-Preliminary-

AP1653AEM

PFC＋constant current LED Driver IC

1. General Description

The AP1653 is a single-channeled white LED driver. It consists of an active PFC circuit that is constructed by a non-inverting buck-boost converter and a constant current circuit. With a single coil and three N-ch MOSFETs, the AP1653 can drive white LEDs which are connected by cascade connection. LED current is dependent on the external resistance setting. The input voltage range is from AC85V to AC275V. LED dimming is controlled by external DC signal ranging 0V to 5V, and up to 3% dimming in current ratio is available. The AP1653 integrates a self power-up circuit, a 5V regulator circuit, LED open state protection, LED short protection, over current protection for MOSFET, thermal shut down for the IC and undervoltage lockout protection (UVLO) circuits. It is able to output an error state flag and supports enable inputs.

2. Features

- Output LED forward direction voltage (VF) by Non-Inverted PFC Buck-Boost Controlling
- Power Supply 13.5V ~ 26V
- Operation Temperature −40 ~ 95°C
- Current Controlling Accuracy ±3% (Does not include the variation of the sense resistor)
  - The AC input voltage or LED forward voltage is changed, the output is stable.
- Soft Start-up Function
- DC Dimming
  - 100% to 3% dimming of LED current is available by External DC Input
- Protection
  - Over Current Protection for external N-ch MOSFET
  - Under Voltage Lock Output Function (UVLO) of the IC
  - LED Open Protection Function
  - LED Short Protection Function
  - Thermal Shut Down of the IC
- Harmonic Regulation “JIS C 61000-3-2 Class C” Compliant
- Package 24-pin TSSOP

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4. Block Diagram

■ Block Diagram

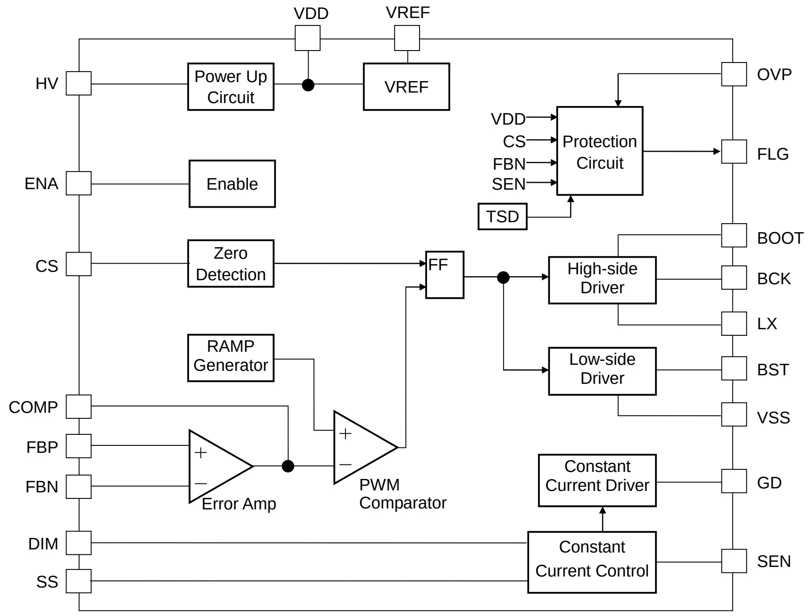


Figure 1. AP1653 Block Diagram

■ Functional Description

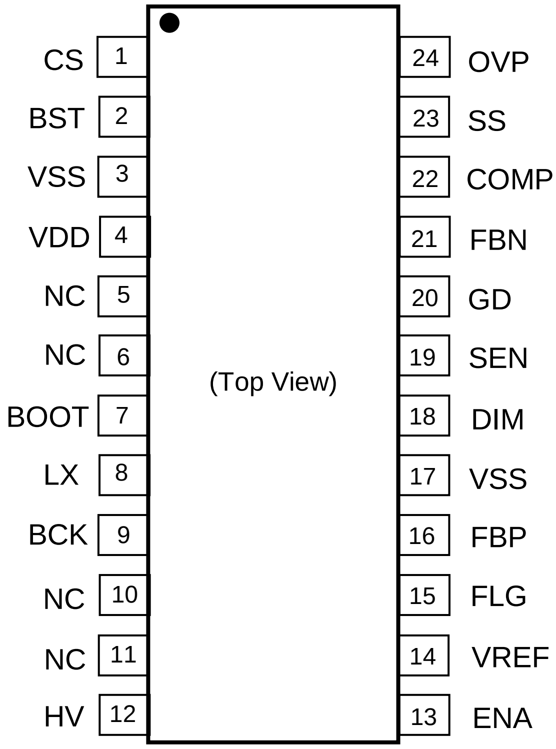
BLOCK Name	Description
Power-up Circuit	Power supply to the HV pin is charged to a capacitor connected to VDD via this block to power-up.
VREF	A linear regulator that generates a 5V (typ) reference voltage from VDD. External supply up to 3mA is accepted.
Enable	Buck-boost PFC converter and constant current circuit are powered up by setting the ENA pin = “H”.
Zero Detection	Zero detection of coil current is executed by this block for boundary conduction operation of buck-boost PFC converter.
RAMP Generator	This block generates RAMP waveform for determining power-on period of the buck-boost PFC converter.
Error Amplifier	Monitor the cathode voltage of LEDs, and output error amount by comparing with the reference voltage.
PWM Comparator	Turn OFF the driver of buck-boost PFC converter by comparing a signal from RAMP generator and a signal from error amplifier.
High-side Driver	Driver circuit for High-side MOSFET of buck-boost PFC converter.
Low-side Driver	Driver circuit for Low-side MOSFET of buck-boost PFC converter.
Constant Current Circuit and Driver	This block keeps LED current constant by controlling an external MOSFET. LED current can be changed by the voltage of the DIM pin. Soft start-up function is available upon power-up.
Protection Circuit	Thermal Shut Down, UVLO, Over Voltage production (OVP, FBN), Over Current Protection (OCPCS, OCPSEN).
TSD	Temperature Sensor for Thermal Shut Down Function

5. Ordering Guide

AP1653AEM Ta = -40～95℃ 24-pin TSSOP

6. Pin Configurations and Functions

■ Pin Configurations



■ Pin Functions

No.	Pin Name	I/O	Function
1	CS	I	Current Detection Pin for Low-side External N-ch MOSFET
2	BST	O	Output Pin for Low-side External N-ch MOSFET Driver This pin is pulled-down by 100kΩ internally.
3	VSS	PWR	Ground Pin
4	VDD	PWR	Power Supply Pin Connect a 47μF bypass capacitor between this pin and the VSS pin.
5,6	NC	-	No Connection Pin. This pin must not connect to anywhere. It is not connected internally.
7	BOOT	PWR	High-side Floating, Power Supply Offset Voltage Input Pin
8	LX	PWR	High-side Floating, Power Supply Absolute Voltage Input Pin
9	BCK	O	Output Pin for High-side External N-ch MOSFET Driver
10,11	NC	-	No Connection Pin. This pin must not connect to anywhere. It is not connected internally.
12	HV	PWR	High Voltage Power Supply Pin for Start-up
13	ENA	I	IC Enable Signal Input Pin The AP1653 enters normal operation mode by inputting “H” level voltage and enters standby mode by inputting “L” level voltage to the ENA pin. In standby mode, all circuits except the power-up, regulator, reference voltage and thermal shut down circuits are stopped.
14	VREF	O	Internal Regulator Output Pin Connect a 10μF capacitor between this pin and the VSS pin.
15	FLG	O	Fault Flag Pin This pin is an active-low open drain output pin. Over current, over voltage, UVLO or thermal shut-down status is output.
16	FBP	I	Reference Voltage Setting Pin for Feedback Error Amplifier of White LED Cathode Voltage
17	VSS	PWR	Ground Pin
18	DIM	I	Dimming Control Analog Input Pin
19	SEN	I	Current Detection Pin for Constant Current
20	GD	O	External N-ch Power MOSFET Driver Pin for Constant Current
21	FBN	I	Input Pin of Feedback Error Amplifier for White LED Cathode Voltage Connect cathode pins of LED.
22	COMP	O	Feedback Error Amplifier Output Pin Connect a CR circuit for phase compensation.
23	SS	O	Soft Start-up Time Setting Pin Connect a 1μF Capacitor.
24	OVP	I	Over Voltage Detection Pin

7. Absolute Maximum Ratings

Parameter	Symbol	min	max	Unit
HV pin Voltage (Note 1)	V_{HVMAX}	-0.3	450	V
LX pin Voltage (Note 1)	V_{LXMAX}	-0.3	450	V
BOOT, BCK pin Voltage (Note 1)	-	-0.3	V_{LXMAX} + 30	V
VDD pin Voltage (Note 1)	V_{DDMAX}	-0.3	30	V
BST pin Voltage (Note 1,Note 2)	V_{BSTMAX}	-0.3	V_{DDMAX} +0.3	V
GD pin Voltage (Note 1,Note 2)	V_{GDMAX}	-0.3	V_{DDMAX} +0.3	V
FBN pin Voltage (Note 1,Note 2)	V_{FBNMAX}	-0.3	V_{DDMAX} +0.3	V
VREF pin Voltage (Note 1)	V_{REFMAX}	-0.3	6.0	V
Voltage for ENA, FLG, FBP, COMP, DIM, OVP, SS, CS, SEN pins (Note 1, Note 3)	-	-0.3	V_{REFMAX} +0.3	V
Allowable power dissipation (Note 4, Note 5, Note 6)	P_D	-	1.15	W
Junction Temperature	T_j	-40	125	°C
Storage Temperature Range	T_{STG}	-55	150	°C

Note 1. All voltages are with respect to ground (VSS pin).
Note 2. The maximum value is limited to 30V when "V_{DDMAX}" exceeds 29.7V.
Note 3. The maximum value is limited to 6V when "V_{REFMAX}" exceeds 5.7V.
Note 4. This value declines by 11.5mW/°C in the condition that the temperature is over 25°C.
Note 5. 100 mm × 100 mm, t=1.0mm CEM Single-sided Board.
Note 6. Thermal design should be designed in consideration with the calorific value of the internal regulator as well as power supplies.

IC Power Dissipation
= VDD × IC Consumption Current 10mA+ VREF External Output [(VDD－VREF) × (－IVREF)]

WARNING: Operation at or beyond these limits may result in permanent damage to the device. Normal operation is not guaranteed at these extremes. These are stress ratings only.

8. Recommended Operation Condition

Parameter	Symbol	min	typ	max	Unit
HV pin Voltage (Note 7)	V_{HV}	GND	-	400	V
LX pin Voltage (Note 7)	V_{LX}	GND	-	400	V
BOOT pin Voltage (Note 7)	V_B	V_{LX}+10.3	V_{LX}+ (V_{DD}-0.7)	V_{LX}+ 26	V
VDD pin Voltage Range (Note 7)	V_{DD}	11	15	26	V
BST pin Voltage Range (Note 7)	V_{BST}	GND	-	V_{DD}	V
GD pin Voltage Range (Note 7)	V_{GD}	GND	-	V_{DD}	V
FBN pin Voltage Range (Note 7)	V_{FB}	GND	-	V_{DD}	V
Voltage for ENA, FLG, FBP, COMP, DIM, OVP, SS, CS, SEN pins (Note 7)	-	GND	-	V_{REF}	V
Operating Temperature Range (Note 8)	T_a	-40	-	95	°C

Note 7. All voltages are with respect to ground (VSS pin).
Note 8. It is a prerequisite that the operating ambient temperature may not exceed the absolute maximum rating value of the junction temperature.

9. Electrical Characteristics

(Ta=25°C, V_{DD}=15V, V_{REF}=5V, ENA=DIM=V_{REF}, V_{FBP}=2.3V, CS=SEN=FBN=SS=OVP=LX=0V (GND), BST=1000pF, BCK=1000pF, GD=300Ω/1000pF, HV=FLG=COMP=OPEN, unless otherwise specified. Each current is defined as positive when it is input to the pin, and defined as negative when it is output from the pin.)

■ Power Consumption

Parameter	Symbol	min	typ	mix	Unit	Condition
Power Consumption	I_{DD1}	—	0.6	2.0	mA	ENA=0V
	I_{DD2}	—	3.4	10.0	mA	f=60kHz

■ Start-up Block (HV pin)

Parameter	Symbol	min	typ	max	Unit	Condition
HV Off Leak Current	I_{HV}	—	—	5	µA	V_{HV}=400V
Start-up VDD Pin Charge Current	I_{CHG1}	-1.8	-1.0	-0.35	mA	V_{HV}=100V, V_{DD}=0V
	I_{CHG2}	-19.0	-10.0	-3.5	mA	V_{HV}=100V, V_{DD}=12.0V
	I_{CHG3}	-2.1	-1.1	-0.45	mA	V_{HV}=100V, V_{REF}=0V
Start-up Current Stop Voltage	V_{VDDH}	12.8	15.0	17.2	V	
Start-up Current Reset Voltage	V_{VDDL}	11.5	13.5	15.5	V	

■ VREF, Enable Block (VREF/ ENA pins)

Parameter	Symbol	min	typ	max	Unit	Condition
VREF Voltage	V_{REF}	4.7	5.0	5.3	V	I_{VREF}=0mA
VREF Voltage Drop	V_{DROP}	—	50	100	mV	I_{VREF}= -3mA, ENA=0V
Over Voltage Protection	$I_{VREFlimit}$	6	40	80	mA	
ENA Pin "L" Level Voltage	V_{EN1}	0.8	1.0	1.2	V	Disable
ENA Pin "H" Level Voltage	V_{EN1}	2.5	3.0	3.5	V	Enable
ENA Pin Pull-down Resistance	R_{EN}	200	500	1000	kΩ	

■ PFC Control Block (CS/ FBN/ FBP/ COMP/ SS pins)

Parameter	Symbol	min	typ	max	Unit	Condition
FBP Input Voltage Range	V_{FBP}	2.0	—	4.0	V	
FBN Control Voltage	V_{FBN}	—	2.3	—	V	FBP=2.3V
BCK, BST Maximum ON Period	T_{ONMAX}	25	28	31	µs	COMP = "H"
Zero Detect Current	I_{ZVS}	0.7	1.0	1.3	µA	
Zero Detect Delay	ZVS_{Delay}	1.8	3.0	4.2	µs	
OFF BLANK	T_{OFFBL}	2.6	4.45	6.3	µs	
SS Charge Current	I_{SS}	1.6	2.0	2.4	µA	
SS Discharge Current	I_{SS_dis}	6.4	8.0	9.6	µA	
BLANK	T_{BLANK}	200	330	500	ns	

■ High-side driver, Low-side Driver (BCK/ BOOT/ LX/ BST pins)

Parameter	symbol	min	typ	max	Unit	Condition
BOOT、LX、BCK pin Off Leak Current	I_{FS}	—	—	1	µA	V_B=V_{LX}=V_{BST}=400V
V_{BL} Power Standby Current	I_{BL}	—	—	5.0	µA	V_B=L
BCK Pin "H" level Voltage	V_{BCKH}	BOOT-0.4	—	—	V	I=-10mA
BCK Pin "L" level Voltage	V_{BCKL}	—	—	0.3	V	I=10mA
BCK Pin Rising Time (Note 9)	tr_{BCK}	—	33	—	ns	Between BCK and LX C_L=1000pF

Parameter	symbol	min	typ	max	Unit	Condition
BCK Pin Falling Time (Note 9)	tf_{BCK}	—	27	—	ns	Between BCK and LX C_L=1000pF
BCK Pin Pull-down Resistance	R_{BCK}	40	100	200	kΩ	
BST Pin "H" Level Voltage	V_{BSTH}	VDD-0.4	—	—	V	I=-10mA
BST Pin "L" Level Voltage	V_{BSTL}	—	—	0.3	V	I=10mA
BST Pin Rising Time (Note 9)	tr_{BST}	—	33	—	ns	Between BST and VSS C_L=1000pF
BST Pin Falling Time (Note 9)	tf_{BST}	—	27	—	ns	Between BST and VSS C_L=1000pF
BST Pin Pull-down Resistance	R_{BST}	40	100	200	kΩ	

Note 9. Reference value.

■ LED Current Control (SEN/ GD/ DIM/ FBN pins)

Parameter	Symbol	min	typ	max	Unit	Condition
SEN Pin Control Voltage	V_{SEN}	0.2375	0.25	0.2625	V	DIM=V_{REF}
LED Drive Current	I_{LED1}	339.6	350	360.6	mA	R_{SEN}=0.714Ω, DIM=V_{REF}
	I_{LED11}	290.0	315	340.8	mA	I_{LED1}=350mA, DIM=3.15V
	I_{LED12}	31.5	35	38.5	mA	I_{LED1}=350mA, DIM=0.356V
	I_{LED13}	8.1	9.5	11.0	mA	I_{LED1}=350mA, DIM=0.1V
DIM Pin Input Voltage Range	V_{DIM1}	0.05	—	0.09	V	LED OFF
	V_{DIM2}	0.105	—	3.5	V	DIM dimming range
	V_{DIM3}	4.5	—	—	V	LED MAX

■ Protection Functions (OVP/ CS/ FBN/ VDD pins)

Parameter	Symbol	min	typ	max	Unit	Condition
Over Heat Protection	T_{TSD}	130	150	170	°C	Rise in Temperature (Tj)
TSD Hysteresis Temperature	T_{TSDHY}	40	55	70	°C	Fall in Temperature after TSD (Tj)
OVP Reference Voltage 1	V_{OVP1}	—	3.05	—	V	
OVP1 Release voltage (Note 10)	V_{OVP1L}	2.65	2.95	3.25	V	
OVP1 Hysteresis of the release and detection (Note 10)	$V_{OVP1HYS}$	0.01	—	—	V	
OVP Reference Voltage 2	V_{OVP2}	—	3.3	—	V	
OVP1/OVP2 Differential voltage detection	$V_{OVP12HYS}$	0.15	—	—	V	
FBN Over Voltage Protection 1(Note 10)	$V_{FBOVPH1}$	4.19	4.65	5.12	V	FBP=2.3V
FBN Over Voltage Protection Release(Note 10)	$V_{FBOVPL1}$	4.10	4.55	5.01	V	FBP=2.3V
FBN Hysteresis Width(Note 10)	V_{FBHYS}	0.1	—	—	V	
FBN Over Voltage Protection 2(Note 10)	$V_{FBOVPH2}$	5.7	6.35	7.0	V	FBP=4.0V
FBN Clamp Voltage(Note 10)	$V_{FBClamp}$	7.5	11.6	15.6	V	
CS Pin Over Current Protection	V_{OCPC}	1.35	1.5	1.65	V	
SEN Pin Over Current Protection	V_{OCPS}	0.45	0.5	0.55	V	
Voltage Protection of UVLO Detection	V_{UVLOH}	11.0	12.2	13.4	V	
Voltage Protection Release of UVLO Detection	V_{UVLOL}	7.6	8.5	9.4	V	
UVLO Hysteresis Width	V_{UVHYS}	3.3	3.7	4.1	V	

Note 10. See "■ Protection Functions" and "■ Protection List".

10. Functional Descriptions

The AP1653 consists of a buck-boost PFC converter, an LED current control circuit / driver, a power-up circuit, a soft-start circuit, an internal regulator (5V) and protection circuits. The buck-boost PFC converter monitors LED cathode current and coil current, and it keeps LED anode voltage in adequate level by switching two external N-ch MOSFETs. The LED current control circuit uses one external N-ch MOSFET, and LED current is adjusted by an external resistor connected between the source of this MOSFET and the ground. Additionally, up to 3% dimming in current ratio is possible according to the DC input signal to the DIM pin.

■ Buck-boost PFC Converter

The buck-boost converter of the AP1653 switches ON/OFF two N-ch MODFETs (Q1, Q2) simultaneously and controls operation to keep critical conduction. When two power MOSFETs are powered on at the same time, the current flows Q1 → L2 → Q2 and current energy is charged to the coil. The switch ON period is determined by a reference voltage (FBP pin), an error amplifier output (COMP pin) generated from LED cathode voltage (FBP pin) and RAMP wave form that is internal generated.
Two power MOSFETs are turned OFF at once when the switch ON period is finished, and the charged energy of the coil is released to C19 via D5 → L2 → D6. In this case, the AP1653 monitors this coil current by a resistor (R6) between anode side of a commutation diode and the ground, and starts next switch ON period when detecting that the coli current flow stops. By repeating this action, the buck-boost converter keeps LED anode voltage in an adequate level.

■ LED Current Control Circuit / Driver

The LED current control circuit of the AP1653 controls LED current to monitor the voltage of the SEN pin which is converted LED current to voltage by resistors R_{SEN} (R30, R45) between external power MOSFET (Q3) and the GND. The maximum value of LED current can be set. The calculation formula for the maximum value of LED current is shown below.

$$I_{LEDmax}\,[\mathrm{mA}] = 250\,[\mathrm{mV}] / R_{SEN}\,[\Omega] \quad (\mathrm{DIM} = 5\,[\mathrm{V}])\ldots(1)$$

Up to 3% dimming in current ratio is available by the DC input signal to the DIM pin. It is able to control LED current even if the voltage of the SEN pin is dropped to 7mV (at minimum) by controlling the internal reference voltage that is determined by the DIM pin voltage and the SEN pin voltage with a chopper comparator. Setting the DIM pin as GND voltage, LEDs are turned OFF and the maximum current is conducted by an input voltage over 4V.

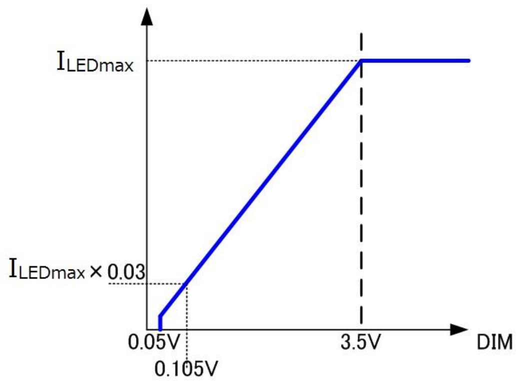


Figure 2. Dimming Characteristics with the DIM pin

■ Power-up Circuit

The AP1653 has the HV pin that is able to input a high voltage commutated from AC100V or AC200V directly and an auto power-up circuit that internally charges a capacitor connected to VDD. When a full-wave rectified voltage is input to the HV pin, the capacitor (C7) that is connected to VDD is charged via the internal power-up circuit. This charge current is 1mA if the voltage at the VDD pin is less than 1V. If the VDD voltage is more than 1V, the capacitor is charged by 10mA. If the VDD voltage increases and gets over 12.2V (typ), UVLO is released and the switching operation of the buck-boost converter is enabled. In this case, the switching operation is started by setting the ENA pin = “H”. Furthermore, if the VDD voltage reaches 15V, the internal power-up circuit is turned OFF and the power supply from the HV pin is stopped. At this time, power loss of the application can be suppressed by supplying the power from the secondary side of the coil for a buck-boost conversion (L2) as it is a transformer.

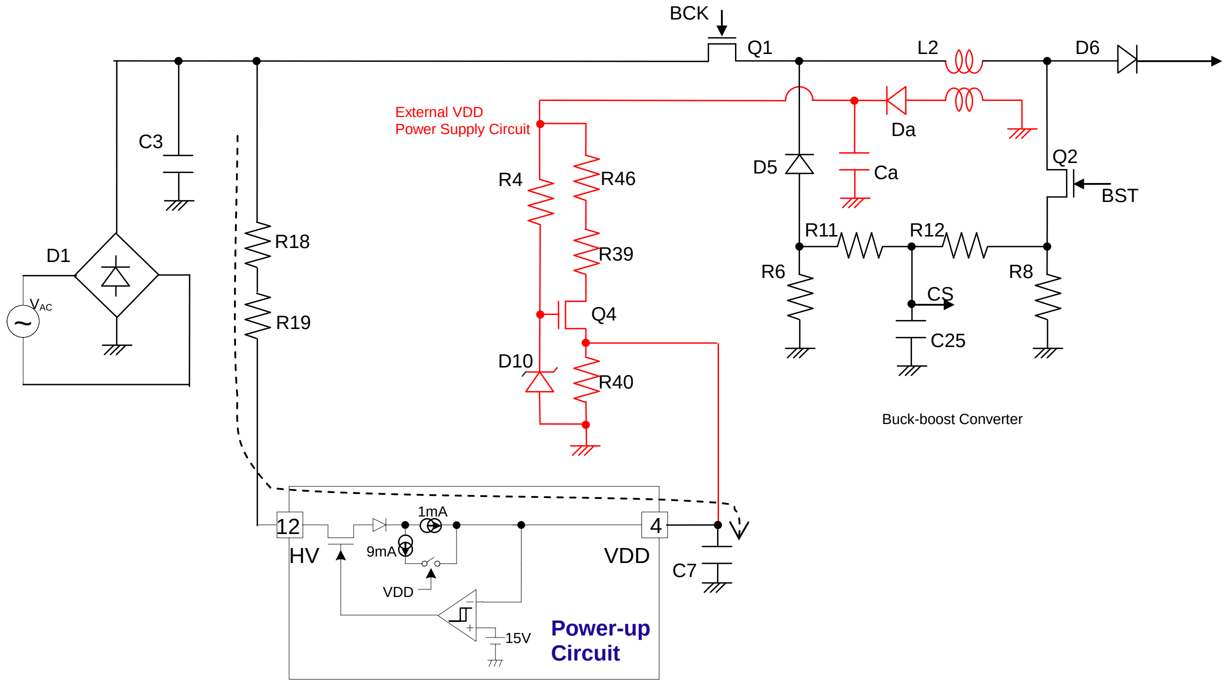


Figure 3. Peripheral Circuit Example 1 of Power-up Circuit

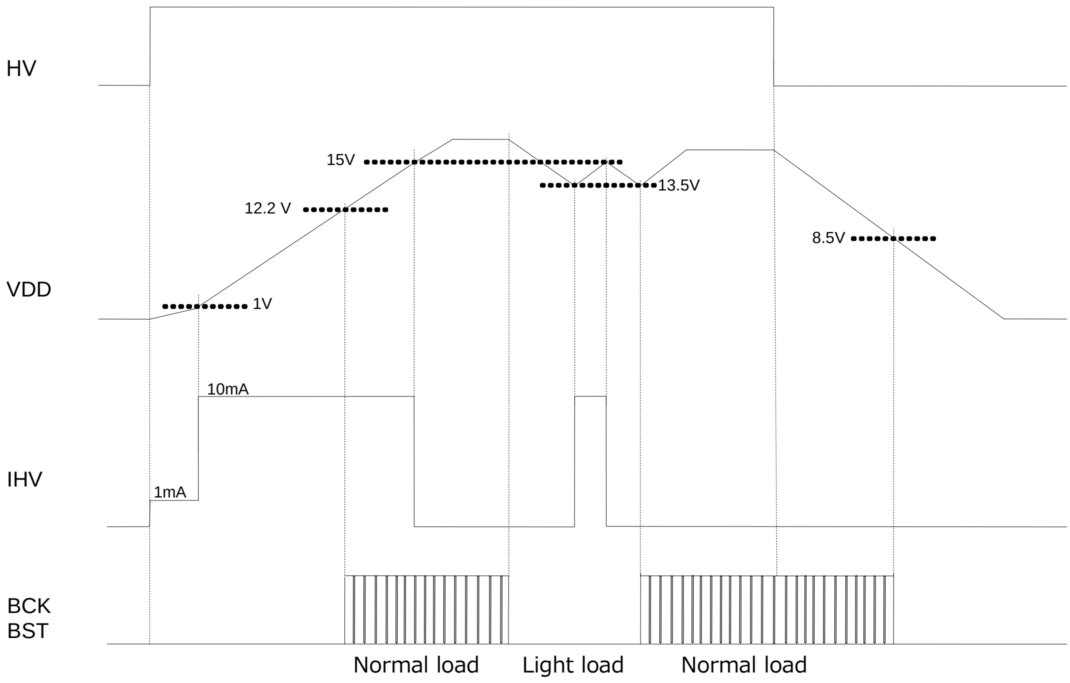


Figure 4. Power-up Characteristics

Note that, when supplying the VDD voltage from an external power supply, the HV pin must be connected to the GRN.

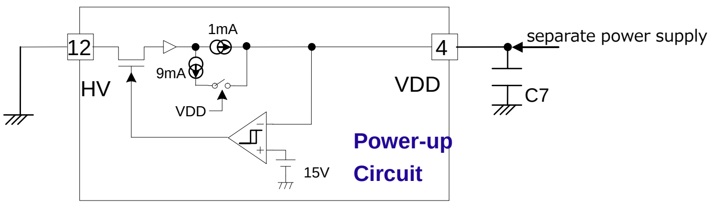


Figure 5. Peripheral Circuit Example 2 of Power-up Circuit

■ Soft-start Circuit

The AP1653 is has a soft-start function. The soft-start circuit starts charging to a capacitor connected to the SS pin by 2μA when VDD voltage exceeds 10V and the ENA pin is set to "H". LED current is limited by a lower voltage of the control voltage between the SS pin and the DIM pin. A recommended value of the capacitor connected to the SS pin is 1μF. Soft-start characteristics vary depending on this capacitance.

■ Internal Regulator Circuit (5V)

The AP1653 integrates a regulator that generates 5V power supply from the VDD pin voltage for internal circuits. The AP1653 is capable of a 3mA (max.) current supply externally from the VREF pin.
Connect a 10μF capacitor between the VREF pin and GND pin for stabilization. The internal RESER signal (RSTL) is released if the VREF voltage exceeds 4V.

■ Power-up Sequence

The AP1653 starts buck-boost conversion and constant current operation when the VDD pin voltage exceeds UVLO release voltage, the internal RSTL signal is released by the VREF circuit and the ENA pin is set to "H". The VREF circuit is independent from the ENA signal, the VREF voltage rises when the VDD voltage is rises up.

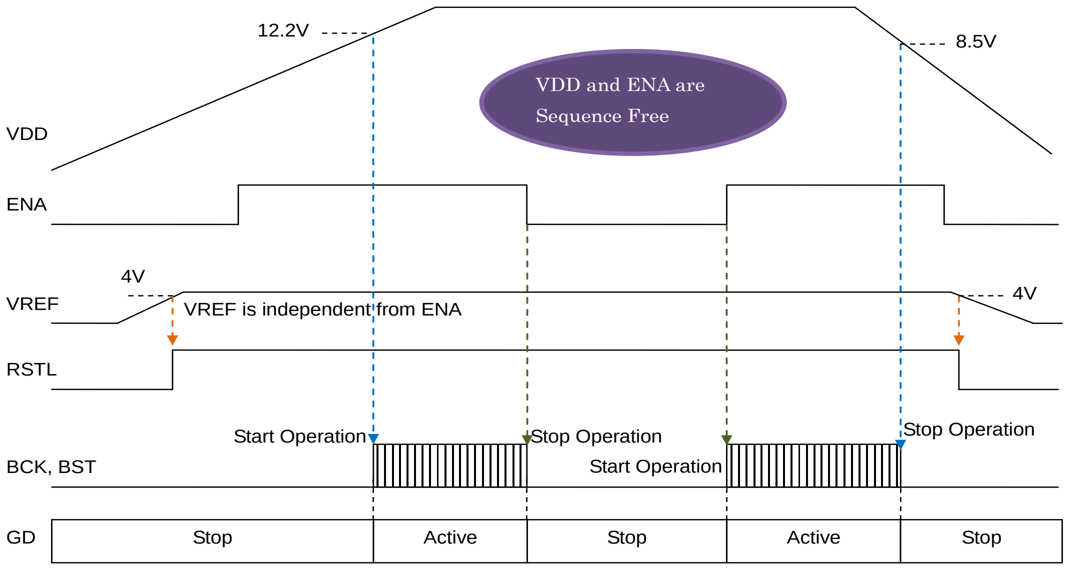


Figure 6. Timing Chart of Power Supply Circuit Block

■ Protection Functions

1) Thermal Shut Down (TSD)
The AP1653 has a temperature sensor. If the temperature of the IC exceeds 150°C the thermal shut down is activated and the AP1653 stops buck-boost conversion and constant current operation. The AP1653 resumes these operations when the temperature is decreased under 95°C.

2) Over Voltage Protection (OVP1, OVP2)
When the OVP pin voltage exceeds 3.05V, the protection function is activated and the AP1653 stops buck-boost conversion and constant current operation. In this case, the AP1653 resumes these operations if the OVP pin voltage is decreased under 2.95V (OVP1). However, when the OVP pin voltage is exceeds 3.3V, the AP1653 is stopped by a latch stop (OVP2) and the BST pin output is stopped at “H” level. This is to protect the LED or the electrolytic capacitor (C19) that is connected to anode side of LED from a short of the high-side MOSFET. It blowouts the AC input fuse (F1) to stop operation. The AP1653 does not resume the operation even if the OVP pin voltage becomes below 2.9V when the operation is stopped by a latch stop. The ENA pin should be set to “L” at least 10ms to once or the VDD should be supplied again to resume the operation.

3) Over Current Protection for the CS pin (OCPCS)
It detects an over current at low-side MOSFET. Connect a resistor between the MOSFET and the ground and input I-V converted voltage to the CS pin. The over current protection is activated when the CS pin voltage exceeds 1.2V, and the AP1653 stops buck-boost conversion and constant current operation. However, there is a BLANK period that masks the detection result. The over current protection is not enabled for 350ns after the MOSFETs are turned on. The CS pin is pulled up by 2μA. The protection will be activated if this pin becomes open state. It is a latch stop protection. The ENA pin should be set to “L” once or the VDD should be supplied again to resume the operation.

4) Over Current Protection for the SEN pin (OCPSEN)
It detects an over current at LEDs. The over current protection is activated when the SEN pin voltage exceeds 0.5V, and the AP1653 stops buck-boost operation and constant current operation. The SEN pin is pulled up by 2μA. The protection will be activated if this pin becomes open state. It is a latch stop protection. The ENA pin should be set to “L” at least 10ms to once or the VDD should be supplied again to resume the operation.

5) Over Voltage Protection for the FBN pin (FBOVP)
The over voltage protection is activated when the FBN pin voltage exceeds 4.65V (when FBP=2.3V), and the AP1653 stops buck-boost operation but it does not stop constant current operation. The AP1653 resumes buck-boost operation when the FBN voltage is decreased under 4.55V. Normally, the AP1653 maintains a stable output by an intermittent operation of the buck-boost conversion for a light load period with this function. The detection voltage will vary automatically according to the FBP pin voltage.

6) Clamp Protection Circuit for the FBN pin (FBClamp)
This protection function is activated when the FBN pin voltage exceeds 8.0V because of a reason such as LED short. In this case, the FBN pin is clamped to 8.0V to protect internal circuit of the IC.

7) UVLO
When the VDD pin voltage exceeds 12.2V, the AP1653 starts buck-boost conversion. If the VDD pin voltage becomes lower than 8.5V, the AP1653 stops buck-boost conversion.

8) FLG pin
The FLG pin is an internal status output pin that indicates a protection function is activated. It is an open drain output pin, and outputs “L” when a protection function is activated. Pull up this output signal to the VDD level of the peripheral circuits.

■ Protection List

Protection Function		Detection	Release	BCK (“H”)	BST (“L”)	GD	Detection pin.
TSD	Automatic	150℃ or more	95℃ or less	OFF	OFF	OFF	―
OVP1	Automatic	3.05V or more	2.95V or less	OFF	OFF	OFF	OVP pin LED Open
OVP2	Latch	3.3V or more	ENA is L level,or,VDD is turned on again	OFF	ON	OFF	OVP pin High-side MOSFET Short
OCPCS	Automatic	1.5V or more	1.5V or less	OFF	OFF	OFF	CS pin
OCPSEN	Latch	0.5V or more	ENA is L level,or,VDD is turned on again	OFF	OFF	OFF	SEN pin
FBOVP	Automatic	4.65V or more	4.55V or less	OFF	OFF	Valid	FBN pin Detection voltage when V_{FBP} = 2.3V
FBClamp	Automatic	11.6V or more	11.6V or less	OFF	OFF	OFF	FBN pin LED Short
UVLO	Automatic	8.5V or less	12.2V or more	OFF	OFF	OFF	VDD pin

11. Recommended External Circuits

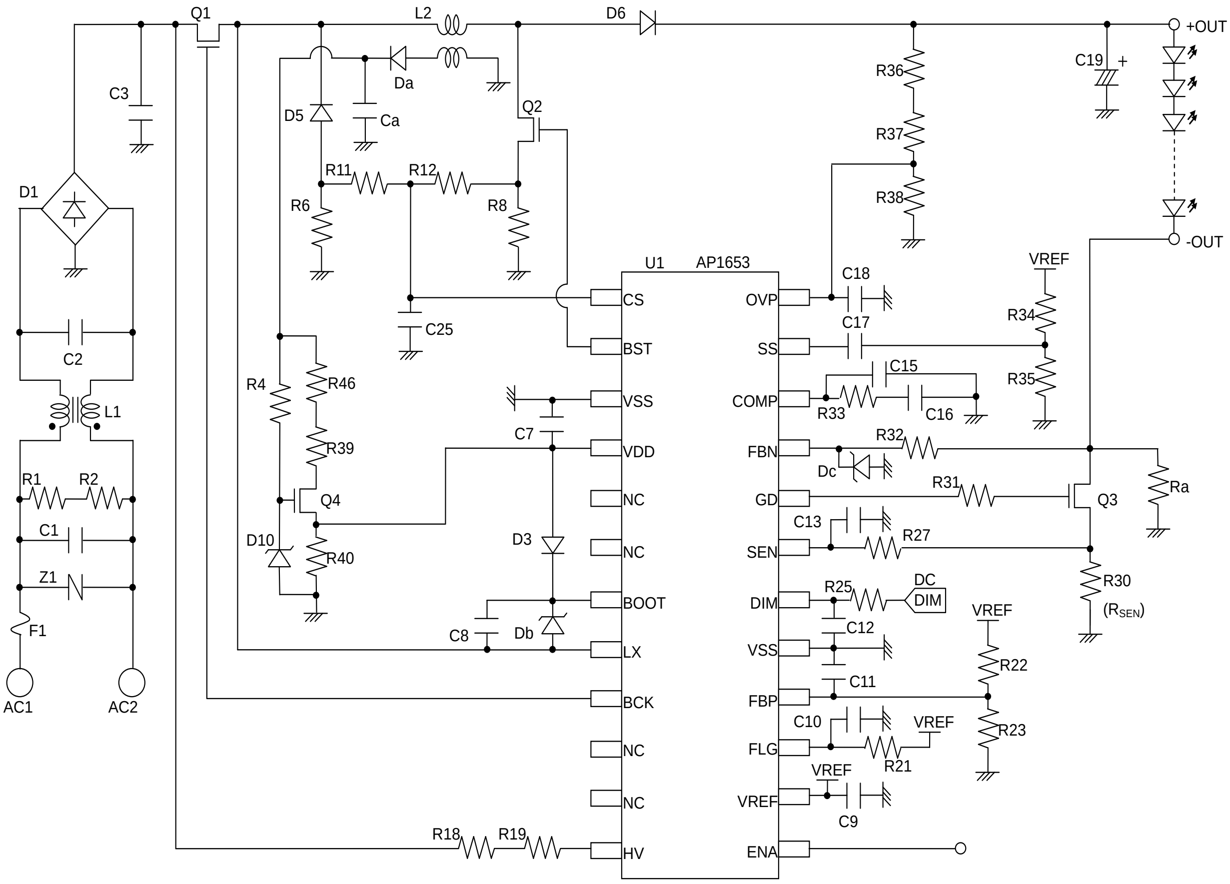


Figure 7. AP1653 External connection circuit example

12. How to Set Peripheral Circuit Constant

Calculation method of the circuit constant for Figure 7 is shown below.

- Setting of the LED Current

LED current is determined by the resistance R30 (R_{SEN}) connected to the SEN pin and the SEN pin voltage. When DIM = 5V, the SEN pin voltage is controlled to 250mV by an internal circuit of the IC. The maximum LED current (I_{LEDmax}) is calculated by the following formula.

$I_{LEDmax} = 0.25 / R30$ • • • (2)

Example: If I_{LED} = 350mA, the resistance R30 should be 0.714Ω.

- How to set the inductance of the coil L2

Inductance is determined by input and output conditions.
Input voltage: AC85 ~ 265V
Load condition: LEDVf=120V, I_{LED}=350mA, ΔLEDVf = ±30%
Maximum load voltage LEDVfmax＝156V

The maximum coil current and ON-Duty of the PFC driver must be determined before calculating the inductance. ON-Duty value is calculated by the equation (3).

$\text{ON-Duty} = (V_{OUT} / V_{IN}) / (1 + (V_{OUT} / V_{IN}))$ • • • (3)

V_{IN} and V_{OUT} are calculated from the following conditions.

$V_{IN} = (V_{IN}\min - V_{D1}) \times \frac{2\sqrt{2}}{\pi}$ • • • (3-1)
$V_{OUT} = LEDVfmax + V_{D5} + V_{D6}$ • • • (3-2)

Example: ON-Duty (3) will be 68.2% if the minimum input voltage V_{IN} min. = 85V ac, maximum load voltage LEDVfmax. = 156V, VD1 = 2V (Vf of D1) and VD5 = VD6 = 1V (Vf of D5 and D6).

Calculate the maximum coil current value (I_{Lmax}) by the set current value (I_{LED}) and ON-Duty which are calculated by equations (3) . It is assumed that I_{LED} has the maximum value including variations for the maximum coil current calculation.
$I_{Lmax} = (\pi/2) \times 2 (I_{LED} / (1 - \text{ON-Duty}))$ • • • (4)

Example: The maximum current of I_{LED} will be 360.5mA since the variation is ±3% when the LED current is 350mA. At this time, the maximum coil current I_{Lmax} is 3.56A by equation (4).

The maximum inductance (Lmax) is calculated from the maximum on-time of the PFC driver which is determined internally and the maximum coil current I_L from equation (4).
$Lmax = (V_{IN} \times T_{ON}) / I_{Lmax}$ • • • (5)

V_{IN} to determine the maximum value (Lmax) is calculated from the following equation.
$V_{IN} = (V_{IN}\max - V_{D1})$ • • • (5-1)

Example: When V_{D1}=2V and T_{ON}=25μs (min.), the maximum value Lmax by (5) is calculated to be 0.829mH. Assuming that the coil variation is ±20%, the Lmax value will be 0.691mH.

20kHz or more is recommended for the switching frequency (F_{PFC}) of the PFC driver. Therefore inductance should be determined as F_{PFC} in equation (6) will be more than 20kHz.
$F_{PFC} = 1 / (((I_{Lmax} \times Lmax) / V_{IN}) + ((I_{Lmax} \times Lmax) / V_{OUT}))$ • • • (6)

V_{IN} and V_{OUT} to determine the switching frequency F_{PFC} are calculated from the following equations.
$V_{IN} = (V_{IN}max - V_{D1})$ • • • (6-1)
$V_{OUT} = LEDVfmax + V_{D5} + V_{D6}$ • • • (6-2)

Example: Switching frequency F_{PFC} will be 23.4kHz when inductance is set to 0.68mH. In this case, the variation of Inductance is ±20%, $V_{D5}=V_{D6}=1V$ and $V_{D1} = 2V$.

The VDD voltage must be supplied from the secondary circuit of the L2 coil. Select external devices to keep the voltage in the recommended range of the VDD. The VDD voltage must not drop below 15.5V. Especially, take extra care when the load is light and the input voltage is at the minimum level. Transforming setting must correspond to the safety standards of each country. Please design a transformer in consideration of safety standard of each country.

- Setting of the Output Capacitor C19

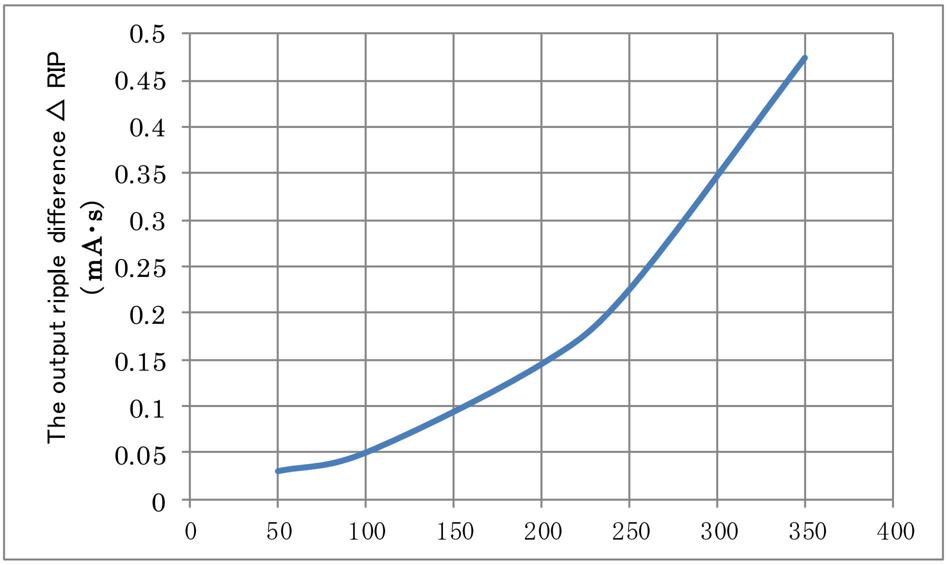
The FBP pin must be set before setting the output capacitor. The FBP voltage is controlled by an internal circuit of the device and the FBN voltage becomes equal to the drain voltage of the FET(Q3) for constant current driver. The minimum value of the FBN voltage can be calculated by the following equation.

$FBNmin = Ronmax \times I_{LED} + V_{SEN}$ • • • (7)
Ronmax is FET(Q3) of Maximum value of on-resistance.

Example: FBNmin will be 0.618V when Ronmax=1Ω, I_{LED}=360.5mA and V_{SEN}=0.2575V.

From equation (7), the minimum value Coutmin of the output capacitor C19 is calculated by the output ripple difference △ RIP.
$Coutmin = \Delta RIP/(V_{FBP}-0.1-FBNmin)$ • • • (8)

△RIP is a variable which changes with the LED current, please refer to the following graph.



Example: Coutmin will be 299.6μF when △RIP =0.474mA･s, V_{FBP}=2.3V and FBNmin=0.618V. The value of output capacitor C19 should be 20% higher or more than the values shown here.

- Setting of the CS terminal

Calculate the maximum current ($I_{ZCS}max$) that flows R6 and R8 resistors for buck PFC converter.

$I_{ZCS}max$ = LEDVf × (1-△LEDVf) / Lmax × ZCS_{DLYMIN} • • • (9)

ZCS_{DLYMIN}: Minimum delay value of zero detection; It will be 1.8us.
From equation (9), the minimum value of R6 and R8 resistors (Rmin) is calculated by equation (10).

Rmin = (0.02-(1.2u-(0.02/R11))・R12) / (I_{ZCS} max) • • • (10)

From equation (10), please set the resistor value as it will be approximately 10% greater than this figure.

Example: The maximum current of ZCS will be 185mA when LEDVf=120V, △LEDVf=30% and Inductance Lmax =0.68mH. From this result, Rmin value will be 0.43Ω by assuming R11 = R12 = 100kΩ. Therefore the setting value should be 0.47Ω by the result of Rmin value.

- OVP Setting for Overvoltage Protection

Calculate the maximum value of the output voltage (Voutmax).

Voutmax = LEDVf × (1+△LEDVf) + V_{FBP} • • • (11)

V_{FBP}: It is the terminal voltage of FBP that is determined by R22 and R23 resistor values.

From Equation (11), OVP setting voltage V_{OV} is used to calculate the R36, R37 and R38 resistances by following equation (12) so that the V_{OV} value is 10% greater or more than the Voutmax value.

V_{OV}= V_{OVP1} / (R38× (R36 + R37 + R38)) • • • (12)

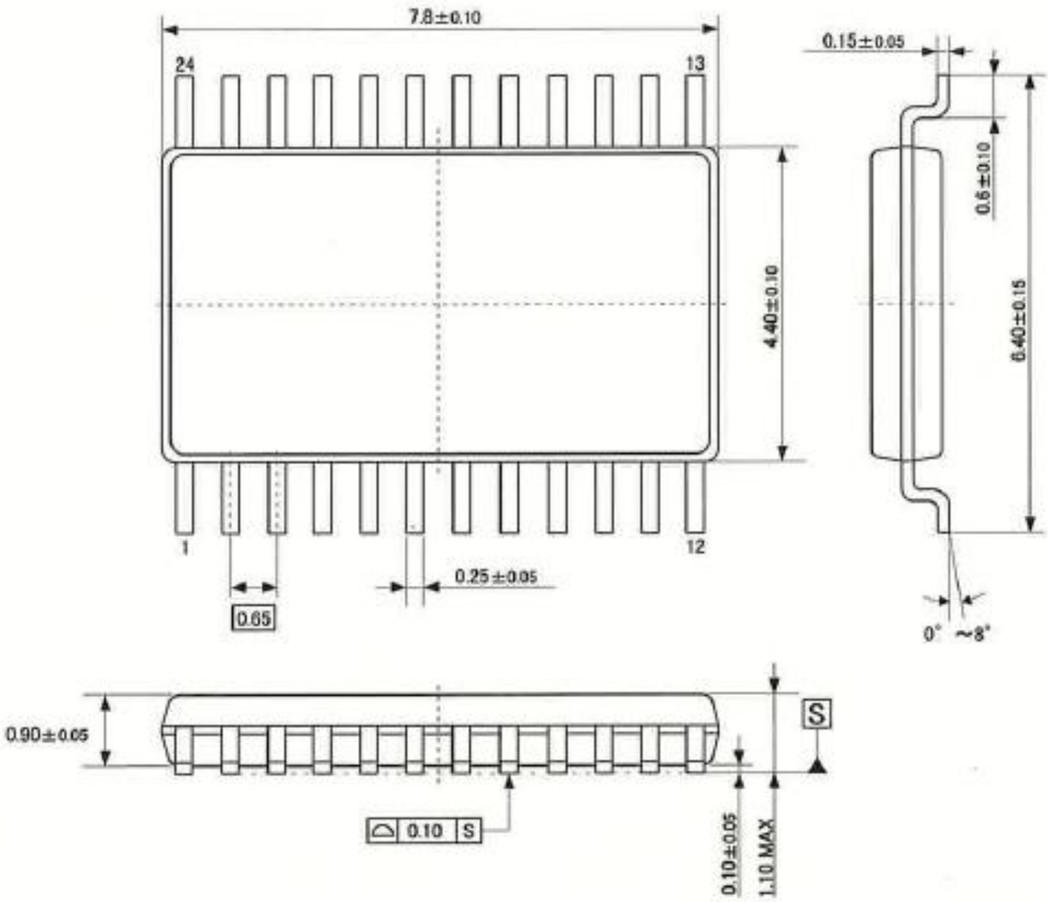
V_{OVP1}: Operating voltage of OVP1; It will be 3.05V (typ).

Example: The maximum output voltage (Voutmax) will be 158.4V when VFBP = 2.4V, LEDVf=120V and △LEDVf=30%. In this case, if R38 = 3kΩ, and R36 = R37 = 100kΩ, OVP setting voltage will be 206.4V. This V_{OV} value meets the condition that the setting value must be greater than 10% of the maximum output voltage (Voutmax).

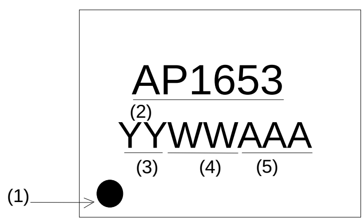
13. Package

■ Outline Dimensions

・24pin TSSOP (Unit: mm)



■ Marking



（１） 1pin Description
（２）Product Name "AP1653"
（３）Year Code（last 2 digits）
（４）Week Code
（５）Management Code

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