW}$=0V to +2V) to HO turn-on.
(Note 9) The term from LO turn-off to HO turn-on with step signal input to VW pin (V$_{VW}$=-4V to +4V).
(Note 10) The term from LO turn-off to HO turn-on, under the self-adjusting dead time operation mode.

(3)-14. Low-side gate driver (LO pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
High level output voltage	V$_{OH\_LO}$	V$_{CC}$=19V, V$_{FB}$=2V, I$_{OL}$=-100mA	14.5	17.5	18.7	V
Low level output voltage	V$_{OL\_LO}$	V$_{CC}$=19V, V$_{FB}$=2V, I$_{OL}$=+100mA	0.15	0.6	1.5	V
High level shorted current	I$_{OH\_LO}$	(Note 11)	-1.0	-0.6	-0.3	A
Low level shorted current	I$_{OL\_LO}$	(Note 12)	0.4	1.0	1.6	A
Rise time	t$_{R\_LO}$	C$_{LO}$=1000pF, LO level 10% to 90%	10	50	100	ns
Fall time	t$_{F\_LO}$	C$_{LO}$=1000pF, LO level 90% to 10%	5	35	70	ns

(Note 11) Pulse input to LO, negative pulse width<1us, 1pulse, low level V$_{LO}$=0V.
(Note 12) Pulse input to LO, positive pulse width<1us, 1pulse, high level V$_{LO}$=19V.

Fuji Electric

Innovating Energy Technology

(3)-15. High-side gate driver (HO pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
High level output voltage	V_{OH_HO}	V_{BS}=19V, V_S=0V, V_{FB}=2V, I_{OH}=-100mA	13.3	17.1	18.7	V
Low level output voltage	V_{OL_HO}	V_{BS}=19V, V_S=0V, V_{FB}=2V, I_{OH}=+100mA	0.12	0.5	1.3	V
High level shorted current	I_{OH_HO}	V_{BS}=19V, V_S=0V, (Note 13)	-1.0	-0.6	-0.3	A
Low level shorted current	I_{OL_HO}	V_{BS}=19V, V_S=0V, (Note 14)	0.6	1.5	2.4	A
Rise time	t_{R_HO}	V_{BS}=19V, V_S=0V, C_{HO}=1000pF HO level 10% to 90%	10	50	100	ns
Fall time	t_{F_HO}	V_{BS}=19V, V_S=0V, C_{HO}=1000pF HO level 90% to 10%	5	30	60	ns

(Note 13) Pulse input to HO, negative pulse width<1us, 1pulse, low level V_{HO}=0V.
(Note 14) Pulse input to HO, positive pulse width<1us, 1pulse, high level V_{HO}=19V.

(3)-16. Brown out protection (VH pin, BO pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Brown-in voltage	V_{BI}	V_H increasing, V_{FB}=2V Switching started point	87	93	99	V
			(61.5)	(65.8)	(70.9)	(V_{ac})
Brown-out voltage	V_{BO}	V_H decreasing, V_{FB}=2V Switching stopped point	85	90	95	V
			(60.0)	(63.6)	(67.2)	(V_{ac})
Hysteresis voltage	V_{BOHYS}	$V_{BOHYS} = V_{BI} - V_{BO}$	1.4	3	6	V
Delay time for Brown-in	t_{PDBI}		116	144	172	us
Delay time for Brown-out	t_{PDBO}	(Note 15)	84	107	130	ms
BO pin hysteresis current	I_{BOHYS}	$V_{BO=}$0.7V	-1.10	-1.00	-0.90	uA
BO pin threshold voltage of Brown-out	V_{BOH}	V_{BO} increasing	0.615	0.650	0.685	V
	V_{BOL}	V_{BO} decreasing	0.600	0.635	0.670	V
	V_{BOHYS2}	$V_{BOHYS2} = V_{BOH} - V_{BOL}$	0.000	0.015	0.030	V
BO pin open detection Voltage	V_{BOOP}		4.1	4.4	4.7	V

(Note 15) V_H decreasing, V_{FB}=2V, the term from V_H step input as $V_H<V_{BO}$ to switching stopped point.

Apr,2018 DS-142J Rev2.1   12/46

(3)-17. Over voltage protection (VCC pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Over voltage threshold	V_{CCOVP}	V_{CC} increasing, V_{FB}=2V, Switching stopped point	27.5	28.5	29.5	V
Delay time to over voltage	t_{VCCDLY}	(Note 16)	244	304	364	us

(Note 16) V_{CC} increasing, V_{FB}=2V, the term from V_{CC} step input as $V_{CC}>V_{INL}$ to switching stopped point.

(3)-18. Over voltage protection (VH pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Over voltage threshold	V_{HOVPH}	VH increasing, VFB=2V, Switching stopped point	475	525	575	V
Restart voltage	V_{HOVPL}	VCC decreasing, VFB=2V, Switching restarted point	450	500	550	V
Hysteresis voltage	$V_{HOVPHYS}$		20	25	30	V

(3)-19. Over current protection (IS pin, MODE pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Over current detection voltage of low side	V_{OCM2}	With PFC or 200Vac line without PFC	-3.7	-3.5	-3.3	V
	V_{OCM1}	100Vac line without PFC	-4.3	-4.0	-3.7	V
Over current detection voltage of high side	V_{OCP2}	With PFC or 200Vac line without PFC	3.3	3.5	3.7	V
	V_{OCP1}	100Vac line without PFC	3.7	4.0	4.3	V
Delay time for low side turn off in over current	t_{DLOCM}	V_{FB}=2V, (Note 17)	50	100	200	ns
Delay time for high side turn off in over current	t_{DLOCP}	V_{FB}=2V, (Note 18)	50	100	200	ns
Reset time of over current detection	t_{OCRST}	V_{FB}=2V, (Note 19)	60	76	92	us
Delay time of over current (MODE pin)	$V_{OCPDLYL}$	Start Voltage for Charge	0.54	0.60	0.66	V
	$V_{OCPDLYH}$	Start Voltage for Discharge	0.72	0.80	0.88	V
	$V_{OCPDHYS}$	$V_{OCPDHYS} = V_{OCPDLYH} - V_{OCPDLYL}$	0.15	0.20	0.25	V
	$I_{OCPDLYC}$	Charge Current	-34.5	-26.5	-18.5	uA
	N_{OCPDLY}	Cycle Number of Charge and Discharge	—	36	—	cycle
Restart time of over current (FA6A30N)	t_{OCOFF}	From switching stop to state setting	660	810	960	ms
IS level shift resistance	R_{ISLVS}		200	240	280	kΩ

(Note 17) The term from V_{IS} step input (-3V to -5V) to LO turn-off point.
(Note 18) The term from V_{IS} step input (+3V to +5V) to HO turn-off point.
(Note 19) V_{IS} is step pulse inputted (0V to -4.5V). The pulse period where the OCP operates by decreasing the pulse period.

FA6A30N_31N Datasheet

(3)-20. Over load Protection (VW, FB pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Blanking time of over load detection by VW	t_{VW}	V_{IS}=0V, V_{VW} pulse step input V_{VW}=0V to 4V, VW detection ignored time	300	500	700	ns
Over load detection VW voltage	V_{OLPVW1}	With PFC or 100Vac line w/o PFC	3.22	3.36	3.50	V
	V_{OLPVW2}	200Vac line w/o PFC	2.96	3.08	3.20	V
Over load detection FB voltage	V_{OLPFBH}	V_{FB} increasing Switching stopped point	4.1	4.3	4.5	V
Over load detection disable FB voltage	V_{OLPFBL}	V_{FB} decreasing, Return point of repeated restart	3.9	4.1	4.3	V
Delay time of over current and over load	t_{OLPDL}Y	V_{FB}=4.5V, The term of switching	60.8	76.8	92.8	ms
Hysteresis voltage	$V_{OLPFBHYS}$	$V_{OLPFBHYS}$ =V_{OLPFBH}-V_{OLPFBL}	0.1	0.2	0.3	V
VW over load detection reset time	t_{OLRST}		86	108	130	us
Restart time of over current and over load (FA6A30N)	t_{OLPOFF}	From switching stop to state setting	660	810	960	ms
VW level shift resistance	R_{VWLVS}	V_{VW}=0V	80	100	120	kΩ

(3)-21. Preventing Arm-short function (IS pin, VW pin))

Item	Symbol	Conditions		MIN.	TYP.	MAX.	Unit
Blanking time of forced turn-off detection	t_{VWDET}	V_{IS}=0V, V_{VW} pulse step input V_{VW}=0V to -1.5V, VW detection ignored time		300	500	700	ns
VW pin threshold voltage of low side forced turn-off	V_{THVWPN}	Normal Mode	V_{IS}=0V, (Note 20), (Note 22)	0.35	0.40	0.45	V
	V_{THVWPS}	Standby Mode		-0.05	0.00	0.05	V
VW pin threshold voltage of high side forced turn-off	V_{THVWMN}	Normal Mode	V_{IS}=0V, (Note 21), (Note 22)	-0.25	-0.20	-0.15	V
	V_{THVWMS}	Standby Mode		0.15	0.20	0.25	V
VW pin detection delay time of low side forced turn-off	$t_{DVWOFFP}$	The term from V_{VW} pulse step input V_{VW}=0V to +2V to LO turn-off		150	250	350	ns
VW pin detection delay time of high side forced turn-off	$t_{DVWOFFM}$	The term from V_{VW} pulse step input V_{VW}=0V to -2V to HO turn-off		150	250	350	ns
IS pin threshold voltage of low side forced turn-off	V_{THISM}	(Note 23)		-1.15	-1.00	-0.85	V
IS pin threshold voltage of high side forced turn-off	V_{THISP}	(Note 24)		0.85	1.00	1.15	V
IS pin detection delay time of low side forced turn-off	$t_{DISOFFM}$	The term from V_{VW} pulse step input V_{VW}=0V to +1.5V, and V_{IS}=-2V to -0.5V to LO turn-off		50	100	200	ns
IS pin detection delay time of high side forced turn-off	$t_{DISOFFP}$	The term from V_{VW} pulse step input V_{VW}=0V to -1.5V, and V_{IS}=+2V to +0.5V to HO turn-off		50	100	200	ns

(Note 20) Pulse step signal is inputted to VW pin as width 4us and amplitude 0V to +V_{VW} with increasing the V_{VW}. Detect LO turn-off level.

(Note 21) Pulse step signal is inputted to VW pin as width 4us and amplitude 0V to -V_{VW} with increasing the V_{VW}. Detect HO turn-off level.

(Note 22) In stand-by mode, forced turn-off is operated by VW. In normal mode, VW does not turn-off directly, but it permits to operate forced turn-off by IS detection.

(Note 23) 2us after LO turn-off, step signal (0V to +1.5V) inputted to V_{VW}. Successively, pulse step signal is inputted to IS pin as width 2us and amplitude 0V to -V_{IS} with increasing the V_{IS}. Detect LO turn-off level.

(Note 24) 2us after HO turn-off, step signal (0V to -1.5V) inputted to V_{VW}. Successively, pulse step signal is inputted to IS pin as width 2us and amplitude 0V to +V_{IS} with increasing the V_{IS}. Detect HO turn-off level.

(3)-22. Thermal shutdown protection (Without external pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Thermal shutdown temperature	T_{JOH}	V_{CC}=19V, V_{FB}=2V, Switching stopped point	126	136	146	℃
Restart temperature	T_{JOHR}	V_{CC}=19V, V_{FB}=2V, Switching restart point	110	120	130	℃

(3)-23. VCC voltage drop protection (VCC pin)

Item	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Drop protection voltage	V_{DVCCL}	VCC decreasing	8.5	9.0	9.5	V
Drop protection disable voltage	V_{DVCCH}	VCC increasing	10.4	11.0	11.6	V
Restart time of drop protection	$t_{DVCCOFF}$	VCC = 19V to V_{DVCCL} - 0.2V to 19V, From switching stop to state setting	660	810	960	ms

7. Characteristic curve

The conditions are as follows unless otherwise specified.

T_j=25℃, V_H=100V, V_{CC}=19V, V_B=19V, V_S=0V, V_{FB}=2.0V, V_{CS}=3.7V, V_{IS}=0V, V_{VW}=0V, V_{STB}=0V, V_{MODE}=0.5V, V_{PGS}=0V, LO pin open, HO pin open.

Notes）

（1）"-" shows source current and "+" shows sink in current regulations of the current.

（2）The data listed here show the typical characteristics of an IC, and does not guarantee the characteristic.

Input voltage dependency

VH pin input current
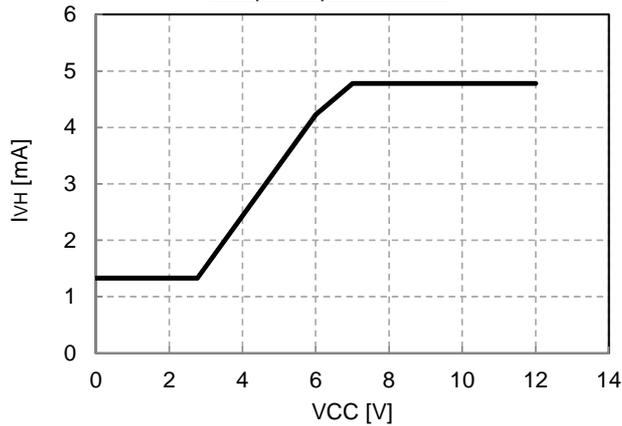
VCC quiescent current
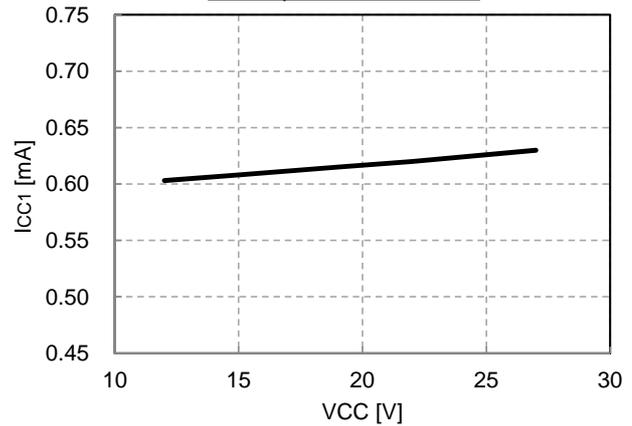
Maximum oscillation frequency
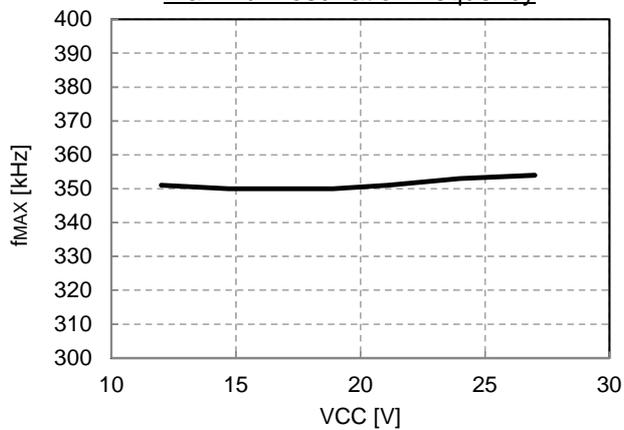
Minimum oscillation frequency
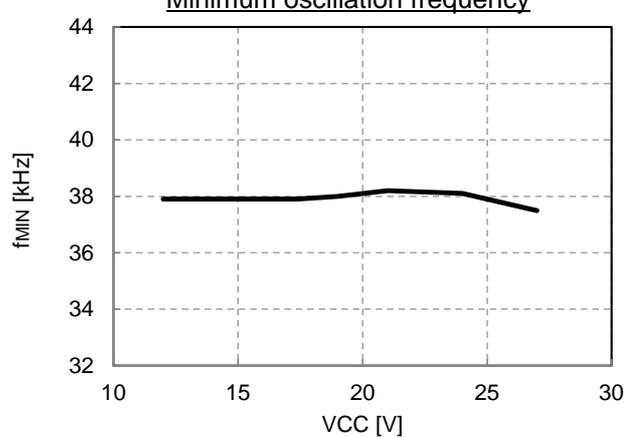
Switching start voltage
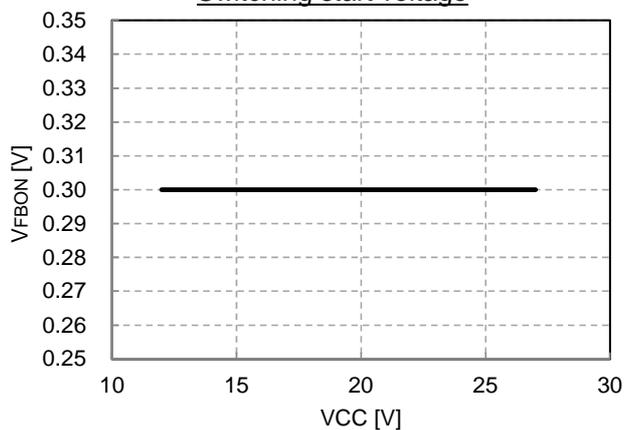
Oscillation frequency

Temperature dependency

VH pin input current

VCC pin Start operation voltage

VCC quiescent current

VB pin Switching start voltage

High-side quiescent current

VCC quiescent current

Temperature dependency

MODE selection time

Maximum oscillation frequency

Minimum oscillation frequency

CS pin source current

STB pin source current

Over load detection VW voltage
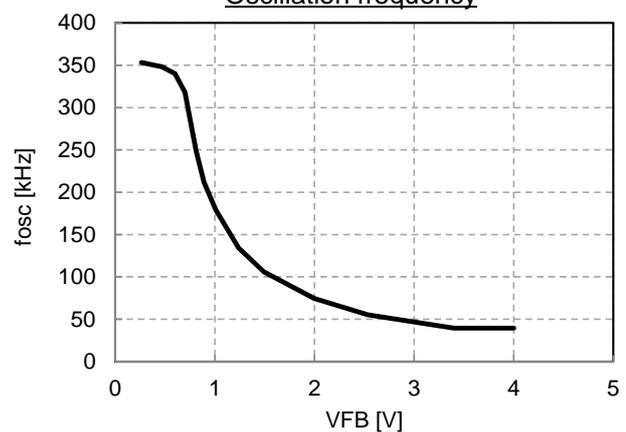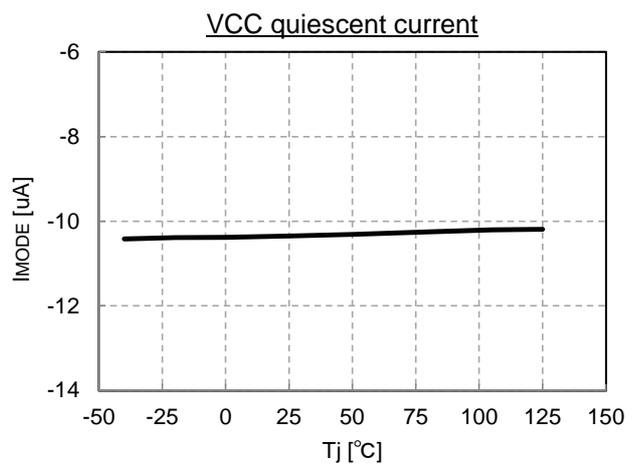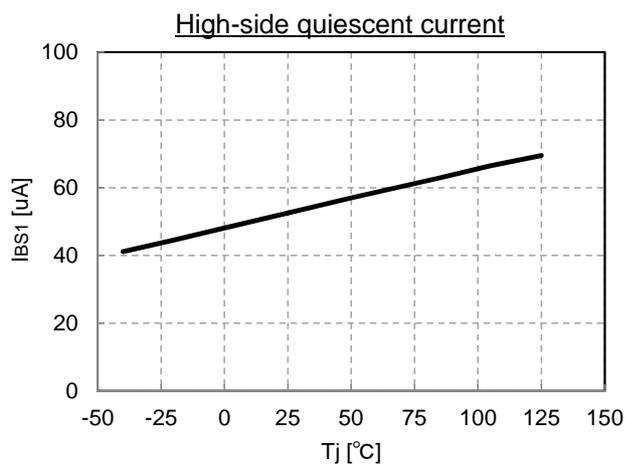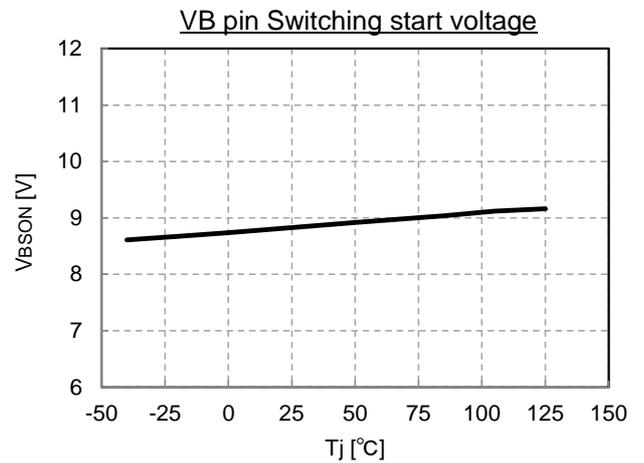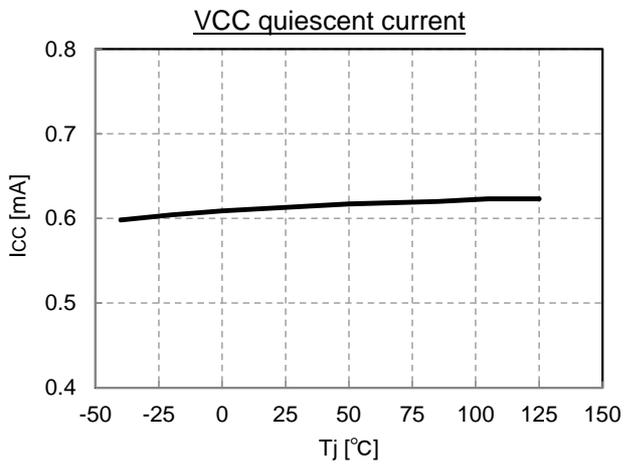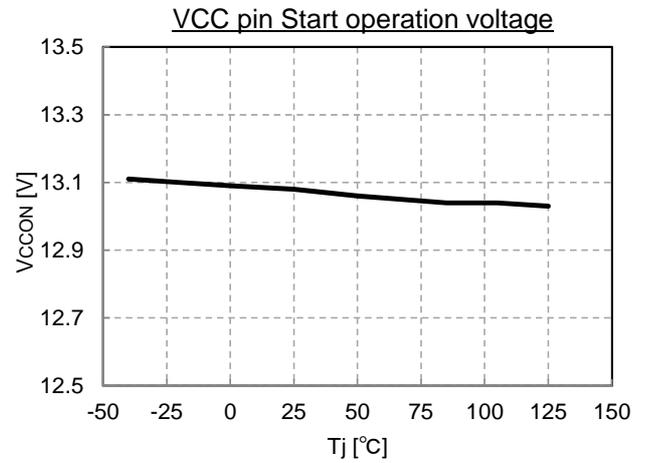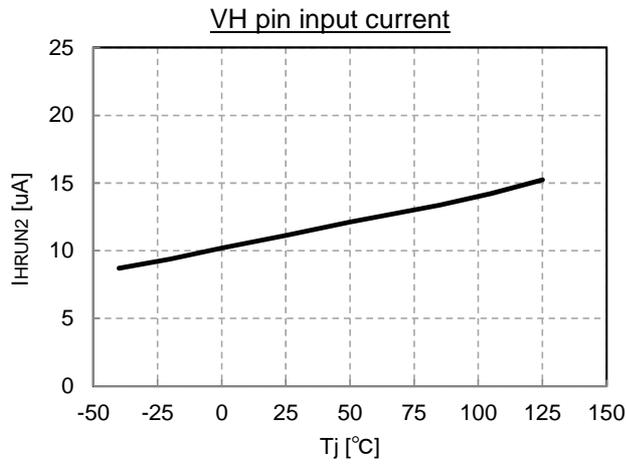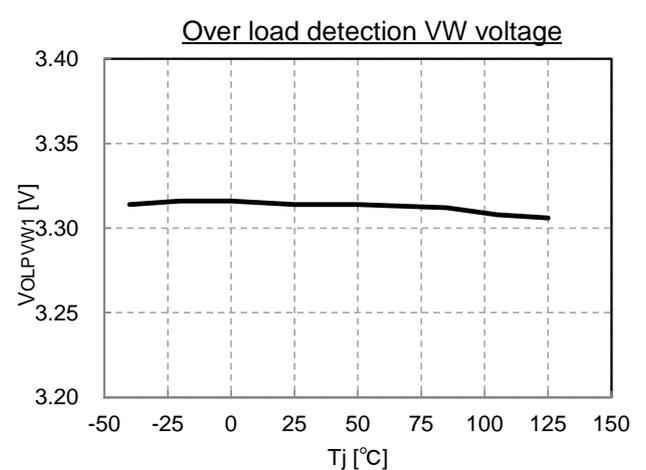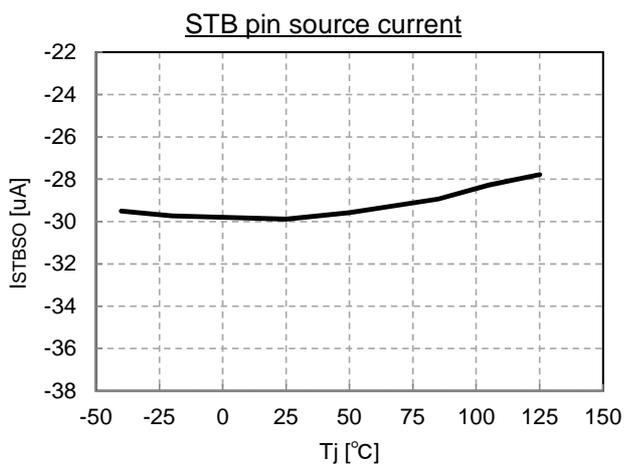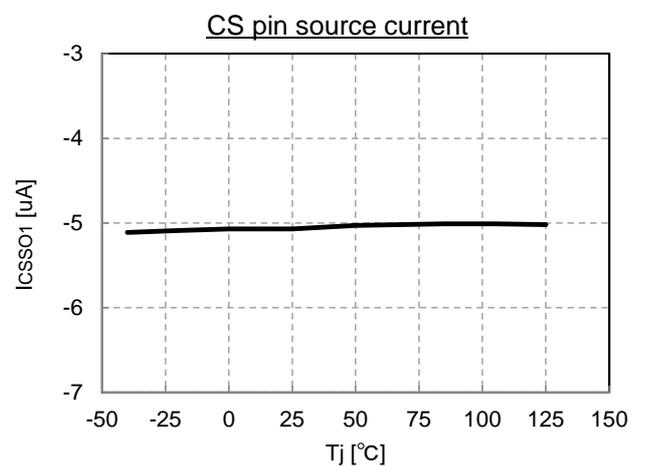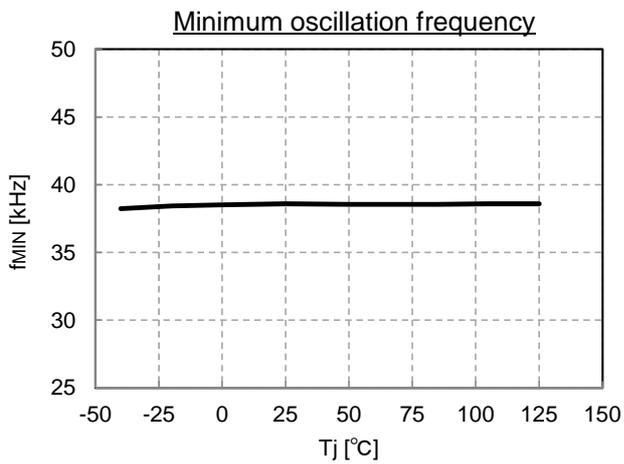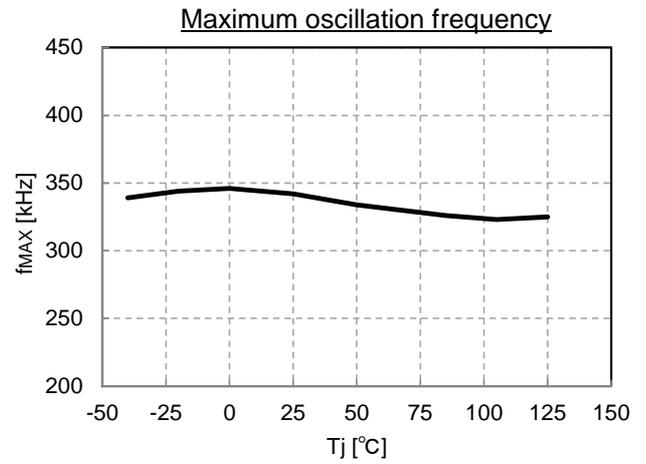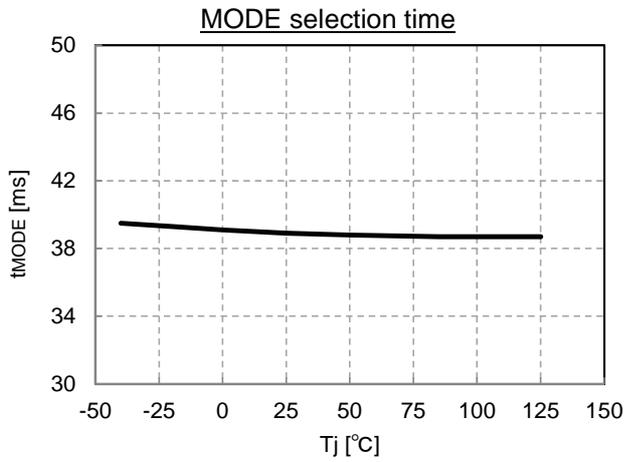
8. LLC Current resonant converter

8-1. LLC current resonant converter

FA6A30/31N is the control IC for the LLC current resonant converter. The LLC current resonant converter has the circuit configuration as shown in Fig. 1 and reduces the transformer's magnetizing inductance and the variation width of switching frequency against load change. When the variation width of switching frequency is reduced, the accuracy of output voltage is improved. If this LLC current resonant converter is used for a multi-output converter, output voltage regulation against the load change of the other output, namely cross-regulation, can be improved.

Since the LLC resonant converter is driven by half-bridge circuit, it requires a floating high-side driver circuit in addition to a low-side driver circuit.
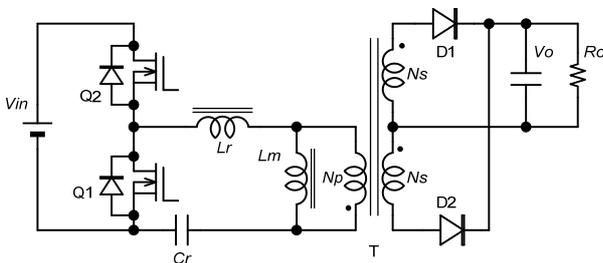
Fig. 1 LLC Current Resonant Converter Circuit

8-2. Operation of LLC current resonant converter

Fig. 1 shows the circuit of the LLC current resonant converter. The high side and low side switch elements Q1 and Q2 turns on and off alternately at the equal duty ratio of 50%. In this figure, Cr is resonant capacitor, Lr is leakage inductance for resonant, T is transformer, and Lm is a magnetizing inductance of T. Np is the winding number of transformer's primary winding and Ns is that of transformer's secondary winding.
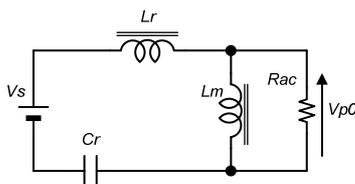
Fig. 2 Equivalent Circuit of LLC Circuit

Fig/ 2 shows the equivalent circuit of LLC converter. The output voltage is indicated as Vp0, converted to the primary-side. The load resistance R0 is indicated as the AC equivalent resistance Rac as shown in Formula (8.1).

$$R_{ac} = \frac{8}{\pi^2} n^2 \frac{V_0}{I_0} = \frac{8n^2}{\pi^2} R_0 \qquad (8.1)$$

where n is the turn ratio of the transformer and indicated in Formula (8.2).

$$n = \frac{N_P}{N_S} \qquad (8.2)$$

The input-output voltage ratio, called voltage gain, can be obtained as Formula (8.3) using the equivalent circuit.

$$\frac{V_{P0}}{V_S} = \frac{1}{1 + \frac{L_r}{L_m}(1 - \frac{\omega_0^2}{\omega^2}) + jQ(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega})} \qquad (8.3)$$

where ω is the angular frequency, and the respective parameters are indicated in the following formulas.

$$\omega = 2\pi f_S \qquad (8.4)$$

$$\omega_0 = \frac{1}{\sqrt{L_r C_r}} \qquad (8.5)$$

$$Q = \sqrt{\frac{L_r}{C_r}} \frac{1}{R_{ac}} \qquad (8.6)$$

The LLC current resonant converter in Fig.1 is a half-bridge converter and the input voltage of equivalent circuit shown in Fig.2 becomes a half as follows:

$$V_S = \frac{V_{IN}}{2} \qquad (8.7)$$

Example:
When the conditions are as follows, the calculation results are shown in Fig. 3 and 4.
- Input voltage V_{IN} 400V
- Output voltage V_o 24V
- Output current I_o 8A (Ro=3Ω)
- Turn ratio of transformer n 9
- Magnetizing inductance L_m 700µH
- Leakage inductance L_r 100µH
- Resonant capacitor C_r 0.033µF

Fig. 3 shows the voltage gain against the switching frequency f_s found with Formula (8.3), and the load resistance R_o is variable. When f_s increases, the voltage gain also increases and begins to decrease gradually after reaching the maximum.

The resonant frequency f_o is decided by Formula (8.5), and voltage gain becomes 1 when f_s equals f_o.

The LLC converter is operated within the frequency range between maximum voltage gain frequency and f_o. In other words, the LLC resonant converter operates in the boost mode, in which the voltage gain is always larger than 1.

As shown in Fig. 3, when the load resistance R_o becomes larger, the voltage gain becomes larger. In addition, when the load resistance R_o is smaller, the maximum gain frequency becomes slightly higher.

Fig.4 also shows the voltage gain against the switching frequency f_s found with Formula (8.3), and the transformer magnetizing inductance L_m is variable. The voltage gain becomes larger when L_m is smaller. In addition, when L_m is larger, maximum voltage gain frequency becomes lower.

Therefore, when the input voltage is lowest, find the voltage gain and decide L_m so that the output voltage can get the rated value.
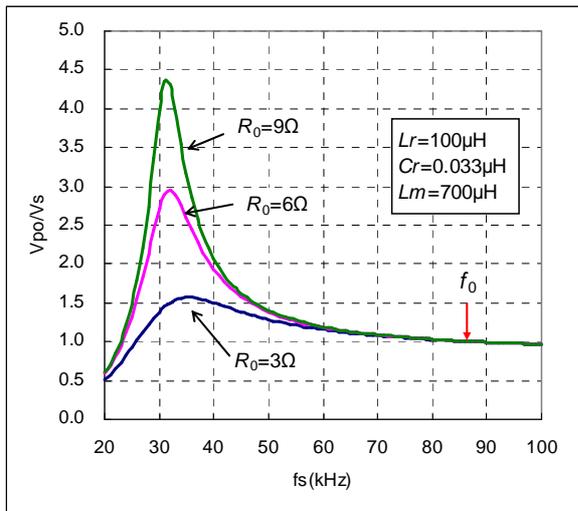

Fig. 3 Output to Input Voltage Characteristics
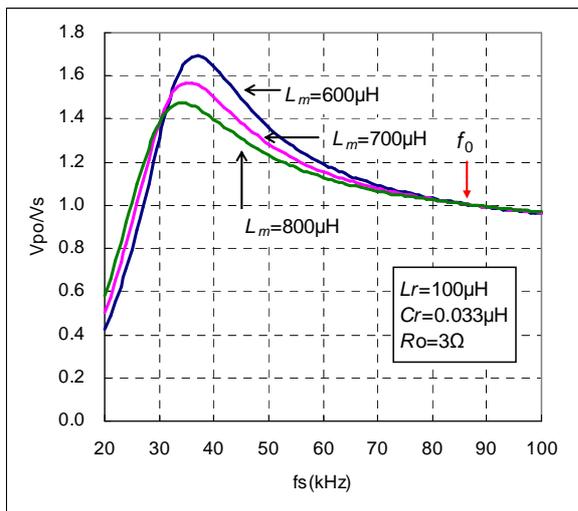
Fig. 4 Output to Input Voltage Characteristics

8-3. Design of transformer for LLC current resonant converter

As described above, the LLC current resonant converter operates in the boost mode and the voltage gain is decided so that it operates in the boost mode even when the input voltage is maximum. At first, seek the winding number of the secondary winding and then decide the winding number of the primary winding. Since the resonant frequency f_o becomes the maximum switching frequency, decide it beforehand within the range where it does not exceed the maximum frequency of this IC.

(1) Use the following formula (8.8) to find the winding number N_s of the transformer's secondary winding

$$N_S = \frac{(V_0 + V_F)T_{on}}{2A_e B_m} \quad (8.8)$$

where Vo is the output voltage (V), V_F is the forward voltage drop [V] of the rectifier diode, T_{on} is the maximum ON time (equal to 1/2 of the switching period at the minimum switching frequency) of the switch element, A_e is the effective cross-section area [cm²] of the transformer core, and B_m is the unsaturated value of the core's magnetic flux density [T].

(2) Use the formula (8.9) to find the ratio of the transformer's primary and secondary winding numbers n in order to operate the converter in the boost mode even when the input voltage is maximum. V_s is the value at the maximum input voltage.

$$n = \frac{N_P}{N_S} \geq \frac{V_S}{(V_0 + V_F)} \quad (8.9)$$

(3) Use the formula (8.10) to find the winding number of the transformer's primary winding.

$$N_P = nN_S \quad (8.10)$$

(4) Find the leakage inductance L_r.
In this converter, the leakage inductance of the transformer is used as the inductor for resonance. From winding number N_p of the primary winding, leakage inductance L_r for the primary winding can be found.
Connecting an additional resonant inductor separately from a transformer does not recommend.

(5) Decide the resonant capacitor C_r.
Use Formula (8.5) to calculate the resonant capacitor C_r from the resonant frequency f_o and L_r.

(6) Decide the magnetizing inductance L_m.
Find the voltage gain so that the output voltage can get the rated value, and decide L_m when the input voltage is minimum. Under this condition, the switching frequency is the minimum. Since the primary inductance of the transformer includes the leakage inductance, primary inductance is equal to sum of L_m and a half of L_r.
Use the formula (8.11) to calculate the gap I_g of the transformer core.

$$l_g = \frac{\mu_0 A_e N_P^2}{L_m} - \frac{l_e}{\mu_C} \quad (8.11)$$

where μ_0 is the absolute permeability of vacuum ($=4\pi\times10^{-7}$ H/m), μ_c is the amplitude permeability ($=3000$), and l_e is the effective magnetic path (mm).

Example:
An example of transformer design is shown below:
- Input voltage V_{IN} 360V (min 340 – max 390V)
- Output voltage V_o 24V
- Output current I_o 8A (Ro=3Ω)
- Used transformer   EER35
  - Ae=107.0 mm²
  - le=90.8 mm
  - Bm=0.35 (T)
- Resonant frequency   approx. 100kHz
- Minimum switching frequency   60kHz (T_{on}=8.3µs)
- Forward voltage drop of rectifier diode V_F 1.0V

(1) Winding number of transformer's secondary winding N_s (Formula (8.8))

$$N_S = \frac{(V_0 + V_F)T_{on}}{2 A_e B_m} = \frac{(24+1)\times 8.3}{2\times 107\times 0.25} = 3.88 \Rightarrow 4$$

(2) Turn ratio n of transformer (Formula (8.9))

$$n = \frac{N_P}{N_S} \geq \frac{V_S}{(V_0 + V_F)} = \frac{195}{(24+1)} = 7.8$$

(3) Winding number N_p of transformer's primary winding (Formula (8.10)

$$N_P = nN_S = 7.8\times 4 = 31.2 \Rightarrow 32$$

Accordingly, n=8

(4) Calculation of transformer's leakage inductance L_r
Since the leakage inductance is 72(nH) per turn in the EER35 transformer, the leakage inductance becomes 73.7 (µH) ($=32^2\times 72$nH) when the winding number (N_p) of the primary winding is 32.

(5) Decide the resonant capacitor C_r.
When f_o=100kHz and L_r=73.7 (µH) are substituted into the formula (8.5) to find C_r, 0.033µF is obtained.

(6) Decide the magnetizing inductance L_m
Find L_m so that the output voltage will be the rated value when the input voltage is minimum. Since the input voltage is 340V(min), the input-to-output voltage ratio is calculated as follows using the transformer turn ratio.

$$\frac{V_{P0}}{V_S} = \frac{V_0 + V_F}{\dfrac{N_S}{N_P}\dfrac{V_{IN}}{2}} = \frac{24+1}{\dfrac{4}{32}\dfrac{340}{2}} = 1.17 \Rightarrow 1.2$$

Therefore, when the switching frequency is at the minimum (f_s=60kHz in this case), find L_m which provides the voltage gain of 1.2 or higher using the formula (8.3).
As a result, if L_m is 600µH or less, it is acceptable. In the case of L_m=600µH, when the formula (8.11) is used to find the gap l_g of transformer core, the value of about 0.2mm can be obtained as calculated below.

$$l_g = \frac{\mu_0 A_e N_P^2}{L_m} - \frac{l_e}{\mu_C} = \frac{4\pi\times10^{-7}\times107\times32^2}{600} - \frac{90.8\times10^{-3}}{3000} \cong 0.2\times10^{-3}$$

8-4. switch-through

Fig. 3 shows the voltage gain against the switching frequency f_s in the LLC current resonant converter. However, the operation mode differs between lower and higher frequency area than maximum gain frequency as shown in Fig. 5.

In the area where the frequency is lower than the maximum voltage gain frequency, the high and low sides of the half-bridge circuit are short-circuited (switch-through), and this phenomenon is called switch-through. In this case, the MOSFET may be damaged. Therefore, usually the converter is operated in the region where frequency is higher than the maximum voltage gain frequency gain not to cause switch-through.
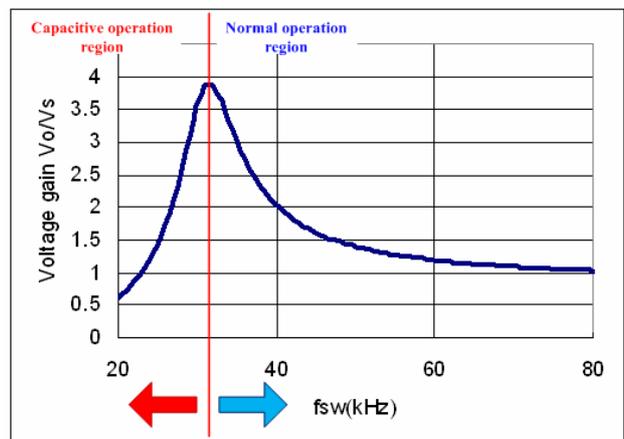

Fig. 5 Operation mode of LLC

(1) Operation in capacitive region

If the frequency becomes low, switch-through operation is started. While Q1 is ON, the current ID1 starts decreasing after reaching the maximum value, eventually the resonance current Icr turns from positive to negative and ID1 also turns from positive to negative. (d)

When Q1 is turned off in this status, current flows through the parasitic diode of Q1. When the opposing Q2 is turned on, the parasitic diode of Q1 enters the status of reverse recovery and may be damaged. (c)

While Q2 is ON, the current ID2 starts decreasing after reaching the maximum value, and eventually the resonance current Icr turns from negative to positive, and ID2 turns from positive to negative. (b)

If Q2 is turned off in this state, current flows through the parasitic diode of Q2. When the opposing Q1 is turned on, the parasitic diode of Q2 enters the status of reverse recovery and may be damaged. (a)

(2) Operation in the normal region

Generally the converter is used in the following operating conditions.

While Q1 is ON, the current ID1 starts decreasing after reaching the maximum value. (a)

When Q1 is turned off while ID1 is in the positive status, current flows through the Q2 side. The opposing Q2 is turned on, and the resonance current Icr changes continuously. (b)

While Q2 is ON, the current ID2 turns from negative to positive and starts decreasing after reaching the maximum value. (c)

When Q2 is turned off while ID2 is in the positive status, current flows through the Q1 side. The opposing Q1 is turned on, and the resonance current Icr changes continuously. (d)

By repeating this operation, the resonance current Icr can be generated.

In other words, before the currents ID1 and ID2 of Q1 and Q2 become negative, MOFET is turned off and operation is switched to the opposing MOSFET. Therefore, operation is continued without any switch-through.

Fig. 6 Operation waveform in capacitive region
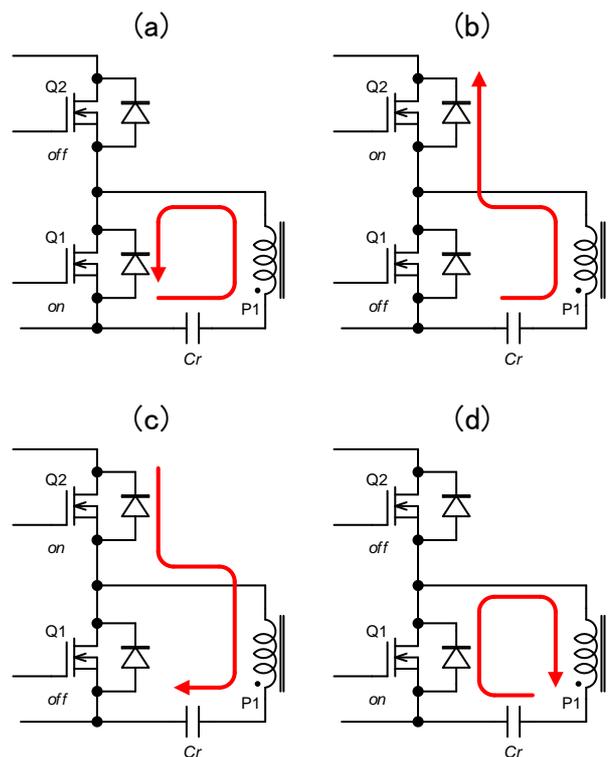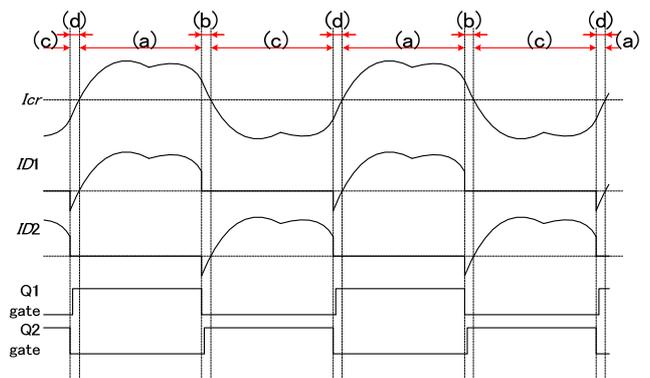
Fig. 7 Normal operation waveform

9. Description of the function (The values in the following description are typical values unless otherwise specified.)

(1) Protection functions

Table 1 lists the protection method of each protection function.

Table 1

Protection function	FA6A30N	FA6A31N	Protection function	FA6A30N	FA6A31N
VW pin overload protection	Auto recovery	Latch	VH pin brown-in / out	Auto recovery	Auto recovery
FB pin overload protection	Auto recovery	Latch	MODE pin external fault stop	Latch	Latch
IS pin overcurrent protection	Auto recovery	Latch	Thermal shutdown protection	Auto recovery	Auto recovery
VH pin overvoltage protection	Auto recovery	Auto recovery	Mode selection resistor open detection	Latch	Latch
VCC pin overvoltage protection	Latch	Latch	VCC voltage drop protection	Auto recovery	Auto recovery

Note: The automatic recovery overcurrent, overload and Vcc voltage drop protection functions allow switching to be resumed after it is suspended for a specified period of time. With the automatic recovery of other protection functions, switching is stopped when temperature or voltage of each pin exceeds the threshold value set within the IC, and switching is resumed when the value decreases within the permissible range.

(2) Oscillating frequency

The LLC current resonance converter is controlled by switching frequency modulation (SFM). Therefore, the IC is equipped with an oscillator, which controls the switching frequency according to the feedback signal from output voltage.

The oscillating frequency changes according to the FB pin voltage as feedback and the CS pin voltage as soft-start setting. The frequency is decided by the lower pin voltage between the FB pin voltage and the CS pin voltage.

The oscillating frequency is set at maximum 350kHz and minimum 38kHz, and Fig. 8 and 9 shows the relation between the oscillating frequency and the FB pin voltage or the CS pin voltage. (The ON pulse width waveform represents the values obtained with the minimum dead time of 430 ns.)

Generally in many cases, the frequency linear control is used for feedback, but the ON-width linear control method is used for this IC. In this method, the frequency change near the operating point can be made smaller than that of the frequency linear control. As the result, the loop gain of the converter can be restricted, and operation will be stable easily.
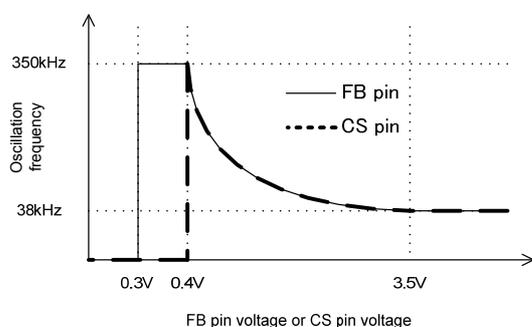
Fig. 8 Dependency of oscillation frequency on FB and CS pin voltages
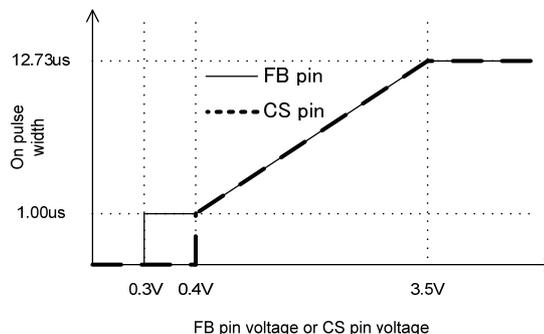
Fig. 9 Dependency of ON pulse width on FB and CS pin voltages

(3) Soft start function

Both the CS pin voltage and the FB pin voltage are kept in the GND level before startup. Since output voltage is insufficient immediately after the startup, the FB pin voltage goes high. Since the CS pin voltage increases charging the capacitor connected to the CS pin, the frequency gradually decreases from high frequency depending on the CS pin voltage, which is called soft start.

Soft start is also implemented when the mode is switched from the low standby mode to the normal operation mode, and in low-standby-mode burst operation, which will be described later, based on the CS pin voltage.

(4) Low standby mode

In principle, the efficiency of an LLC current resonant converter decreases at light load, and loss of several watts is generated under no load condition. Consequently, an auxiliary power supply is required in general as energy-saving measures in standby operation mode, which hinders downsizing.

This IC uses STB pin to switch modes from the normal operation mode to the low-standby mode, thereby achieving low standby power without using an auxiliary power supply. When the IC is switched to low standby mode, the IC operates in burst mode in which IC repeats start and stop of switching. In detail, the capacitor of the CS pin is charged/discharged depending on the FB pin voltage, and the frequency changes depending on this CS pin voltage. Consequently, the IC operates in burst mode with soft start and soft end enabled at start/stop switching. To decrease standby power, it is better to lower the output voltage in standby mode. Therefore, in some application, DC/DC converter may be necessary for standby output to stabilize voltage.

(5) Preventing switch-through function

In the current resonance circuit, if the currents ID1 and ID2 becomes negative and then the MOSFET on the opposite side is turned on, switch-through occurs and the MOSFETs on the high and low sides are arm-shorted . In the worst case, they may be destroyed.

Usually the minimum frequency is restricted to prevent switch-through. However, this method is not good enough against input voltage and load change and also restricts setting of the operating point.

In this IC, the resonant current Icr is always monitored, MOFET is turned off before the currents ID1 and ID2 of Q1 and Q2 become negative, and the opposing MOSFET is turned on. Therefore, operation is continued without any switch-through.

The resonant current is shunted by the shunt capacitor C_{rd}, converted into the voltage V_{is} by the resistor R_{is} and detected by the IS pin as shown in Fig. 10.

When you use this IC, connect the primary winding of transformer and resonant capacitor in parallel with the low-side Q2.
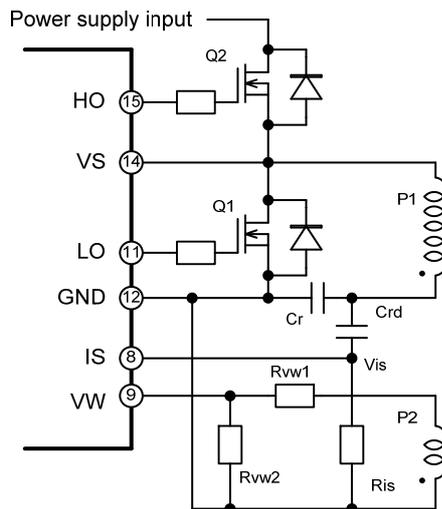

Fig. 10 Switch-through prevention function circuit diagram

The preventing switch-through function has two functions, namely the forced turn-off function and the dead time automatic adjusting function.

(5-1) Forced turn-off function

During normal operation, the MOSFET is turned off according to oscillator. However, the IC turns off the MOSFET forcibly in the following two cases because there is a possibility that switch-through may occur.

・When the VW pin voltage rises over the forced turn-off threshold V_{THVWP} (threshold voltage is switched between normal operation mode V_{THVWPN} and low standby mode V_{THVWPS}) and the voltage of the IS pin, which detects the resonance current Icr, exceeds V_{THISM}.

・When the VW pin voltage drops below the forces turn-off threshold V_{THVWM} (threshold voltage is switched between normal operation mode V_{THVWMN} and low standby mode V_{THVWMS}) and the voltage of the IS pin, falls below V_{THISP}.

Fig. 11 shows the relation among the VW auxiliary winding, the resonance current Icr and the forced turn-off detecting point.
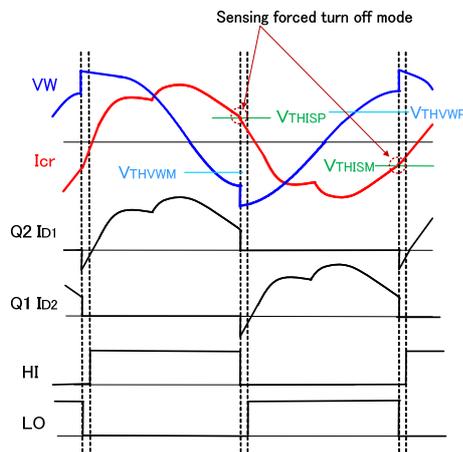
Fig. 11 Arm-short prevention function waveform

(5-2) Self-adjusting dead time function

During startup or burst operation, the through current or the hard switching are more likely to occur at the switching frequency near the maximum frequency. This IC is equipped with the self-adjusting dead time function to prevent such problems.

By detecting the gradient dV/dt of the VW auxiliary winding voltage, this function detects the VS pin voltage change and turns on the high-side or low-side MOSFET. MOSFET is turned off according to the off signal of the oscillator.

The automatic adjustment range of dead time is set within the IC, and the minimum dead time is 430 ns and the maximum dead time is 20 us.

In transformer design, the polarity of the VW auxiliary winding must be reversed with respect to the primary winding P1 as shown in Fig. 12. The VW auxiliary winding can also be used as VCC auxiliary winding for supplying power to the VCC pin.
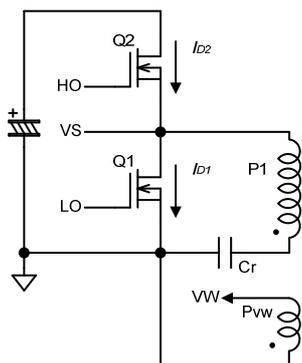

Fig. 12 Outline of primary side circuit

The principle of the dead time automatic adjusting function by the VW auxiliary winding Pvw is as follows.
When the VS voltage is inverted, the formula (9-1) can be obtained.

$$N \cdot V_{vw} = V_s + V_{cr} - V_i \qquad (9\text{-}1)$$

When the formula (9-1) is differentiated, the formulas (9-2) and (9-3) can be obtained.

$$\frac{dV_{vw}}{dt} = \frac{1}{N}\left(\frac{dV_s}{dt} + \frac{dV_{cr}}{dt}\right) \quad \text{(9-2)}$$

$$= \frac{1}{N}\left(\frac{I_{cr}}{C_{vs}} + \frac{I_{cr}}{C_r}\right) \quad \text{(9-3)}$$

Since usually Cr >> CVS is valid, Formula (9-3) can be approximated.

$$\frac{dV_{vw}}{dt} \approx \frac{1}{N}\frac{dV_s}{dt} \quad \text{(9-4)}$$

Accordingly, with Formula (9-4), the VS voltage change can be detected by the VW auxiliary winding voltage change (dV_{VW}/dt).

When the switching frequency is high, the VW voltage changes only very slightly during on period because the resonant current is small as shown in Fig. 13. Therefore, the waveform of VW voltage is almost the same as that of the VS voltage.

Accordingly, after a constant delay (t_{DVWONP} or t_{DVWONM}) because the VS voltage inversion is detected by VW voltage, the turn-on signal is sent.

When the switching frequency is low, dV/dt of the VW voltage is detected during on period and the turn-on signal for the next cycle can be obtained because the resonance current is large as shown in Fig. 14. In this case, the dead time is the minimum dead time t_D.
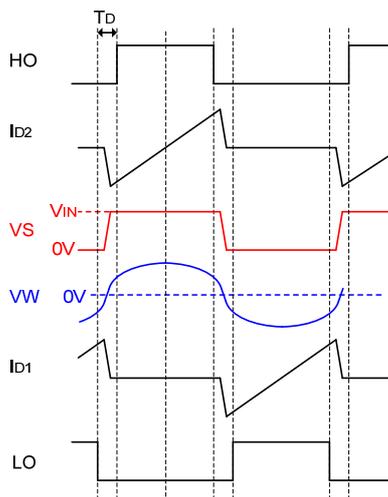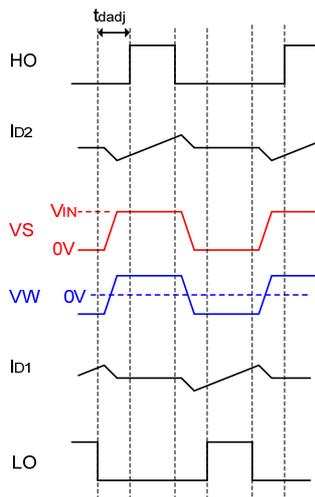
Fig. 13 Waveforms at higher frequency operation   Fig. 14 Waveforms at lower frequency operation

(6) Startup circuit and startup operation

When power is turned on, the capacitor connected to the VCC pin is charged by the current supplied from the startup circuit to the VCC pin through the VH pin, and Vcc voltage increases. When Vcc voltage reaches 11.5 V, the bias voltage for internal circuit is started, and operation mode setting is made first.

With this IC, constant current is output from the MODE pin in the operation mode setting period, and each operation mode is set according to the resistance value connected to the MODE pin. During this period, the VCC pin voltage is maintained within a range from 11 V to 11.5 V by ON/OFF control of the startup circuit.

After the operating mode setting period (40 ms), the MODE pin voltage decreases, and when it decreases to 0.6 V, the VCC pin voltage starts increasing again and the MODE pin voltage is clamped at 0.48 V. When the VCC pin voltage reaches the start operation voltage of 13 V, CS pin voltage starts rising. When the CS pin voltage reaches to 0.4 V, switching is started with the soft start which decreases the frequency gradually from the maximum oscillating frequency of 350 kHz.

If the voltage supplied from the VCC auxiliary winding is higher than 11 V, the startup circuit is operated only at the time of startup, and after the startup, operation is continued with the voltage of the auxiliary winding used as the power supply.
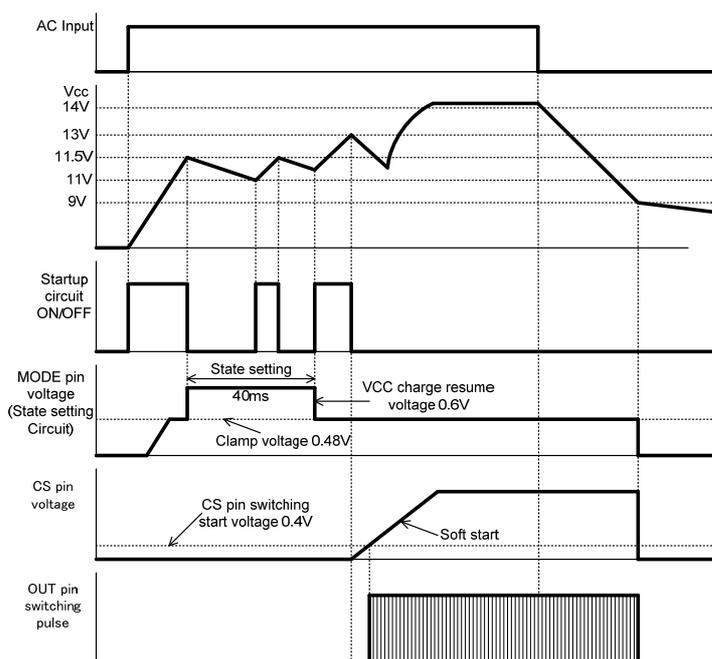

Fig. 15 Startup operation waveform

(7) Dynamic Self Supply (DSS) function

By the DSS function, if the VCC pin voltage decreases to the start-up circuit start voltage of 11 V after the startup, the startup circuit is set to ON/OFF, thereby maintaining the VCC pin voltage within the range from 11 V to 11.5 V, in such case that switching is stopped by the protective function of overvoltage, overload and etc. However, since the IC cannot operate only with the current supplied from the startup circuit in normal switching state, VCC voltage from the auxiliary winding must be supplied.

(8) Correction of each level based on the input voltage

By detecting VH pin peak voltage, the threshold voltage, etc., of each function is switched depending on the input voltage, thereby correcting the voltage to be maintained at an appropriate level. Table 2 lists the items to be corrected. See the specifications for details.

Table 2

Level-correcting function	Item
Soft start function at Standby⇒Normal	CS pin source current
Low standby mode	CS pin charge/discharge current
	CS pin switching start/stop voltage
Overcurrent protection (IS pin)	Over current detection voltage of low side / high side
Overload protection (VW pin)	Over load protection VW voltage

(9) Operating mode setting function

The burst operation settings (High frequency mode or Low frequency mode) in low standby mode and with/without PFC setting is corrected according to the resistor between the MODE pin and the GND at startup. Table 3 lists the details of operating mode settings. When the resistor is found to be in open state at startup, IC stops in latch mode.

Table 3

Resistor R_{MODE}	Mode	Burst setting	With/Without PFC
56kΩ	A	High frequency mode (HM)	With
100kΩ	B	High frequency mode (HM)	Without
200kΩ	C	Low frequency mode (LM)	With
330kΩ	D	Low frequency mode (LM)	Without

(10) Protection by external signal(Latch type)

The MODE pin also has the protection function to stop switching by external signal. If MODE pin is pulled down below 0.35V of threshold voltage for external fault stop for 304 us of delay time, IC stops switching.

(11) Overload protection

■Auto recovery type(FA6A30N)

If the VW pin voltage over the over load threshold of VW pin, or the FB pin voltage over the over load threshold of FB pin for the delay time of over load of 76.8 ms, switching is stopped forcibly. If each pin voltage drop below threshold for the over load detection reset time of 108 us or longer the overload detection is reset.

When switching is stopped, power supply from the auxiliary winding is stopped and the startup circuit maintains the VCC pin voltage within a range from 11 V to 11.5 V.

When 810 ms elapses after the switching is stopped, IC is reset and starts startup sequence (operation state setting sequence) again. State setting operation takes time of 40ms. Therefore Switching stop period for over load is 850ms. After 850ms elapses, switching is resumed. If overload state is continuing at that time, start and stop operations are repeated. If load condition is changed to normal, operation goes back to normal.

During soft start (until the CS pin voltage increases to 4 V) at the time of startup, the overload protection function based on the FB pin voltage is invalidated.
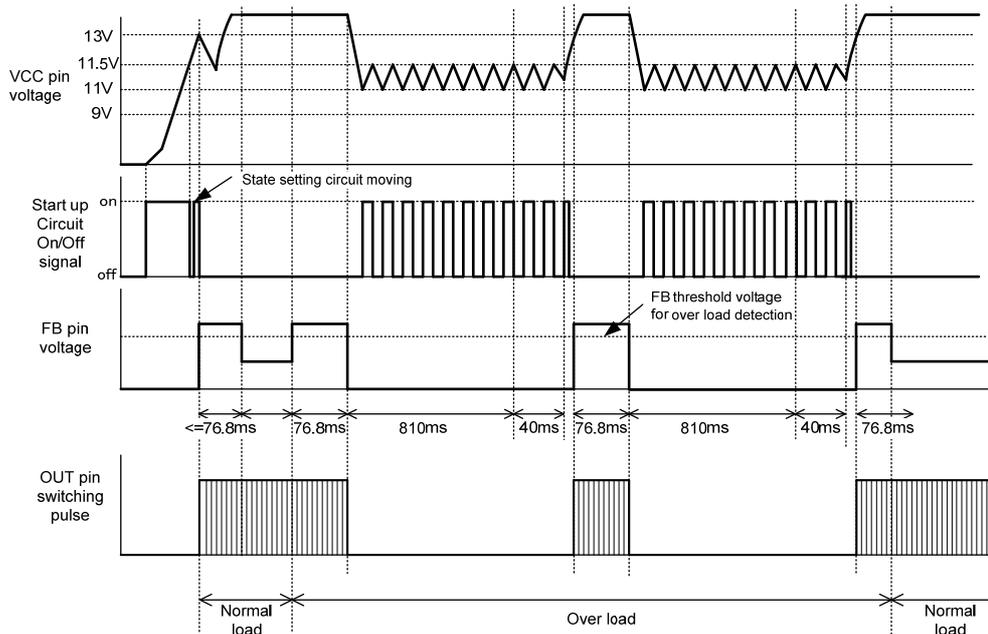
Fig.16 Overload detection operation by FB pin
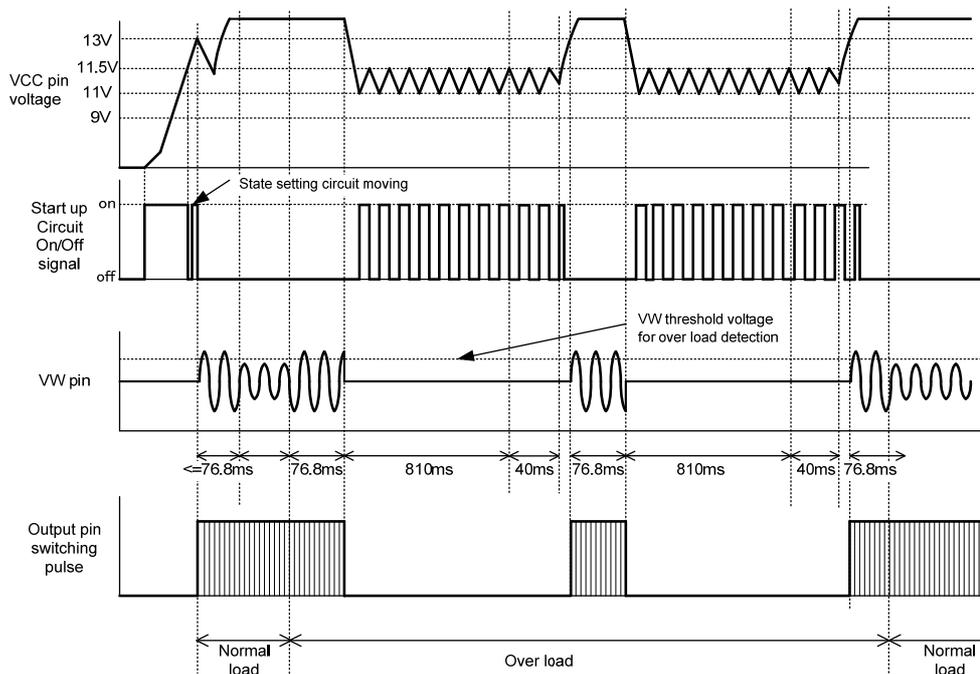

Fig.17 Overload detection operation by WV pin

■**Timer latch type(FA6A31N)**

If the state where the VW pin voltage remains at the over load detection VW voltage or higher, or the FB pin voltage remains at the over load detection FB voltage or higher, is continued for the delay time of over load of 76.8 ms or longer, switching is stopped forcibly. If detection is not made for a period equivalent to the over load detection reset time of 304 μs or longer while the overload detection state continues, the overload detection is reset.

When switching is stopped, supply of current from the auxiliary winding is stopped, and the VCC pin voltage decreases to 11 V or lower, the startup circuit is operated, and the VCC voltage is maintained within a range from 11 V to 11.5 V.

To reset the overload latch, it is necessary to stop the supply of VCC voltage from the startup circuit by interrupting the input voltage, thereby decreasing the VCC voltage to the IC reset voltage of 8.5 V or lower.

During soft start (until the CS pin voltage increases to 4 V) at the time of startup, and in the low standby mode, the overload protection function based on the FB pin voltage is invalidated.
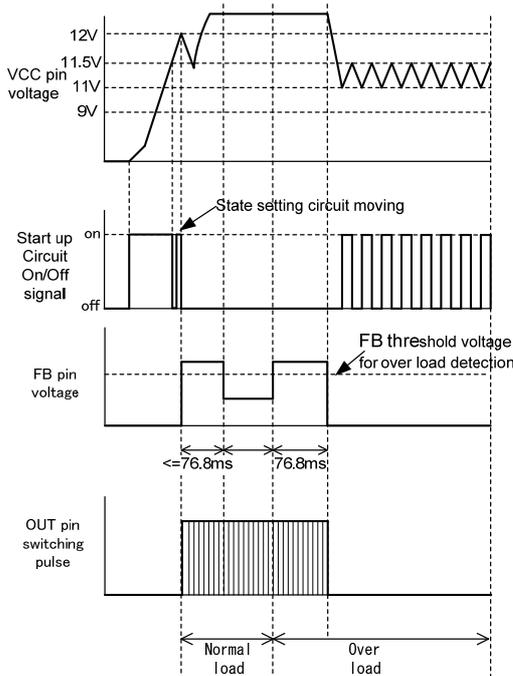
Fig. 18 Overload detection operation by FB pin
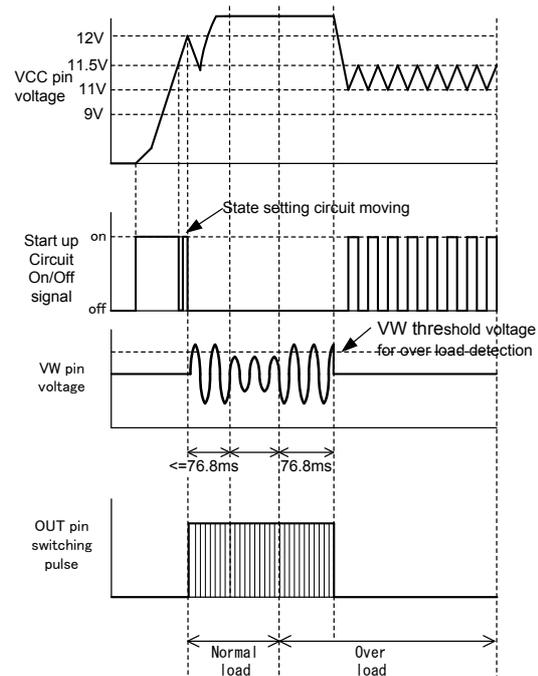
Fig. 19 Overload detection operation by VW pin (timer latch type)

(12) Overcurrent protection function

As shown in Fig. 10, the resonant current is shunted by the shunt capacitor C_{rd}, converted into the voltage V_{is} by the resistor R_{is} and detected by the IS pin.

If the IS pin voltage exceeds the over current threshold voltage, the MOSFET is turned off at every oscillation cycle.

If the IS pin voltage over the over current threshold for the delay time, switching is stopped forcibly. If IS pin voltage drop below threshold for the over current detection reset time of 76 μs or longer, the overcurrent detection is reset. The delay time of over current can be set within the range from 1 to 40 ms using a capacitor and resistor of MODE pin which have a built-in CR oscillator and counter.

In the case of Auto recovery type, When 810 ms elapses after the switching is stopped, IC is reset and starts startup sequence (operation state setting sequence) again. State setting operation takes time of 40ms. Therefore Switching stop period for over current is 850ms. Switching is restarted when the restart time of over current has elapsed.

In the case of latch type, latch off occurs when the delay time of over current has elapsed.

(13) Overvoltage protection (VCC pin)

If the secondary output becomes overvoltage, the voltage of the auxiliary winding also increases. The VCC pin has a function of detecting the voltage of this auxiliary winding, and if the VCC pin voltage exceeds the over voltage threshold of 28.5 V for 304 μs, switching stops.

(14) Overvoltage protection function (VH pin)

If the peak voltage of the VH pin increases to the over voltage threshold of 525 Vdc, switching is stopped, and it is resumed when the VH pin voltage decreases to the restart voltage of 500 Vdc.

(15) Under voltage lockout function

To prevent circuit malfunction due to decreased Vcc, an under voltage lockout circuit is integrated. When the VCC pin voltage increases from 0V, operation is started when the voltage reaches start operation voltage of 13 V. When the VCC voltage decreases, operation is stopped when the voltage reaches shutdown voltage of 9 V.

In addition, the voltage between the VB pin and the VS pin, namely high-side Vcc, is also detected, and operation is started when the high side Vcc increases to the VBS switching start voltage of 8.8 V, and the operation is stopped when it decreases to the VBS switching stop voltage of 7.5 V.

(16) Internal thermal shutdown protection function

If the IC temperature increases to 136°C, switching is stopped. When the temperature decreases to 120°C, the switching is resumed.

(17) Discharge function of the input filter X-capacitor at AC power interruption

By connecting the VH pin to the X-capacitor of the AC line filter through full-wave rectification, the X-capacitor can be discharged when AC input is powered off. This function eliminates discharge resistor for X-capacitor, thereby decreasing standby power.

The recommended capacitance of connectable X-capacitor is 2 μF or lower.

(Requirement in UL60950 regarding electric shock: The voltage value of the power supply input part shall be attenuated to 37% or lower of the peak value within 1 s after the AC input voltage is powered off.)

(18) Level-fixed VH pin brown-in/out function

The brown out function and brown in function are integrated. The brown out function stops switching when the AC line voltage decreases and the brown-in function does not allow switching until the AC line voltage increases to a specified voltage.

The VH pin voltage is directly monitored by this function. If VH pin voltage decreases below the brown out threshold of 90Vdc, switching does not stop immediately but stops with delay time of 107ms. If the VH pin voltage exceeds the brown-in threshold of 93 Vdc, switching starts with delay time of 144 μs.

While the output pulse of the OUT pin is stopped by the brown-out function, the VCC voltage is maintained between the range from 11 V to 11.5 V by of the startup circuit.

(19) Level-adjustable BO pin brown-in/out function

By inputting the resistor-divided voltage derived from the DC voltage obtained by rectifying AC input voltage to the BO pin, the level-fixed VH pin brown-in/out function can be disabled, and brown-in/out voltage can be set arbitrarily by the voltage divided by resistors of the BO pin. In this case, the BO pin judges the brown-in/out voltage.

If the BO pin is brought into an open state, the normal level-fixed VH pin brown-in/out function is validated. In this case, the BO pin judges whether there are resistors connected during operating mode setting at the time of startup, and switches the brown-in/out function between the VH and the BO pins.

(20) VCC voltage drop protection function

When VCC voltage falls to 9V or less under the condition of output short etc. IC stops switching and VCC voltage is maintained by internal start up circuit. When 810 ms elapses after the switching is stopped, IC is reset and starts startup sequence (operation state setting sequence) again. State setting operation takes time of 40ms. Therefore Switching stop period for over voltage is 850ms.
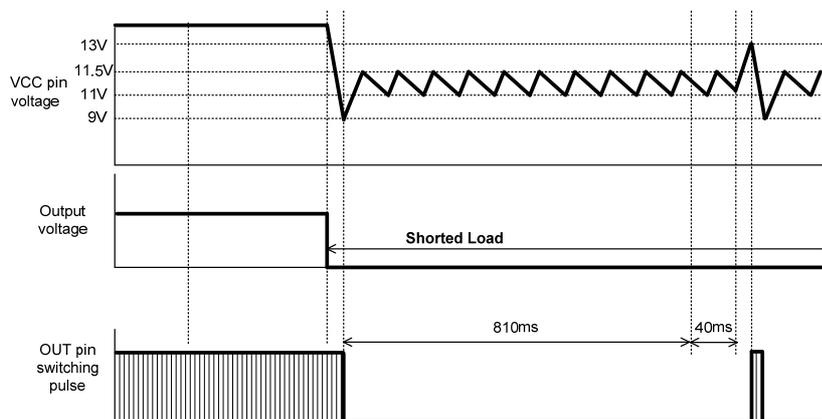

Fig. 20 VCC voltage drop protection function

10. How to use each pin and advice for designing

(The values that appear in the following description are typical values, unless otherwise specified.）

No.1 : VH pin

(1) Function

   (i) Supplies the startup current from the VH pin to the VCC pin.
   (ii) Discharges the X-capacitor of the AC line filter when AC input is powered off.
   (iii) Fixed-level brown-in/out function is provided.
   (iv) Each function level is corrected by input voltage detection.
   (v) Detects the overvoltage of the AC line and stops switching.

(2) How to use

(i) Supplying startup current

 - Connection method

   Connect to AC line voltage via a startup resistor and diodes. (See Fig. 21 and 22)

 - Operation

   This IC integrates a 600V startup circuit and achieves low power consumption.

   In Fig. 21, the half-wave rectified waveform of the AC line voltage is input to the VH pin. The startup time of this method is the longer.

   Note that although this IC integrates the X-capacitor discharge function when the AC power is powered off, discharge is guaranteed only when the full-wave rectification is applied. If the half-wave rectification is applied, X-capacitor may not be discharged depending on the voltage polarity of the X-capacitor at the time of AC power off. Therefore in case of the half-wave rectification, additional discharge measures must be taken.

   Fig. 22 shows the method of inputting full-wave rectified waveform of the AC line voltage into the VH pin. With the full-wave rectification, the startup time will be approximately half of that of the half-wave rectification shown in Fig. 21, X-capacitor discharge function operate correctly.

   This IC has the function of discharging the X-capacitor of the input line filter when the AC power is powered off. If the VH pin is connected to DC voltage which means rectified and smoothed AC line voltage as shown in Fig. 23, the discharging function of the X-capacitor may malfunction, thereby causing heating and damage. Never adopt this connection method.

   If power is turned on, the capacitor connected to the VCC pin is charged by the current supplied from the startup circuit to the VCC pin via the VH pin, and the VCC voltage increases. When Vcc exceeds the start operation voltage of 13 V of the undervoltage lockout circuit (UVLO), the internal supply is started to operate the IC.

   If Vcc is supplied from the auxiliary winding, the startup circuit is remains in off state. Since it is not possible to keep operating the IC using the current supplied from the startup circuit without using the auxiliary winding in normal operation state, Vcc voltage should be supplied from the auxiliary winding.
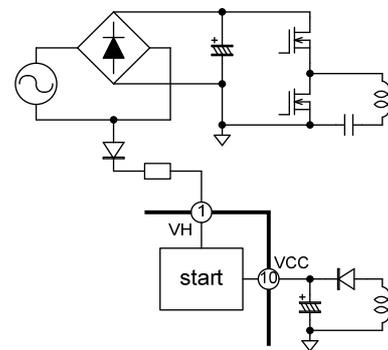

Fig. 21 VH pin circuit (1)
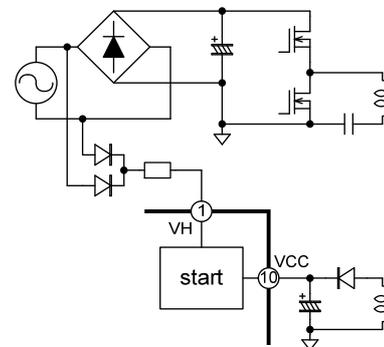

Fig. 22 VH pin circuit (2)
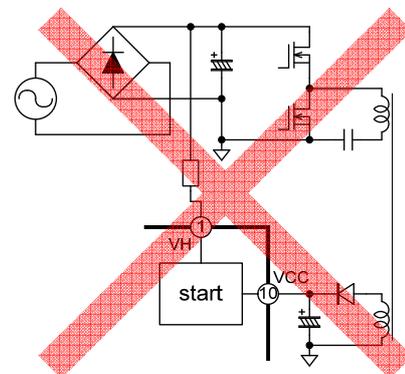
Fig. 23 Connection that should not be adopted

(ii) AC line filter X-capacitor discharge function
- Connection method
    This function operates with the connection method shown in Fig. 22 only.
- Operation
    The AC input voltage is monitored by the VH pin, and when the AC input is cut off, the discharging function of the X capacitor will operate after 56ms of the delay time of AC cutting detection.
    The function discharges the X-capacitor with average current of 2mA repeating ON and OFF state; ON state is for 1.5ms and OFF state is for 0.5ms.
    When the AC input is resumed, the X-capacitor discharging function stops.

(iii) Brown-in and brown-out functions
 - Connection method
    Operation is allowed with the connection shown in Fig. 21 and 22.
 - Operation
    When the VH pin voltage increases to the VH pin brown-in voltage of 93 Vdc or higher, and the VH pin brown-in detection delay time of 144 μs elapses in that state, switching is started.
    Also, when the AC input voltage decreases to below the VH pin brown-out voltage of 90 Vdc, and the VH pin brown-out detection delay time of 107 ms elapses in that state, output switching stops.

    While the switching is suspended by the brown-out function, the startup circuit is controlled as ON and OFF to maintain the VCC voltage is within the range from 11V to 11.5V. Switching operation is resumed when the VH pin voltage reaches the VH pin brown-in voltage.

    By inputting the resistor-divided voltage derived from the DC voltage obtained by rectifying AC input voltage to the BO pin, the level-fixed VH pin brown-in/out function can be disabled, and brown-in/out voltage can be set arbitrarily by the voltage divided by resistors of the BO pin. In this case, the BO pin judges the brown-in/out voltage.

(iv) Correction of each function level by input voltage detection
- Connection method
    Operation is allowed with the connection methods shown in Fig. 21 and 22.
- Operation
    Based on the input voltage detected as VH pin peak voltage, the detection level of each function is switched, thereby correcting it at an appropriate level.
    Table 4 lists the functions to be corrected according to the input voltage.

Table 4

Level-correcting function	Item
Soft start function at Standby⇒Normal	CS pin source current
Low standby mode	CS pin charge/discharge current
	CS pin switching start/stop voltage
Overcurrent protection (IS pin)	Over current detection voltage of low side / high side
Overload protection (VW pin)	Over load protection VW voltage

(v) Overvoltage detection of input voltage
- Connection method
    Operation is allowed with the connection methods shown in Fig. 21 and 22.
- Operation
    If the VH pin voltage exceeds 525V, it is judged as overvoltage and switching is stopped. When the VH pin voltage becomes lower than 500Vdc while switching is stopped, it is judged that the overvoltage state is released and switching operation is restarted.

(3) Advice on design
 ①VH pin resistor
    To prevent damage to the IC due to surge voltage of the AC line, it is recommended to connect a VH pin resistor of 2 kΩ to 40 kΩ to the VH pin in series. Startup is allowed up to 40 kΩ but give sufficient consideration because the startup time varies depending on the resistor and the capacitor of the VCC pin.
    The VH pin resistor cannot be adjusted to control the startup time and startup voltage.

 ②Capacitance of X-capacitor when the input filter X-capacitor discharge function is used
    To satisfy the requirements of UL60950 regarding electric shock, this IC integrates a discharge function for the voltage at the power input part to 37% or lower of the peak value within 1 s after the AC input voltage is powered off.
    The recommended capacitance of connectable X-capacitor is 2 μF or lower.

No.2 : NC pin
    This pin is not connected to the IC internally because it is located next to the high-voltage pin (VH).

No.3 : BO pin
(1) Function
    Adjustable brown-in/out function is provided.

(2) How to use
 - Connection method
    As shown in Fig. 24, DC input voltage, which is rectified and smoothed AC line voltage, is input to BO pin via resistor voltage divider. A capacitor is also connected between the BO pin and the GND.
 - Operation
    Brown-in/out voltage can be adjusted by inputting the resistor divided DC main voltage to BO pin. The level-fixed VH pin brown-in/out function is disabled when voltage divider resistor is connected to BO pin.
    1μA current is output from the BO pin during the period of the operating mode setting at startup. Therefore, if the BO pin is made to be in open state, the voltage of the BO pin rises to above the BO pin open detection voltage of 4.4 V at start up and the level-fixed VH pin brown-in/out function is enabled.

(3) Advice on design
　① BO pin resistance
　　The formula for calculating the resistance is shown below:

$$R1[M\Omega] = \frac{(V_{BI} \times V_{BOL} - V_{BO} \times V_{BOH})}{(V_{BI} - V_{BOH})} = \frac{(V_{BI} \times 0.635 - V_{BO} \times 0.65)}{(V_{BI} - 0.65)}$$

$$R2[M\Omega] = \frac{(V_{BI} \times V_{BOL} - V_{BO} \times V_{BOH})}{V_{BOH}} = \frac{(V_{BI} \times 0.635 - V_{BO} \times 0.65)}{0.65}$$

　　V_{BI}= BO pin brown-in voltage (arbitrary setting)
　　V_{BO}= BO pin brown-out voltage (arbitrary setting)
　　V_{BOH}= BO pin brown-out threshold voltage =0.65V
　　V_{BOL}= BO pin brown-out threshold voltage =0.635V

　Example:
　　When V_{BI}=100 Vdc and V_{BO}=85 Vdc are selected, R1 and R2 are respectively calculated to R1=83 kΩ and R2=12.7 MΩ.

　② Capacitor between the BO pin and the GND
　　When the input voltage V_{IN} is a DC voltage such as PFC output, approximately 1nF of capacitor C1 between BO pin and GND is recommended to suppress the noise.
　　If the input voltage V_{IN} contains AC ripples such as the rectified AC line voltage (Fig. 24), select C1 so that the time constant of C1 and R1 become approximately 50 ms to remove AC ripples.
　　When the ripples of the input voltage V_{IN} are large, the CR time constant must be further increased, or the hysteresis of the brown-in/out voltage must be set large, to prevent the BO pin voltage from exceeding the brown-in/out threshold due to the ripples. Note, however, that the delay time for detection also increases if the CR time constant increases.
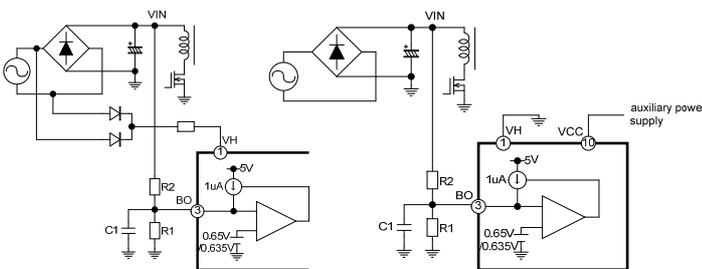
**Fig. 24 BO pin parts connection circuit**

No.4 : FB pin
(1) Function
　(i)　The feedback signal from the secondary side is input.
　(ii)　The overload state is detected.
　(iii)　Switching is stopped when the FB pin voltage is low

(2) How to use
　(i) Input of feedback signal
　- Connection method
　　Output of the photo-coupler is connected. In addition, a capacitor is connected in parallel to the photo coupler to suppress the noise.(See Fig. 25.)
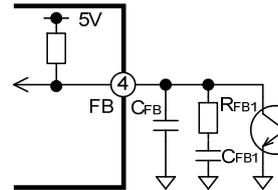
Fig. 25 FB pin part connection diagram

　- Operation
　　FB pin is biased form internal bias voltage through a resistor.
　　The voltage of the FB pin is input into the oscillator, and the frequency is determined by the FB pin voltage or the CS pin voltage, whichever is lower.
　　When the FB pin voltage rises to 0.3V, switching is started at 350kHz. When voltage rises to 0.4V, the switching frequency starts to decrease. When the voltage rises to 3.5V or higher, the oscillation frequency decreases down to minimum of 38 kHz(Fig. 8).

　(ii) Overload detection
　- Connection method
　　The same as the one described in (i).
　- Operation
　　When overload state occurs and the output voltage of the power supply decreases to below the setting, the FB pin voltage increases. If the state in which the FB pin voltage is at the over load detection FB voltage of 4.3 V or higher continues for the delay time of over load of 76.8 ms, switching stops.
　　Note that the overload detection by the FB pin is canceled at the time of soft start (until the CS pin voltage increases to 4V).
　　See 9. (11) Overload operation for details.

　(iii) Switching stop when FB pin voltage is low
　- Connection method
　　The same as the one described in (i)
　- Operation
　　When the FB pin voltage rises from near 0V at startup, etc., switching operation is stopped at less than 0.30V, and it is started when the voltage becomes 0.3V or over. After switching operation is started, it is stopped when the FB pin voltage becomes lower than 0.26V.

(3) Advice on design

The FB pin is the input pin for the feedback signal from the secondary constant voltage control. Insert a filter, which consists of resistor and capacitor, between the FB pin and the GND pin to prevent malfunction caused by noise. (See Fig. 25)

See the following for the guideline of constants of parts. C_{FB1}=0.47uF, R_{FB1}=2.2kΩ、C_{FB2}=1000pF

Make the wiring between the photo coupler and the FB pin/the GND as short as possible to avoid noise. Also do not place the wiring near the transformer.

<u>**No.5 : CS pin**</u>

(1) Function

(i) Soft start during startup

(ii) Burst operation and soft start/end function in burst operation

(2) How to use

(i) Soft start during startup

- Connection method

Connect a capacitor between the CS pin and the GND. (See Fig. 26.)
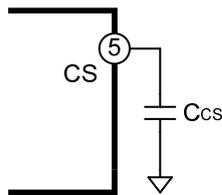
Fig. 26 CS pin parts connection diagram

- Operation

Once the IC is activated, the CS pin source current of 5.5μA is output from the CS pin to charge the capacitor connected between the CS pin and the GND. When the CS pin voltage increases to 0.4 V, switching is started at 350 kH, and with the increase of the CS pin voltage, the operating frequency decreases, ensuring soft start operation. (See Fig. 8.)

(ii) Standby mode operation and soft start/end function

- Connection method

Connect a capacitor between the CS pin and the GND.

- Operation

In the low standby mode, the CS pin is charged/ discharged according to the FB pin voltage, ensuring burst operation. (See Fig. 27.)

(a) When the FB pin voltage decreases to the FB pin burst soft-end start voltage V_{FBSE}, the CS pin enters the discharging mode and discharges the capacitor connected to the CS pin. Note that even if the CS pin voltage increases, it is clamped at 5 V.

(b) When the CS pin voltage decreases, the switching frequency increases and when CS pin decreases to below the CS pin switching stop voltage V_{CSOFF}, switching is stopped. This operation is soft end. Eventually the CS pin voltage reaches almost 0V.

(c) After the switching is stopped, output voltage of the converter decreases and FB pin voltage starts increasing.

(d) When the FB pin voltage increases to the FB pin burst soft-start start voltage V_{FBSS}, the CS pin enters the charging mode, and charges the capacitor of CS pin.

(e) When the CS pin voltage increases and exceeds the CS pin switching start voltage V_{CSON}, switching is started with soft start.

(f) With the increase of the CS pin voltage, the switching frequency gradually decreases.

(g) By the switching operation, output voltage of the converter increases and FB pin voltage decreases.

As a result of returning from the state described in (g) to that in (a), burst operation is ensured, thereby achieving low standby power operation
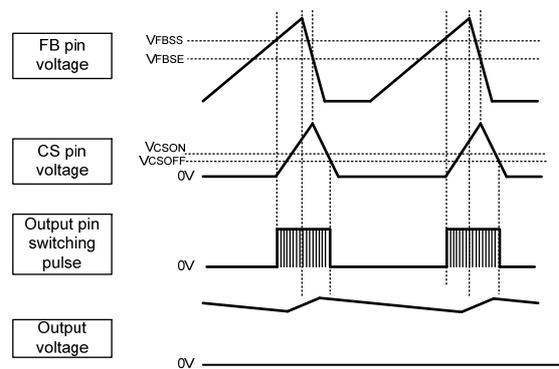

Fig. 27 Burst operation waveform in low standby mode

(3) Advice on design

When low standby mode is to be used, adjust the capacitor of the CS pin to be approximately from 0.01 μF to 0.047 μF considering the transformer audio noise and standby power at the time of burst operation.

When the low standby mode is not to be used, adjust the capacitor to be 0.01 μF or higher taking the soft start time only into consideration.

No.6 : STB pin

(1) Function

(i) Selection between normal mode and low standby mode.

(2) How to use

(i) Selection between normal mode and low standby mode

- Connection method

Connect a resistor、capacitor, and a switch element such as transistor or photo-coupler between the STB pin and the GND (See Fig. 28).
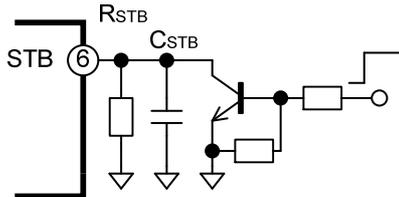
Fig. 28 Standby mode switching circuit diagram

- Operation

Operating mode can be switched between the normal mode, where IC operates with normal switching, and the low standby mode, where low standby power is achieved with burst operation, depending on the voltage of the STB pin.

By pulling down the STB pin voltage below the low standby mode detection voltage of 0.3 V (V_{THSTBL}), IC operates in the normal mode.

To switch to the low standby mode, open the switch elements. Since 30μA current is output from the STB pin, FB pin voltage rises. It is necessary to adjust this STB pin voltage within the range from the low standby mode detection voltage of 0.35 V (V_{THSTBH}) and the ultra-low standby mode detection voltage of 1.5 V ($V_{THSSTBH}$), by adjusting the resistor connected between the STB pin and the GND.

When the low standby mode detection delay time of 105 ms elapses after the STB pin voltage reaches the low standby mode detection voltage of 0.35 V (V_{THSTBH}), burst operation is started.

(3) Advice on design

① STB pin resistor and capacitor

When using low standby mode, it is recommended that the resistor R_{STB} connected between the STB pin and the GND is 33 kΩ .

It is also recommended that the capacitor C_{STB} is 1000pF.

② Improvement of standby power

At standby mode, average output voltage of the converter is kept the same voltage as normal operation by feedback control, though ripple voltage becomes large by burst operation. As the result, standby power becomes higher slightly.

We recommend output voltage switch circuit which lowers the output voltage at standby mode to decrease standby power.

In addition, we recommend FB pin response switch circuit to decrease ripple voltage caused by burst mode operation at standby mode. (See Fig. 29)
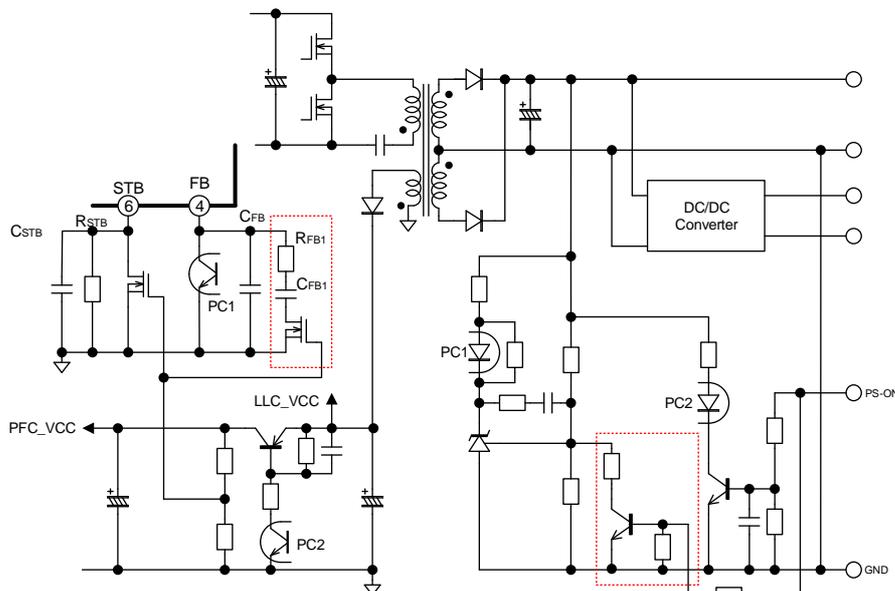

Fig. 29 Output voltage and FB pin response switch circuit at standby mode

No.7 : MODE pin

(1) Function

(i) Burst mode condition and PFC condition (with/without PFC) are selected according to the MODE pin resistor.

(ii) Set the delay time for overcurrent protection (IS pin).

(iii) Protection operates by an external signal.

(2) How to use

(i) Operating mode setting

- Connection method

Connect a resistor and a capacitor in parallel between the MODE pin and the GND. (See Fig. 30.)
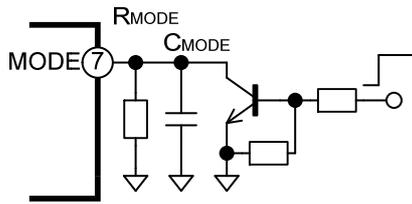
Fig.30 MODE pin parts connection diagram

- Operation

When the VCC pin voltage rises to 11.5 V at start up, the mode selection source current of 10 μA is output from the MODE pin, and mode setting is made depending on the voltage generated resistor between the MODE pin and the GND. Note that if the resistor is in open state at the time of operating mode setting, the MODE pin voltage increases to above the mode selection resistor open detection voltage of 4.4 V. Consequently, IC stops in latch mode.

The operating mode setting time is set at 40 ms. After the setting time elapses, the VCC pin voltage increases again, and when it reaches the start operation voltage of 13 V, switching is started.

During normal operation, the MODE pin is kept at 0.48 V. (See the startup operation waveform in Fig. 15.)

There are four selectable modes. (See Table 5.)

(ii) Setting the delay time for overcurrent protection (IS pin)

- Connection method

The same as the one described in (i).

- Operation

The MODE pin voltage is clamped at 0.48 V during normal operation. If the IS pin detects state of overcurrent, constant current of 26.5 μA is output from the MODE pin to charge the capacitor. When the MODE pin voltage reaches 0.8 V, the output of the constant current is stopped, and the capacitor is discharged by the resistor. When the MODE pin voltage decreases to 0.6 V, the constant current is output again. The MODE pin repeats this oscillation state, and when the number of times of oscillation reaches 36, switching is stopped. (See Fig. 31.)

The delay time is settable in a range approximately from 1 ms to 40 ms.
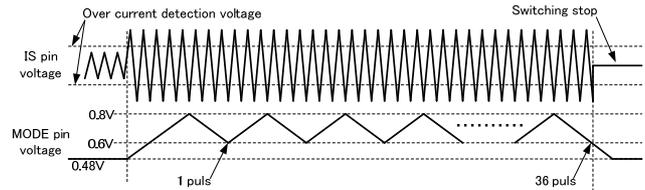
Fig. 31 Overcurrent delay time counting operation

(iii) Protection by external signal input

- Connection method

Pull down the MODE pin by external signals. (See Fig. 30)

- Operation

The MODE pin is kept at 0.48 V during normal operation. At this time, source current of 25 μA is output from the MODE pin. If the MODE pin voltage is pulled down below the threshold voltage for external fault stop of 0.35 V for 304 μs, output switching stops.

(3) Advice on design

① Each settings based on the MODE pin resistor

See Table 5 for the details of resistance between the MODE pin and the GND.

As for burst setting, if switching frequency at rating output power is higher than 100 kHz, high frequency mode is selected and if switching frequency at rating output power is lower than 70 kHz, low frequency mode is selected, generally. If switching frequency at rating output power is between 70 kHz and 100 kHz test both high frequency mode and low frequency mode and select mode according to the test result.

In addition, if operation at burst mode has no problem, it is acceptable that low frequency mode is selected though switching frequency is higher than 100 kHz. It is also acceptable that high frequency mode is selected though switching frequency is lower than 70 kHz.

Table 5

MODE pin resistor	MODE	With/Without PFC setting	Burst setting
56kΩ	A	With	High frequency mode
100kΩ	B	Without	High frequency mode
200kΩ	C	With	Low frequency mode
330kΩ	D	Without	Low frequency mode

② Output over voltage protection circuit using MODE pin
 Secondary overvoltage protection in Latch mode can be made using MODE pin.
Example circuit is shown in Fig. 32.
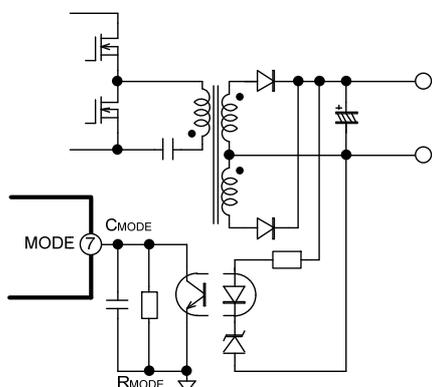
Fig. 32 Secondary overvoltage protection using MODE pin

③ Setting the delay time for overcurrent protection
 (IS pin)
 The delay time for overcurrent using the capacitor and the resistor of the MODE pin is calculated as below. Table 6 lists the relation between "a" and "b" values in the formula and the resistance value, and the chart in Fig. 33 exhibits the relation between the delay time for overcurrent and the capacitor.

 Since the MODE pin also has the function of setting the operating mode by resistance value, to set the delay time for overcurrent T_{OCPDLY}, it is necessary to determine the capacitor, C_{MODE}, depending on this resistor.

$$t_{OCPDLY}[ms] = a \times C_{MODE}[nF] + b$$

Table 6

| R_{MODE}	a	b
56kΩ	1.212	0.392
100kΩ	1.479	0.461
200kΩ	2.406	0.656
330kΩ	3.867	0.913
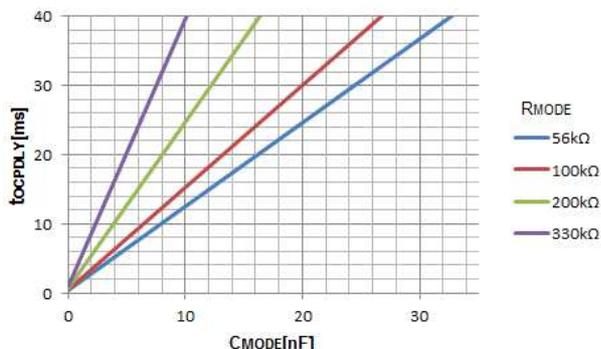
Fig. 33 Guideline for setting delay time for overcurrent protection

No.8 : IS pin

(1) Function
 (i) This pin detects the resonant current for the forced turnoff function to prevent switch through.
 (ii) This pin detects the resonant current for over current protection.

(2) How to use
 (i) Detection of resonant current for the preventing switch-through function
 − Connection method
 Because the loss increases when the current flowing into the resonant capacitor is monitored directly, a shunt capacitor is connected, the current is converted into the voltage by the resistor and it is input into the IS pin in order to detect the resonant current.
 To prevent influence of noise, connect a capacitor (Cis=100pF recommended) between the IS pin and the GND. In addition, set CR filter depending on noise level. (See Fig. 34)
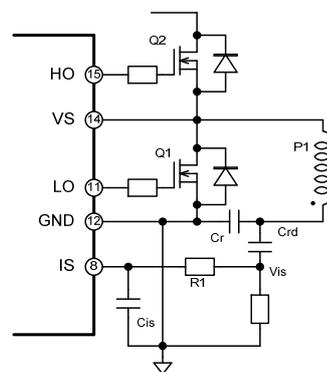

Fig. 34 IS pin parts connection diagram

- Operation
 See Section 9.(5) for details of the preventing switch-through function.

(ii) Overcurrent protection
- Connection method
 The same as the one described in (i).
- Operation
 If the IS pin voltage exceeds the over current detection voltage, the MOSFET is tuned off for each oscillation cycle, and then other MOSFET is turned on after the dead time. If the overcurrent state continues, turning on/off is repeated.
 If this overcurrent detection state continues for a period of the delay time for overcurrent having been set by the CR constant of the MODE pin, switching is stopped. (See Fig. 31.)
 Switching is suspended for the period of the restart time of over current of 810 ms, and switching is resumed when the restart time of overcurrent has elapsed.
 If overcurrent is not detected for a period equivalent to the reset time of over current detection of 76 μs, overcurrent detection is reset.

(3) Advice on design

① Overcurrent detection

The capacitance of the shunt capacitor Crd is recommended to be approximately 1/100 of that of the resonant capacitor Cr.

Overcurrent is detected by dividing the current by the capacitance ratio of Crd/Cr, and converting the current into voltage using an overcurrent resistor Ris.

For example, to detect overcurrent at Icr=4A, the current is divided into 40 mA by the capacitance ratio Crd/Cr (1:100 recommended). When the over current detection voltage of low/high side (V_{OCP} or V_{OCM}) of the IS pin is ±4 V (which is corrected depending on the AC input voltage and with/without PFC settings), the overcurrent resistor Ris becomes 100 Ω.

$$Ris = \frac{V_{OCP}(or V_{OCM}) \times Cr}{Icr \times Crd}$$

② Inserting a CR filter

The switching noise of MOSFET may cause malfunction of the overcurrent detection function and the preventing switch-through function of IS pin, and operation may become unstable. In such cases, add a CR filter to the IS pin as shown in Fig. 34.

The value of CR filter recommends approximately Cis=100pF and R1=100ohm.

Select a filter depending on the magnitude of the noise, but the selection requires special attention because delay factor increases, thereby increasing fluctuation in overcurrent detection level if the time constant of Rcs × Ccs increases.

No.9 : VW pin

(1) Function

(i) Detects the current state during of switching monitoring the auxiliary winding voltage which has the reversed polarity to the main winding for the preventing switch-through function.

(ii) Detects the overload state.

(2) How to use

(i) Voltage detection for arm-short prevention function

- Connection method

The auxiliary winding voltage which has the reversed polarity to main winding is input to VW pin through voltage divider resistor. The auxiliary winding can also be used as Vcc winding.

To prevent influence of noise, connect a capacitor between the VW pin and GND.

Connection of two zener diodes may be needed so that the pin voltage may not exceed absolute maximum rating.
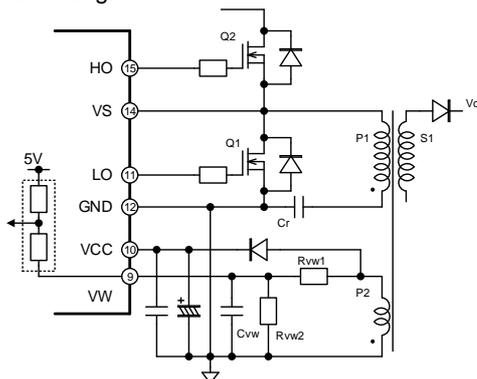
Fig.35 VW pin circuit

- Operation

Connect the auxiliary winding voltage which has the reversed polarity to main winding to VW pin. See 9 (5) Arm-short prevention function for details of operation.

(ii) Overload detection

- Connection method

The same as the one described in (i).

- Operation

Since the peak voltage of the auxiliary winding on the primary side is proportional to the load on the secondary side, by detecting the peak voltage of the auxiliary winding, high-precision overload protection function can be achieved. The auxiliary winding voltage is input to the VW pin through resistor voltage divider and the voltage divider should be adjusted according to overload load detection level. If the VW pin voltage over the over load detection VW voltage for a period equivalent to the delay time of over load of 76.8 ms, switching stops.

In the case of automatic recovery type, intermittent operation is performed under overload, and when the overload state is reset, normal operation is resumed. In the case of timer latch type, switching stops when overload state is reached, and thus latch off occurs.

If detection is not performed for a period equivalent to the over load detection reset time of 108 μs or longer while the overload detection state continues, overload detection is reset.

See 9 (11) Overload operation for details.

(3) Advice on design

① Calculating the VW pin resistance

The resistor R_{VW1} is recommended within the range from 10 kΩ to 20 kΩ.

The formula for calculating the resistor R_{VW2} is shown below:

$$R_{VW2} = \frac{R_{VW1} \times V_{OLPVW}}{(V_{OLPP2} - V_{OLPVW})}$$

where,

V_{OLPVW} = Over load detection VW voltage
= 3.08V or 3.36V

(It is corrected according to the input voltage and PFC with/without settings.)

V_{OLPP2} = measured voltage of auxiliary winding P2 at overload

However, since the dependency of P2 auxiliary winding voltage against the load varies with leakage inductance, etc. determine R_{VW2} (voltage divider ratio with R_{VW1}) with evaluation of overload on actual converter.

If the resistor R_{VW1} becomes large, the effect of the VW level shift resistor within the IC increases. When the effect of the VW level shift resistance taken into consideration, the following calculating formula can be used:

$$R_{VW2} = \frac{R_{VW1} \times V_{OLPVW}}{(V_{OLPP2} - V_{OLPVW}) + [(5 - V_{OLPVW}) \times \frac{R_{VW1}}{R_{VWLVS}}]}$$

where, R_{VWLVS} = VW level shift resistance

② Connecting the capacitor

Connecting a capacitor C_{VW} of 22 pF (typ) to 56 pF is recommended to prevent influence of noise. If noise is large, thus causing malfunction, it is possible to increase the capacitor. In this case, however, pay careful attention because delay may be caused in overload detection due to the filter circuit with R_{VW1}, thereby affecting the detection level, or delay may also be caused in forcibly turning off the arm-short prevention function and it may malfunction.

No.10 : VCC pin

(1) Function
  (i) Supplying the power of IC
  (ii) Preventing malfunction by detecting low voltage
  (iii) Overvoltage protection at secondary-side overvoltage

(2) How to use
  (i) Supplying power of IC
  - Connection method
   Generally, the auxiliary winding voltage provided in the transformer is rectified/smoothed and connected. (See Fig. 36.)
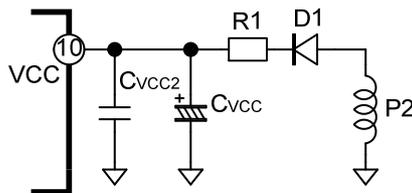

Fig. 36 VCC terminal part connection diagram

  - Operation
   Make the setting so that the voltage supplied from the auxiliary winding during normal operation will be in the range from 14 to 27 V. Since the start-up circuit stop voltage is 12.1 V (max.), the VCC pin voltage should be 14 V or higher (recommended operation condition) not to allow the startup circuit to be activated during normal operation.
   Since it is not possible to keep operating the IC only with the current supplied from the startup circuit, without the auxiliary winding under normal operation conditions, supply VCC voltage from the auxiliary winding.

(ii) Preventing malfunction by detecting low voltage
- Connection method
  The same as the one described in (i).
- Operation
   To prevent circuit malfunction when Vcc voltage decreases, an under voltage lockout circuit is incorporated.
   At the startup, switching is started when the VCC pin voltage increases to the start operation voltage of 13 V. (It is also necessary that the voltage between the VB pin and the VS pin becomes higher than VBS switching start voltage of 8.8 V.) When the VCC voltage decreases to below 9V, the IC stops operation.
   When the IC stops operating by the under voltage lockout circuit, the OUT pin is forcefully put in Low state.

(iii) Overvoltage protection on the secondary side
- Connection method
  The same as the one described in (i).
- Operation
   If the VCC pin voltage exceeds the over voltage threshold voltage of 28.5 V for the delay time of overvoltage protection of 304 μs, switching stops in latch mode.

(3) Advice on design
  ①Connection of the bypass capacitor
   Since high current flows in the VCC pin when the MOSFET is driven, relatively large noise is generated on VCC pin. In addition, noise is also generated by the current supplied by the auxiliary winding. If this noise is large, the IC may malfunction.
   Therefore, connect the bypass capacitor C_{VCC2}(0.1uF ～) between VCC-GND near the IC in addition to the electrolytic capacitor C_{VCC} as shown in Fig. 36.

  ②Auxiliary winding P2
  Determine the number of turns of the P2 winding using the following formula. When the number of turns of the secondary winding for output voltage Vo is defined as S1, the number of turns of the P2 winding can be calculated as follows:

$$P_2 = \frac{V_{CC}}{V_o} S_1 \qquad \text{(10-1)}$$

  ③Rectifier diode and resistors, and electrolytic capacitor
   In the VCC supply circuit shown in Fig. 36, use the low forward voltage diode for the rectifier diode D1.
   In case that low standby mode is used, Vcc capacitor may be enlarged so that Vcc voltage will not drops while switching stop period of burst mode.

  ④Decreasing the startup time
   In case that low standby mode is used, Vcc capacitor may be enlarged and it causes longer start up time.
   If it is necessary to decrease start up time, use the circuit as shown in Fig. 37.
   Capacitor should be selected as Cvcc3 < Cvcc1.
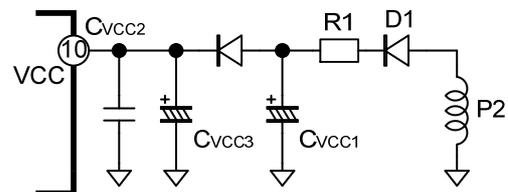
**Fig.37 Vcc circuit for shorter start up time**

No.11 : LO pin

(1) Function

This pin drives the MOSFET of the low side.

(2) How to use

- Connection method

LO pin is connected to gate of the MOSFET via the resistor. (See Fig. 38 and 39.)
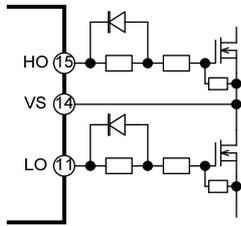
Fig. 38 OUT pin circuit 1   **Fig.39 OUT pin circuit 2**
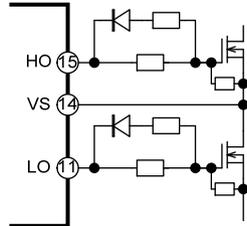
- Operation

During ON period of the MOSFET, LO pin is H state and outputs almost the VCC voltage.

During OFF period of the MOSFET, LO pin is L state and outputs almost 0V.

(3) Advice on design

Gate resistor is connected to limit the OUT pin current and prevent the oscillation on the gate pin voltage.

No.12 : GND pin

(1) Function

This is the reference pin for the voltage of each part of the IC.

(2) Advice on design

GND pin is connected to both signal GND and Gate drive GND. Each GND wiring should be connected to GND pin with the impedance as low as possible.

No.13 : NC pin

This pin is not connected to the IC internally because it is located next to the high-voltage pin (VS).

No.14 : VS pin

(1) Function

This is the floating ground pin for the high-side driver.

(2) How to use

- Connection method

In the main circuit of the current resonant converter, the source of the high-side MOSFET and the drain of the low side MOSFET are connected and the connected point is input to the VS pin with low impedance. (See Fig. 40.)
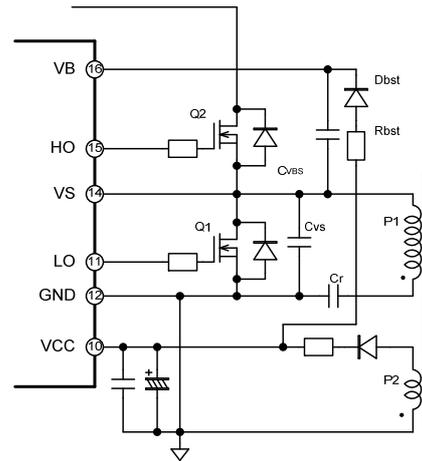

Fig. 40 Output part circuit

- Operation

Since the high-side MOSFET and the low-side MOSFET turns on and off alternately, the VS pin voltage changes. The high side driver operates with the VS pin as the reference voltage and with the bootstrap circuit.

(3) Advice on design

When the high side MOSFET Q2 turns off, the current flowing Q1 goes to the body diode of low side MOSFET Q1.

VS pin voltage may drop by tens of volts for hundreds of ns at high side turn off depending on the inductance and current change rate of main current. The large minus voltage of VS pin may cause malfunction or damage of the IC.

Therefore, take the countermeasures such as lowering the switching speed by connecting the capacitor C_{VS} between VS and GND, and making the wiring inductance to be small.

However, too large C_{VS} causes a hard switching. Please determine C_{VS} with the confirmation of the actual power supply.

No.15 : HO pin

(1) Function

This pin drives the high-side MOSFET.

(2) How to use

− Connection method

HO pin is connected to gate of the MOSFET via the resistor (See Fig. 38 and 39.)

− Operation

During the period when the MOSFET is turned on, the state is set to the H output state and almost the VB voltage is output. During the period when MOSFET is turned off, the state is set to the L output state and almost the VS voltage is output.

(3) Advice on design

Gate resistor is connected to limit the OUT pin current and prevent the oscillation on the gate pin voltage.

No.16 : VB pin

(1) Function

  (i) Power supply pin of the high-side driver

  (ii) Detects low voltage to prevent malfunction.

(2) How to use

<u>(i) Supplies power to the high-side driver</u>

- Connection method

  Connect the bootstrap capacitor C_{VBS}, the bootstrap diode Dbst and the charge-current limiting resistor Rbst as shown in Fig. 40.

- Operation

  During the period when the low-side MOSFET is on, the bootstrap capacitor C_{VBS} is charged from the VCC pin via the bootstrap diode Dbst. The high-side driver operates with the voltage charged C_{VBSS}.

<u>(ii) Detecting low voltage to prevent malfunction</u>

- Connection method

  The same as the one described in (i).

- Operation

  To prevent circuit malfunction at the time of decreased power supply voltage, an under voltage lockout circuit is integrated.

  When the voltage between the VB pin and the VS pin increases and reaches the VBS switching start voltage of 8.8 V, switching is started (it is also necessary for the VCC pin voltage to increase and reach the switching start voltage of 9 V or higher).

  When the VCC power supply voltage decreases and the voltage between the VB pin and the VS pin decreases to the VBS switching stop voltage of 7.5 V, the IC operation stops.

  When high side driver is stopped by the under voltage lockout circuit, the HO pin is forced to be in the Low state.

(3) Advice on design

  The loop among the bootstrap capacitor C_{VBS}, VS pin and VB pin should be as small as possible.

①<u>Selecting a bootstrap capacitor C_{VBS}</u>

  In Fig. 40, at the state where Q2 is ON and Q1 is OFF, the V_{VBS} voltage decreases due to the Q1 gate charging current, the high-side driver operating current of IC I_{BS2}, and C_{VBS} leakage current.

  Therefore, to prevent the voltage between the VB pin and the VS pin from decreasing to the VBS switching stop voltage of 7.5 V (V_{BSOFF}) or lower during the Q2 ON period, select the value of C_{VBS}.

  The minimum capacitance required for C_{VBS} is calculated using the following formula, but select the capacitance with enough margin.

  A bootstrap capacitor C_{VBS} having the capacitance of 0.47 μF (min.) – 1.0 μF (typ) is recommended.

$$C_{VBS} > \frac{Qg + I_{IBS2} \times Ton + Icbs(leak) \times Ton}{V_{CC} - V_{BSOFF} - Vf - V_{LS}}$$

where,

 Qg: Gate charge of MOSFET

 I_{BS2}: High-side operating current of IC

 Ton: Maximum ON time of high-side MOSFET Q2

 Icbs(leak): Leakage current of bootstrap capacitor

 V_{CC}: Low-side power supply voltage

 V_{BSOFF}: VBS switching stop voltage

 Vf: Forward voltage of bootstrap diode

 VLS: Low-side MOSFET Q1 ON voltage

Example:

$$C_{VBS} > \frac{100nc + 0.1mA \times 5us + 0.01uA \times 5us}{14V - 7.5V - 0.6V - 5V} = 0.11uF$$

②<u>Selecting a charging current limiting resistor Rbst</u>

  Be sure to insert Rbst to prevent generation of rush current at the time of initial charging of C_{VBS}. To prevent damage of the diode Dbst, select Rbst so that the peak current of the Dbst will be in the range of maximum ratings.

③<u>Selecting bootstrap diode Dbst</u>

  Select a fast-recovery diode with small reverse recovery time. If the reverse recovery time is long, the reverse recovery current to the low-side power supply VCC increases when the high-side MOSFET is set to ON, and thus Vcc supply efficiency for VBS decreases. In addition, VCC ripple may cause malfunction.

  Use the rating voltage to be that of the low-side MOSFET or higher, taking derating into consideration.

  The average current I_{FAV} can be found by multiplying the gate charge quantity Qg of the MOSFET by the operation frequency fsw as follows:

$$I_{FAV} = Qg \times fsw$$

The peak current is considered to be the current found by dividing the maximum low-side power supply voltage value VCC by Rbst.

● **Other advice on designing**

(1) Preventing malfunction due to negative voltage of the pin

If large negative voltage is applied to each pin of the IC, the parasitic devices inside the IC may be operated, thus causing malfunction. Confirm that the voltage of -0.3 V or less is not applied to each pin.

If negative voltage is applied due to noise, connect a Schottky diode between each pin and the GND.

The forward voltage of the Schottky diode can suppress the negative voltage at each pin. In this case, use a Schottky diode whose forward voltage is low.

(2) Loss calculation

To use the IC within the rating, it is necessary to confirm the loss of the IC. However, since it is difficult to measure the loss directly, the method of confirming the loss by calculation is shown below.

If the voltage applied to the VH pin is defined as V_H, the current fed to the VH pin during operation as I_{HRUN2}(VH=400V), power supply voltage as V_{CC}, VCC operating current as I_{CC3}, gate input charge of the MOSFET to be used as Qg1 and Qg2, and switching frequency as fsw, the total loss Pd of the IC can be calculated using the following formula.

$$P_d = V_{CC} \times (I_{CC3} + Qg1 \times f_{SW} + Qg2 \times f_{SW}) + V_H \times I_{HRUN2}$$

A rough value can be found using the above formula, but note that Pd is slightly larger than the actual loss value. Also note that each specific characteristic value has temperature characteristics or variation.

Example:

If the VH pin is connected to AC 240V via a full-wave rectification, the average voltage to be applied to the VH pin is approximately 215 V. In this state, assume that Vcc＝20V、Qg1=Qg2=100nC、fsw=100kHz (when Tj = 25°C). Since I_{HRUN2}=10uA and I_{CC3}=0.9mA from the specifications, the standard IC loss can be calculated as follows:

Pd≒20V×(0.9mA+100nC×100kHz+100nC ×100kHz)
                    +215V×10uA

      ≒420mW

11. Precautions for pattern design

In the switching power supply, large pulse current flows in the GND wiring and surge voltage (noise) is generated. The noise may causes malfunction of the IC. (unstable voltage, unstable waveform, abnormal latch stop, etc.) Malfunction may also be caused by injected surge voltage/current such as lighting surge test, AC line surge test and electrostatic discharge test.

Please design the PCB layout and trace with consideration of the followings to prevent the malfunction.

Current path in switching power

(1) Main circuit current which flows from input smoothing capacitor to transformer primary winding, MOSFET and current sense resistor.
(2) Current which flows from auxiliary winding to VCC capacitor and driving current which flows from IC to the MOSFET
(3) Control circuit current around the IC such as feedback signal
(4) Filter current which flows between primary and secondary via the Y-Capacitor.

Points in pattern designing

- The GND wiring of the above (1)-(4) should be separated so as not to affect each other.
- To minimize the surge voltage of MOSFET, loop length of the main circuit should be designed as short as possible.
- Especially separate the GND patterns in the main circuit system and the control circuit system from each other, and connect the GND patterns as near the (-) pin of the electrolytic capacitor as possible.
- The electrolytic capacitor between VCC pin and GND should be connected close to the IC.
- The bypass capacitor of the VCC pin should be connected as close as possible to the IC.
- The bootstrap capacitor between the VB – VS pins should be connected close to each pin using the shortest wiring.
- Capacitors for filter such as FB pin and CS pin should be connected close to each pin using the shortest wiring.
- The loop area of IS pin and GND wiring should be as small as possible.
- The IC and control circuit should not be arranged inside the main circuit loop.
- Control circuit and signal wiring should not be placed under the transformer and coil so as not to affect the leakage flux.
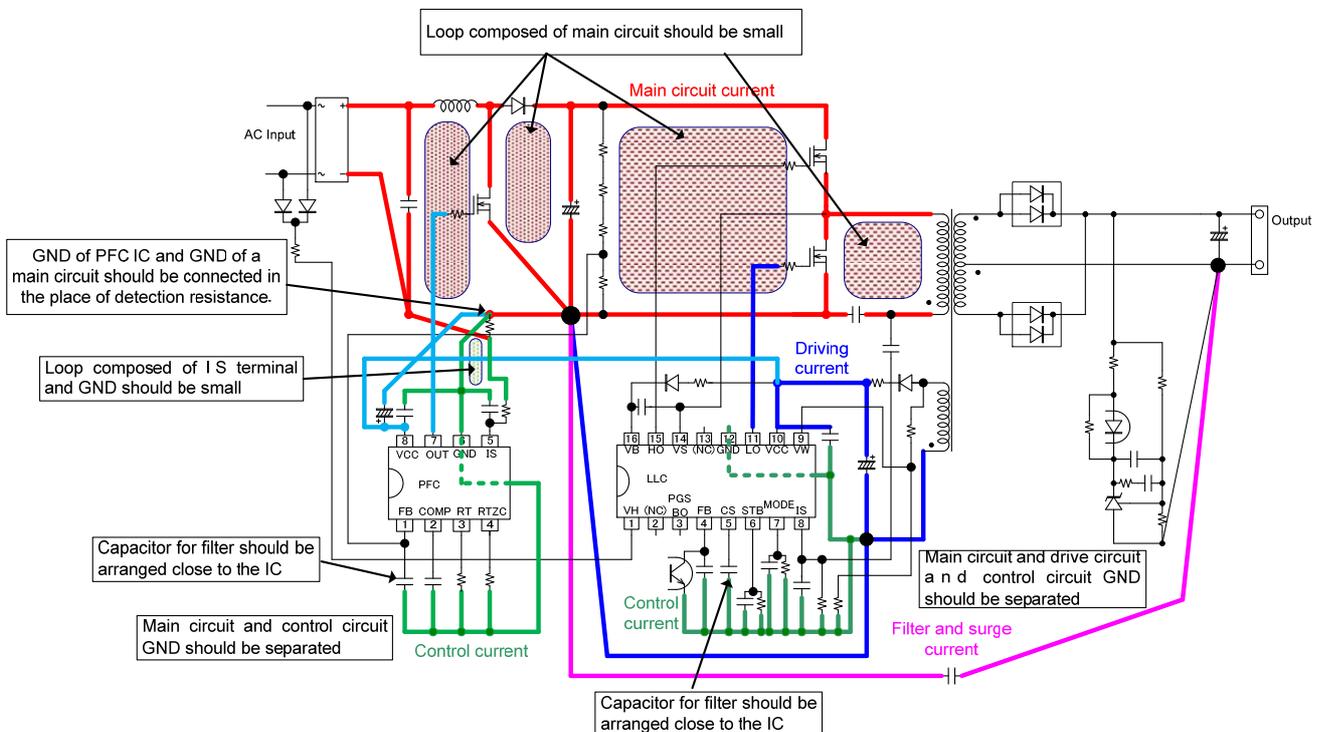

Fig. 41 Pattern design image

12. Application circuit example
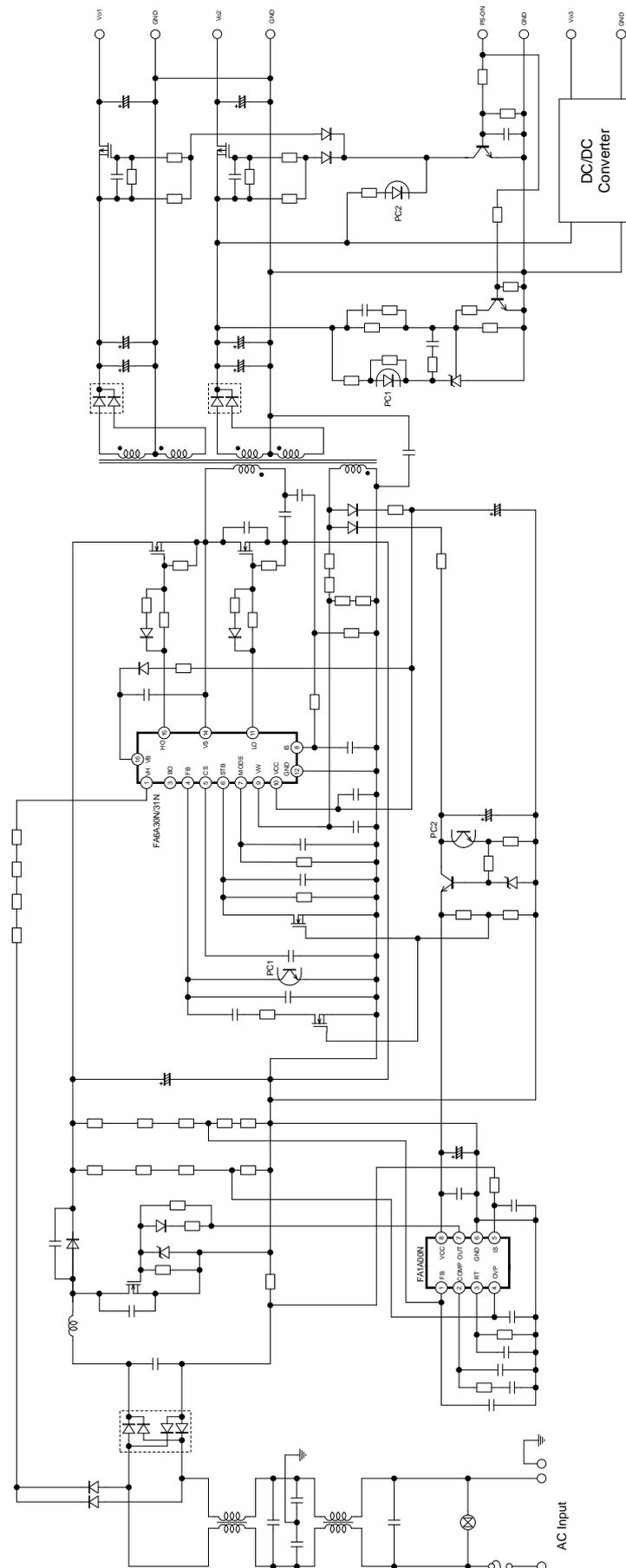
Note:

This example of application circuit is a reference material to explain the typical usage of this IC and does not warrant any operation or characteristics.

45/46

Notice

1. The contents of this note (Product Specification, Characteristics, Data, Materials, and Structure etc.) were prepared in April 2018.The contents will subject to change without notice due to product specification change or some other reasons. In case of using the products stated in this document, the latest product specification shall be provided and the data shall be checked.

2. The application examples in this note show the typical examples of using Fuji products and this note shall neither assure to enforce the industrial property including some other rights nor grant the license.

3. Fuji Electric Co.,Ltd. is always enhancing the product quality and reliability. However, semiconductor products may get out of order in a certain probability.Measures for ensuring safety, such as redundant design, spreading fire protection design, malfunction protection design shall be taken, so that Fuji Electric semiconductor product may not cause physical injury, property damage by fire and social damage as a result.

4. Products described in this note are manufactured and intended to be used in the following electronic devices and electric devices in which ordinary reliability is required:
   - Computer - OA equipment - Communication equipment (Pin) - Measuring equipment
   - Machine tool - Audio Visual equipment - Home appliance - Personal equipment
   - Industrial robot etc.

5. Customers who are going to use our products in the following high reliable equipments shall contact us surely and obtain our consent in advance. In case when our products are used in the following equipment, suitable measures for keeping safety such as a back-up-system for malfunction of the equipment shall be taken even if Fuji Electric semiconductor products break down:
   - Transportation equipment (in-vehicle, in-ship etc.) - Communication equipment for trunk line
   - Traffic signal equipment - Gas leak detector and gas shutoff equipment
   - Disaster prevention/Security equipment - Various equipment for the safety.

6. Products described in this note shall not be used in the following equipments that require extremely high reliability:
   - Space equipment - Aircraft equipment - Atomic energy control equipment
   - Undersea communication equipment - Medical equipment.

7. When reprinting or copying all or a part of this note, our company's acceptance in writing shall be obtained.

8. If obscure parts are found in the contents of this note, contact Fuji Electric Co.,Ltd. or a sales agent before using our products. Fuji Electric Co.,Ltd. and its sales agents shall not be liable for any damage that is caused by a customer who does not follow the instructions in this cautionary statement.

- The contents will subject to change without notice due to product specification change etc.
- Application examples and component in this sheet is for the purpose of assisting in the design. Therefore, This sheet has not been made in consideration of the margin.
- Before using, Please design in consideration of the parts variation and use condition.