HA17431 Series
Shunt Regulators
Application Note

HITACHI

ADE-504-004B (Z)
Rev.3
6/5/01
Hitachi Company or Division

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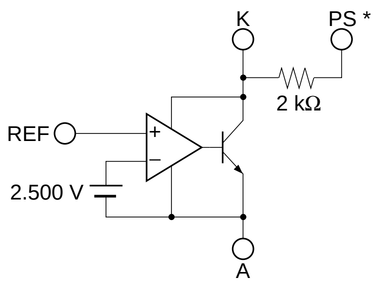
Contents

Section 1 Outline

The HA17431 series is a family of voltage referenced shunt regulators. The main application of these products is in voltage regulators that provide a variable output voltage. The HA17431 series products are provided in a wide range of packages; TO-92 and TO-92MOD insertion mounting packages and MPAK-5, UPAK, and FP-8D surface mounting packages are available. The on-chip high-precision reference voltage source can provide ±1% accuracy in the V versions, which have a V_{KA}max of 16 volts. The HA17431VLP, which is provided in the MPAK-5 package, is designed for use in switching mode power supplies. It provides a built-in photocoupler bypass resistor for the PS pin, and an error amplifier can be easily constructed on the supply side.

1.1 Features

- The V versions provide 2.500 V ±1% at Ta = 25°C
- The HA17431VLP includes a photocoupler bypass resistor (2 kΩ)
- The reference voltage has a low temperature coefficient
- The MPAK-5 and UPAK miniature packages are optimal for use on high mounting density circuit boards
- A wide operating temperature range (–40 to +85°C) is provided by the TO-92, TO-92MOD, and FP-8D package versions



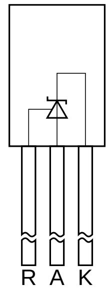
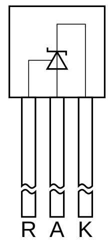
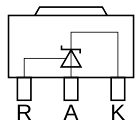
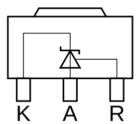
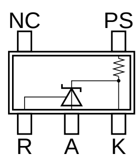
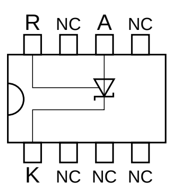
Note: The PS pin is only provided by the HA17431VLP.

Figure 1.1 Block Diagram

1.2 Selection Guide

Item		HA17431 V Version	HA17431 A Version	HA17431 Normal Version	Package	Temp. Range
Reference voltage	Accuracy	±1% (at 25°C)	±2.2%	±4%		
	Max	2.525 V	2.550 V	2.595 V		
	Typ	2.500 V	2.495 V	2.495 V		
	Min	2.475 V	2.440 V	2.395 V		
Cathode voltage		16 V max	40 V max	40 V max		
Cathode current		50 mA max	150 mA max	150 mA max		
Wide temperature use		HA17431VPJ	HA17431PNAJ		TO-92	–40 to +85°C
			HA17431PAJ		TO-92MOD	
				HA17431PJ	TO-92MOD	
			HA17431FPAJ		FP-8D	
				HA17431FPJ	FP-8D	
Industrial use		HA17431VLP			MPAK-5	–20 to +85°C
		HA17431VP	HA17431PNA		TO-92	
		HA17431VUP	HA17431UPA		UPAK	
		HA17432VUP	HA17432UPA		UPAK	
			HA17431PA		TO-92MOD	
				HA17431P	TO-92MOD	
			HA17431FPA		FP-8D	
				HA17431FP	FP-8D	
Commercial use			HA17431UA		UPAK	
			HA17432UA		UPAK	

1.3 Pin Arrangement by Product

Product Name	Package	Pin Arrangement
HA17431PA	TO-92MOD	
HA17431VP (2.5 V series) HA17431PNA	TO-92	
HA17431UA HA17431UPA HA17431VUP	UPAK	
HA17432UA HA17432UPA HA17432VUP	UPAK	
HA17431VLP (2.5 V series)	MPAK-5	
HA17431FPA	SOP-8	

Section 2 Specifications

2.1 Absolute Maximum Ratings (Ta = 25°C)

Item	Symbol	HA17431VLP	HA17431VP	HA17431VPJ	Unit	Notes
Cathode voltage	V_{KA}	16	16	16	V	1
PS term. voltage	V_{PS}	V_{KA} to 16	—	—	V	1, 2, 3
Continuous cathode current	I_K	–50 to +50	–50 to +50	–50 to +50	mA	
Reference input current	Iref	–0.05 to +10	–0.05 to +10	–0.05 to +10	mA	
Power dissipation	P_T	150*4	500*5	500*5	mW	4, 5
Operating temperature range	Topr	–20 to +85	–20 to +85	–40 to +85	°C	
Storage temperature	Tstg	–55 to +150	–55 to +150	–55 to +150	°C	

Item	Symbol	HA17431P/PA	HA17431FP/FPA	HA17431UA/UPA	Unit	Notes
Cathode voltage	V_{KA}	40	40	40	V	1
Continuous cathode current	I_K	–100 to +150	–100 to +150	–100 to +150	mA	
Reference input current	Iref	–0.05 to +10	–0.05 to +10	–0.05 to +10	mA	
Power dissipation	P_T	800*6	500*7	800*8	mW	6, 7, 8
Operating temperature range	Topr	–20 to +85	–20 to +85	–20 to +85	°C	
Storage temperature	Tstg	–55 to +150	–55 to +125	–55 to +150	°C	

Item	Symbol	HA17431PJ/PAJ	HA17431FPJ/FPAJ	Unit	Notes
Cathode voltage	V_{KA}	40	40	V	1
Continuous cathode current	I_K	–100 to +150	–100 to +150	mA	
Reference input current	Iref	–0.05 to +10	–0.05 to +10	mA	
Power dissipation	P_T	800*6	500*7	mW	6, 7
Operating temperature range	Topr	–40 to +85	–40 to +85	°C	
Storage temperature	Tstg	–55 to +150	–55 to +125	°C	

Item	Symbol	HA17431VUP	HA17432VUP	Unit	Notes
Cathode voltage	V_{KA}	16	16	V	1
PS term. voltage	V_{PS}	—	—	V	1, 2, 3
Continuous cathode current	I_K	–50 to +50	–50 to +50	mA	
Reference input current	Iref	–0.05 to +10	–0.05 to +10	mA	
Power dissipation	P_T	800	800	mW	6, 7, 8
Operating temperature range	Topr	–20 to +85	–20 to +85	°C	
Storage temperature	Tstg	–55 to +150	–55 to +150	°C	

Item	Symbol	HA17432UA/UPA	HA17431PNA	HA17431PNAJ	Unit	Notes
Cathode voltage	V_{KA}	40	40	40	V	1
Continuous cathode current	I_K	–100 to +150	–100 to +150	–100 to +150	mA	
Reference input current	Iref	–0.05 to +10	–0.05 to +10	–0.05 to +10	mA	
Power dissipation	P_T	800*6	500*5	500*5	mW	5, 6
Operating temperature range	Topr	–20 to +85	–20 to +85	–40 to +85	°C	
Storage temperature	Tstg	–55 to +150	–55 to +150	–55 to +150	°C	

Notes:
1. Voltages are referenced to anode.
2. The PS pin is only provided by the HA17431VLP.
3. The PS pin voltage must not fall below the cathode voltage. If the PS pin is not used, the PS pin is recommended to be connected with the cathode.
4. Ta ≤ 25°C. If Ta > 25°C, derate by 1.2 mW/°C.
5. Ta ≤ 25°C. If Ta > 25°C, derate by 4.0 mW/°C.
6. Ta ≤ 25°C. If Ta > 25°C, derate by 6.4 mW/°C.
7. 50 mm × 50 mm × t 1.5 mm glass epoxy board, Ta ≤ 25°C. If Ta > 25°C, derate by 5 mW/°C.
8. 15 mm × 25 mm × t 0.7 mm alumina ceramic board, Ta ≤ 25°C. If Ta > 25°C, derate by 6.4 mW/°C.

2.2 Electrical Characteristics

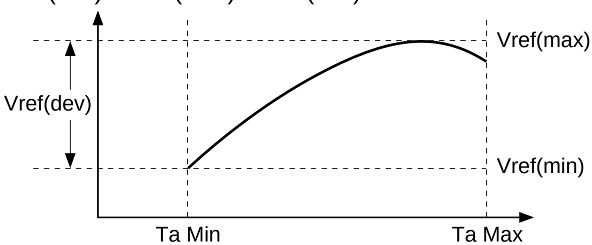
HA17431VLP/VP/VPJ/VUP, HA17432VUP (Ta = 25°C, I_K = 10 mA)

Item	Symbol	Min	Typ	Max	Unit	Test Conditions	Notes
Reference voltage	Vref	2.475	2.500	2.525	V	V_{KA} = Vref	
Reference voltage temperature deviation	Vref(dev)	—	10	—	mV	V_{KA} = Vref Ta = –20°C to +85°C	1
Reference voltage temperature coefficient	ΔVref/ΔTa	—	±30	—	ppm/°C	V_{KA} = Vref 0°C to 50°C gradient	
Reference voltage regulation	ΔVref/ΔV_{KA}	—	2.0	3.7	mV/V	V_{KA} = Vref to 16 V	
Reference input current	Iref	—	2	6	µA	R1 = 10 kΩ, R2 = ∞	
Reference current temperature deviation	Iref(dev)	—	0.5	—	µA	R1 = 10 kΩ, R2 = ∞ Ta = –20°C to +85°C	
Minimum cathode current	Imin	—	0.4	1.0	mA	V_{KA} = Vref	2
Off state cathode current	Ioff	—	0.001	1.0	µA	V_{KA} = 16 V, Vref = 0 V	
Dynamic impedance	Z_{KA}	—	0.2	0.5	Ω	V_{KA} = Vref I_K = 1 mA to 50 mA	
Bypass resistance	R_{PS}	1.6	2.0	2.4	kΩ	I_{PS} = 1 mA	3
Bypass resistance temperature coefficient	$\Delta R_{PS}/\Delta$Ta	—	+2000	—	ppm/°C	I_{PS} = 1 mA 0°C to 50°C gradient	3

(Ta = 25°C, I_K = 10 mA)

Item	Symbol	Min	Typ	Max	Unit	Test Conditions		Notes
Reference voltage	Vref	2.440	2.495	2.550	V	V_{KA} = Vref		A
		2.395	2.495	2.595				Normal
Reference voltage temperature deviation	Vref(dev)	—	11	(30)	mV	V_{KA} = Vref	Ta = –20°C to +85°C	1, 4
		—	5	(17)			Ta = 0°C to +70°C	1, 4
Reference voltage regulation	ΔVref/ΔV_{KA}	—	1.4	3.7	mV/V	V_{KA} = Vref to 10 V		
		—	1	2.2		V_{KA} = 10 V to 40 V		
Reference input current	Iref	—	3.8	6	µA	R1 = 10 kΩ, R2 = ∞		
Reference current temperature deviation	Iref(dev)	—	0.5	(2.5)	µA	R1 = 10 kΩ, R2 = ∞ Ta = 0°C to 70°C		4
Minimum cathode current	Imin	—	0.4	1.0	mA	V_{KA} = Vref		2
Off state cathode current	Ioff	—	0.001	1.0	µA	V_{KA} = 40 V, Vref = 0 V		
Dynamic impedance	Z_{KA}	—	0.2	0.5	Ω	V_{KA} = Vref I_K = 1 mA to 100 mA		

Notes: 1. Vref(dev) = Vref(max) – Vref(min)

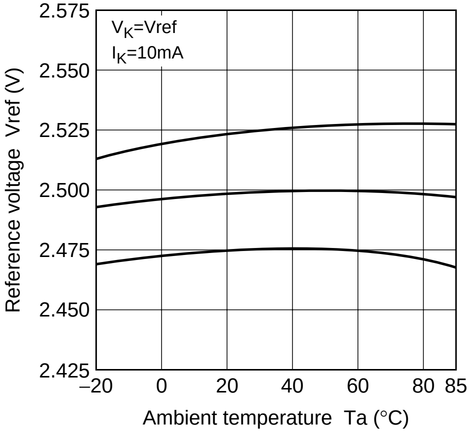


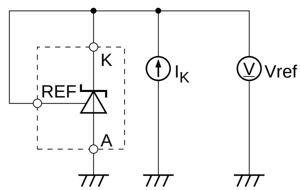
2. Imin is given by the cathode current at Vref = $Vref_{(IK=10mA)}$ – 15 mV.
3. R_{PS} is only provided in HA17431VLP.
4. The maximum value is a design value (not measured).

Section 3 Characteristics Curves

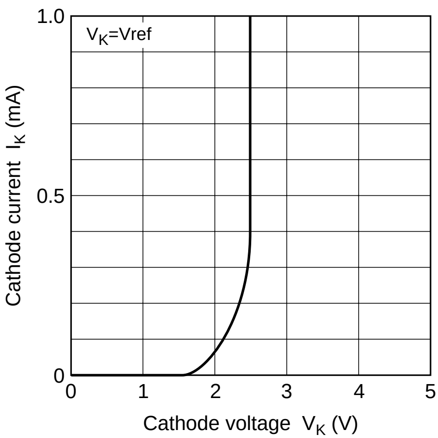
HA17431VLP/VP/VPJ/VUP, HA17432VUP

Reference Voltage Temperature Characteristics

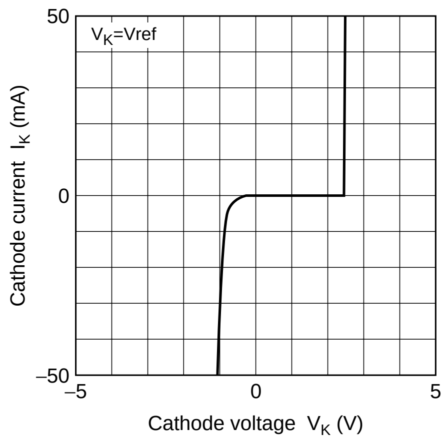




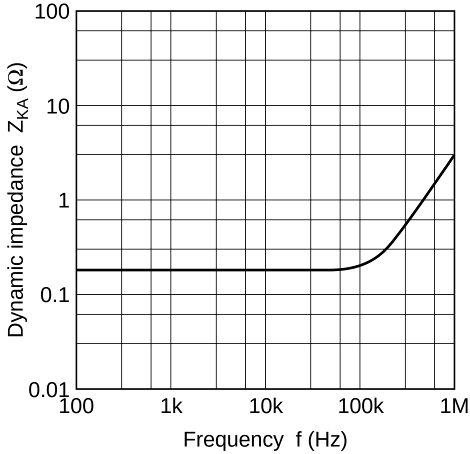
Cathode Current vs. Cathode Voltage Characteristics 1

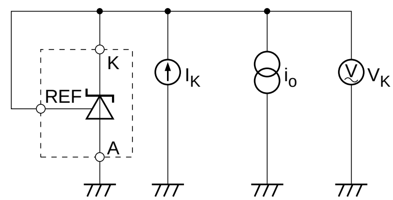


Cathode Current vs. Cathode Voltage Characteristics 2



Dynamic Impedance vs. Frequency Characteristics

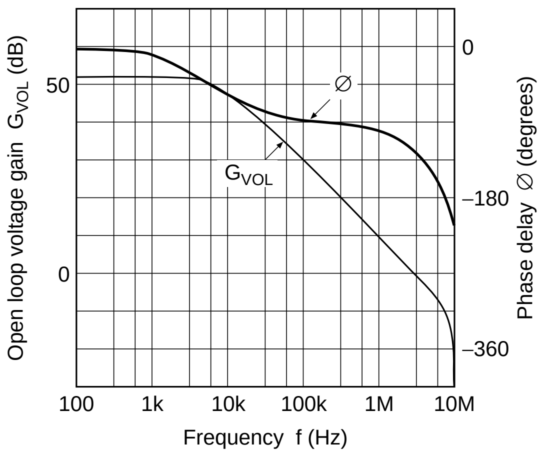


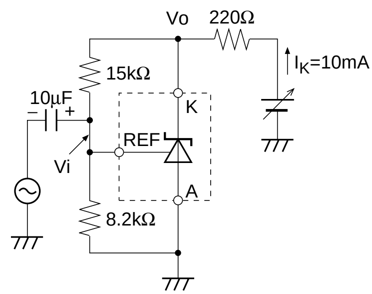


i_o = 2mA_{P-P}

$$Z_{KA} = \frac{V_K}{i_o} \ (\Omega)$$

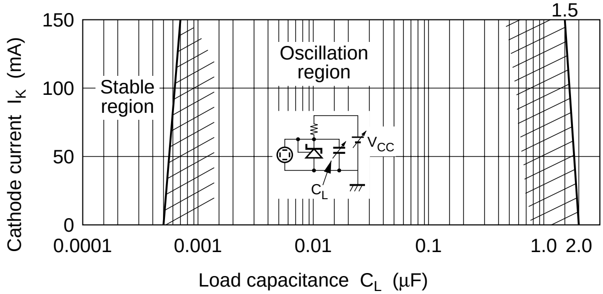
Open Loop Voltage Gain, Phase vs. Frequency Characteristics



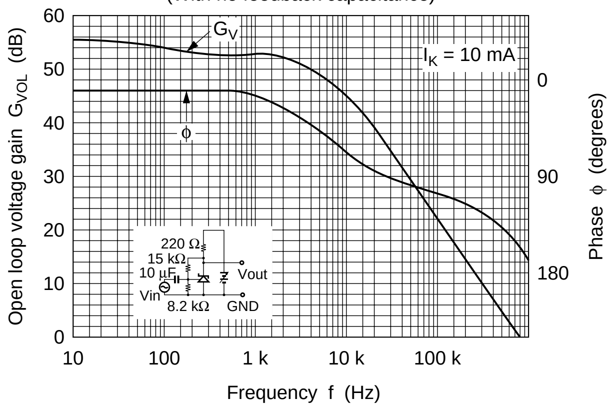


$$G = 20\log\left(\frac{Vo}{Vi}\right) \text{(dB)}$$

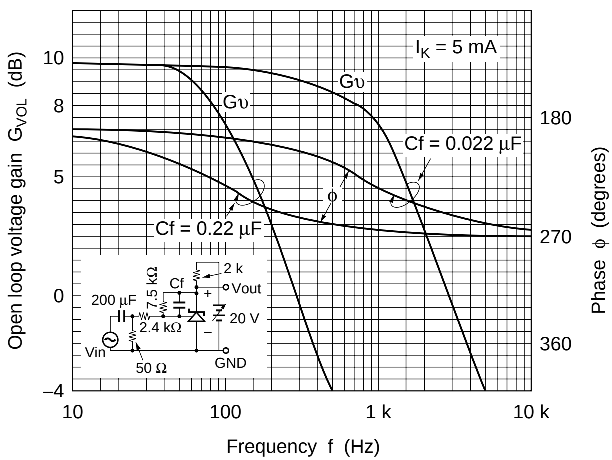
Oscillation Stability vs. Load Capacitance between Anode and Cathode



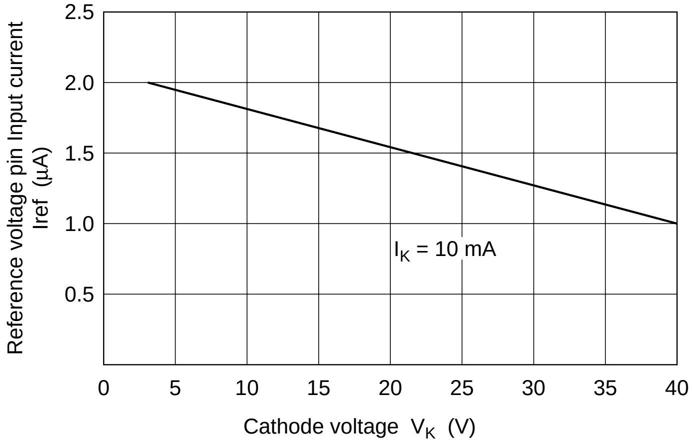
Open Loop Voltage Gain, Phase vs. Frequency Characteristics (1)
(With no feedback capacitance)



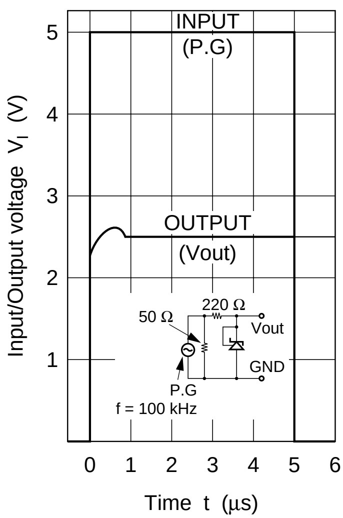
Open Loop Voltage Gain, Phase vs. Frequency Characteristics (2)
(When a feedback capacitance (Cf) is provided)



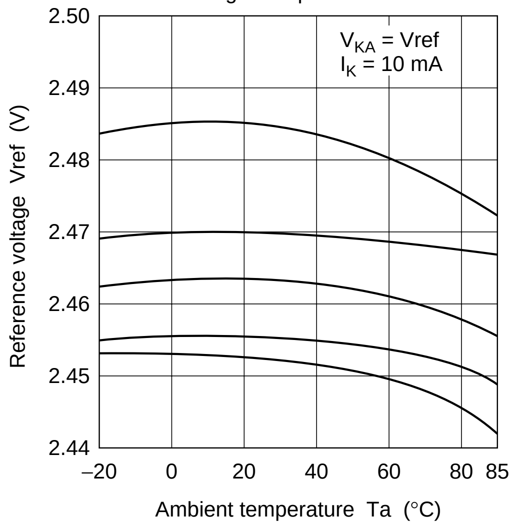
Reference Voltage Pin Input Current vs. Cathode Voltage Characteristics



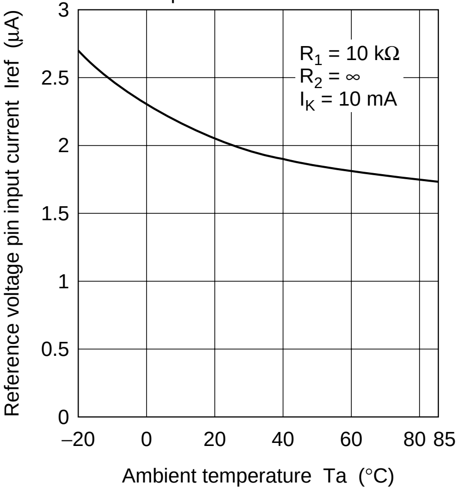
Pulse Response



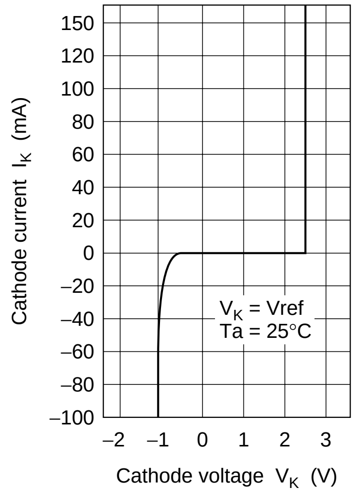
Reference Voltage Temperature Characteristics



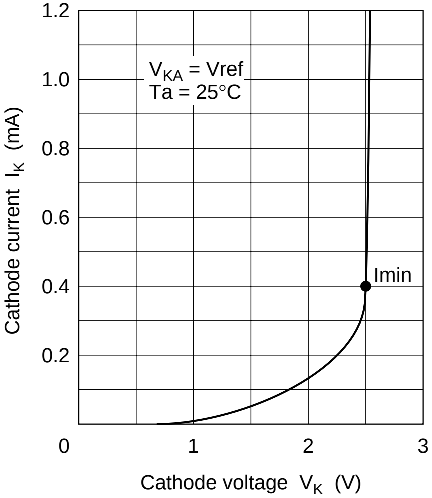
Reference Voltage Pin Input Current Temperature Characteristics



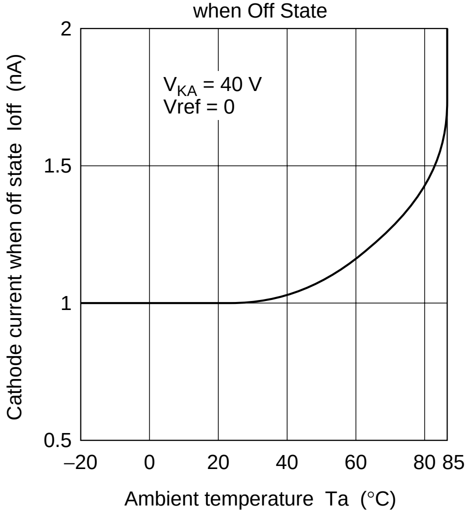
Cathode Current vs. Cathode Voltage Characteristics (1)



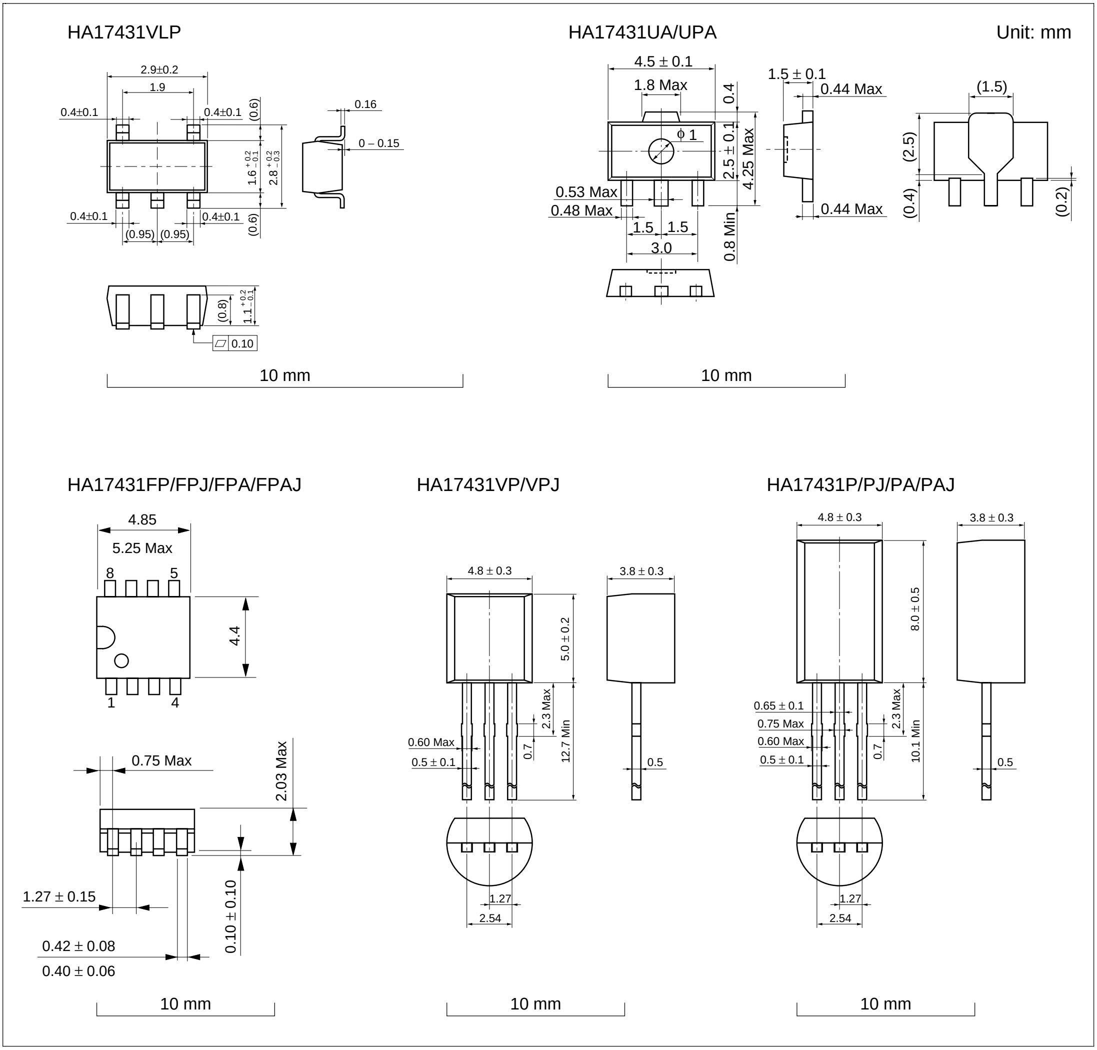
Cathode Current vs. Cathode Voltage Characteristics (2)



Cathode Current Temperature Characteristics when Off State



Section 4 Outline Dimensions



Section 5 MPAK-5 and UPAK Marking Patterns

The marking patterns shown below are used on MPAK-5 and UPAK products. Note that the product code and mark pattern are different. The pattern is laser printed.

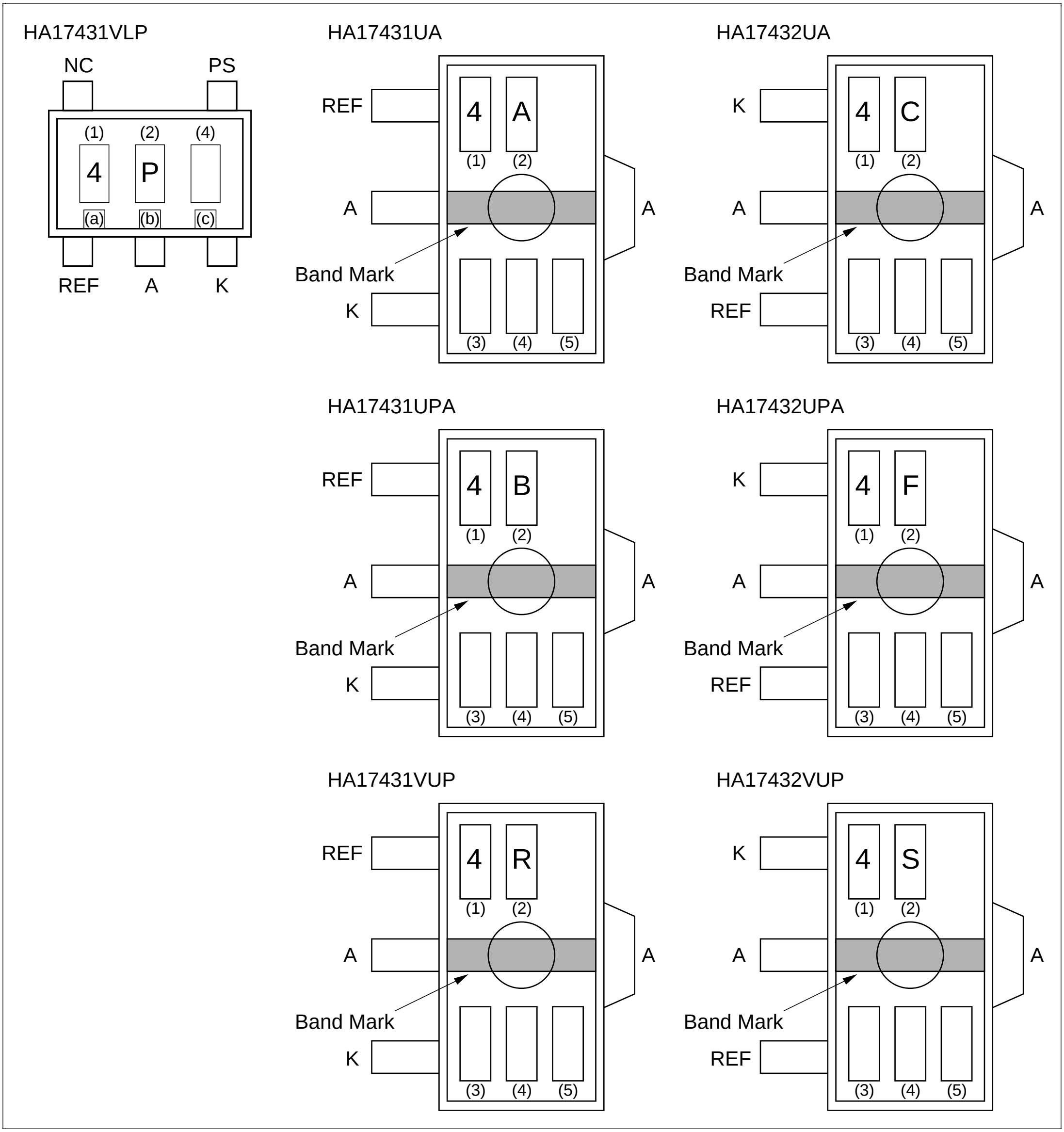


Figure 5.1 MPAK-5 and UPAK Marking Patterns

Notes: 1. Boxes (1) to (5) in the figures show the position of the letters or numerals, and are not actually marked on the package.

2. The letters (1) and (2) show the product specific mark pattern.

Product	(1)	(2)
HA17431VLP	4	P
HA17431VUP	4	R
HA17431UA	4	A
HA17431UPA	4	B

Product	(1)	(2)
HA17432VUP	4	S
HA17432UA	4	C
HA17432UPA	4	F

3. The letter (3) shows the production year code (the last digit of the year) for UPAK products.
4. The bars (a), (b) and (c) show a production year code for MPAK-5 products as shown below. After 2005 the code is repeated every 8 years.

Year	1997	1998	1999	2000	2001	2002	2003	2004
(a)	Bar	Bar	Bar	Bar	None	None	None	None
(b)	None	None	Bar	Bar	None	None	Bar	Bar
(c)	None	Bar	None	Bar	None	Bar	None	Bar

5. The letter (4) shows the production month code (see table below).

Production month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Marked code	A	B	C	D	E	F	G	H	J	K	L	M

6. The letter (5) shows manufacturing code for UPAK products.

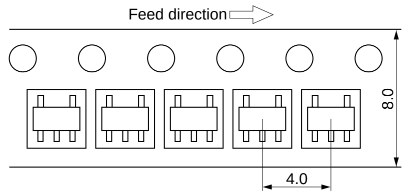
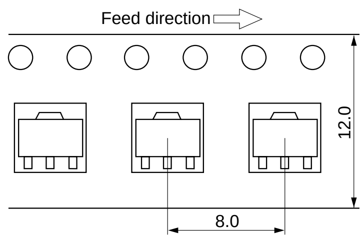
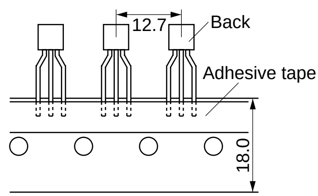
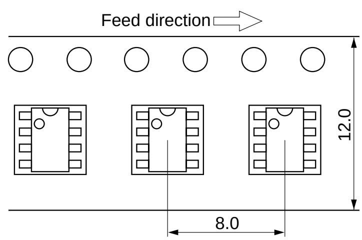
Section 6 Ordering Information

Taping specifications must be attached after the product name. The quantity must be a multiple of ordering unit (see table below).

ex. HA17431VLP-EL 15,000pcs

Quantity
Taping code
Product name

Table 6.1 Taping Specifications

Package	Taping Code	Packing	Ordering Unit	Illustration
MPAK-5	EL	Embossed taping L type in 180 ϕ reel	3000 pcs	
UPAK	TL	Embossed taping L type in 180 ϕ reel	1000 pcs	
TO-92 TO-92MOD	TZ	Fan-folded taping in 336 $\times$ 262 $\times$ 47 mm^3 box (TO-92), Fan-folded taping in 330 $\times$ 200 $\times$ 43 mm^3 box (TO-92MOD)	2500 pcs	
FP-8D	EL	Embossed taping L type in 330 ϕ reel	2500 pcs	

Section 7 Application Examples

As shown in the figure below, this IC operates as an inverting amplifier, with the REF pin as an input pin. The open-loop voltage gain is given by the reciprocal of "reference voltage deviation by cathode voltage change" in the electrical specifications, and is approximately 50 to 60 dB. The REF pin has a high input impedance, with an input current Iref of 3.8 µA typ (V version: Iref = 2 µA typ). The output impedance of the output pin K (cathode) is defined as dynamic impedance Z_{KA}, and Z_{KA} is low (0.2 Ω) over a wide cathode current range. A (anode) is used at the minimum potential, such as ground.

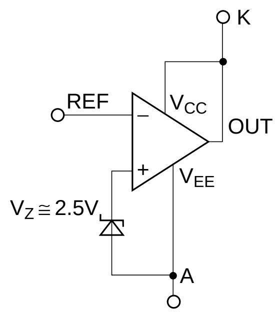
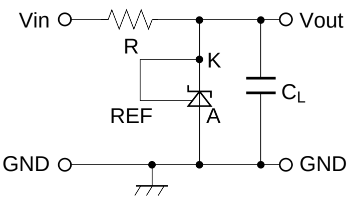


Figure 7.1 Operation Diagram

7.1 Application Hints

No. **Application Example** — **Description**

1 Reference voltage generation circuit

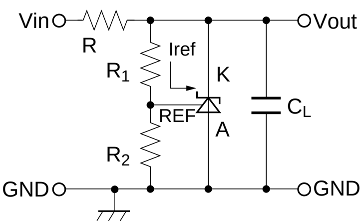


This is the simplest reference voltage circuit. The value of the resistance R is set so that cathode current $I_K \geq 1$ mA.

Output is fixed at Vout ≅ 2.5 V.

The external capacitor C_L ($C_L \geq 3.3\ \mu F$) is used to prevent oscillation in normal applications.

2 Variable output shunt regulator circuit

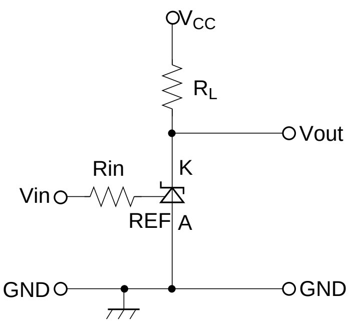


This is circuit 1 above with variable output provided.

$$\text{Here,} \quad \text{Vout} \cong 2.5\ \text{V} \times \frac{(R_1 + R_2)}{R_2}$$

Since the reference input current Iref = 3.8 μA typ (V version: Iref = 2 μA typ) flows through R_1, resistance values are chosen to allow the resultant voltage drop to be ignored.

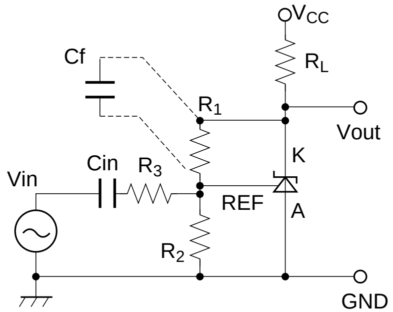
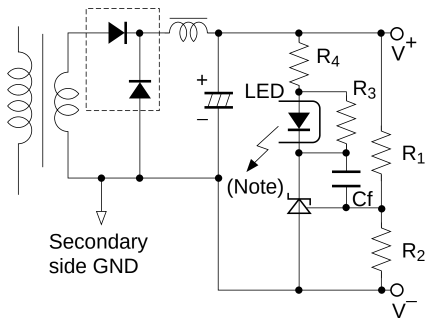
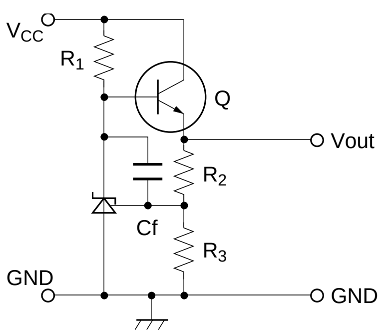
3 Single power supply inverting comparator circuit

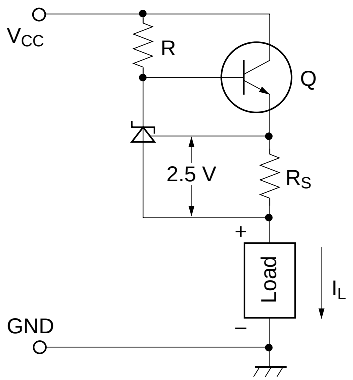
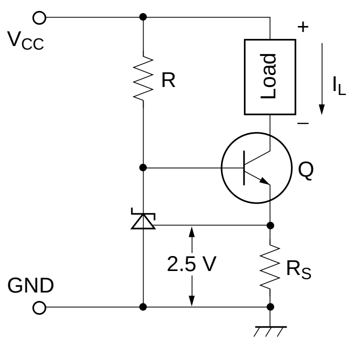


This is an inverting type comparator with an input threshold voltage of approximately 2.5 V. Rin is the REF pin protection resistance, with a value of several kΩ to several tens of kΩ.

R_L is the load resistance, selected so that the cathode current $I_K \geq 1$ mA when Vout is low.

Condition	Vin	Vout	IC
C1	Less then 2.5 V	V_{CC} (V_{OH})	OFF
C2	2.5 V or more	Approx. 2 V (V_{OL})	ON

No.	Application Example	Description
4	AC amplifier circuit  Gain G = $\frac{R_1}{R_2 // R_3}$ (DC gain) Cutoff frequency fc = $\frac{1}{2\pi\, Cf\, (R_1 // R_2 // R_3)}$	This is an AC amplifier with voltage gain G = $-R_1 / (R_2//R_3)$. The input is cut by capacitance Cin, so that the REF pin is driven by the AC input signal, centered on 2.5 V_{DC}. R_2 also functions as a resistance that determines the DC cathode potential when there is no input, but if the input level is low and there is no risk of Vout clipping to V_{CC}, this can be omitted. To change the frequency characteristic, Cf should be connected as indicated by the dotted line.
5	Switching power supply error amplification circuit  Note: LED: Light emitting diode in photocoupler R_3: Bypass resistor to feed I_K(>Imin) when LED current vanishes R_4: LED protection resistance	This circuit performs control on the secondary side of a transformer, and is often used with a switching power supply that employs a photocoupler for offlining. The output voltage (between V+ and V–) is given by the following formula: Vout $\cong$ 2.5 V $\times \frac{(R_1 + R_2)}{R_2}$ In this circuit, the gain with respect to the Vout error is as follows: G = $\frac{R_2}{(R_1 + R_2)} \times \left[\text{HA17431 open loop gain}\right] \times \left[\text{Photocoupler total gain}\right]$ As stated earlier, the HA17431 open-loop gain is 50 to 60 dB.
6	Constant voltage regulator circuit  	This is a 3-pin regulator with a discrete configuration, in which the output voltage Vout = 2.5 V $\times \frac{(R_2 + R_3)}{R_3}$. R_1 is a bias resistance for supplying the HA17431 cathode current and the output transistor Q base current.

No.	Application Example	Description
7	Discharge type constant current circuit 	This circuit supplies a constant current of $I_L \cong \frac{2.5\ V}{R_S}$ [A] into the load. Caution is required since the HA17431 cathode current is also superimposed on I_L. The requirement in this circuit is that the cathode current must be greater than Imin = 1 mA. The I_L setting therefore must be on the order of several mA or more.
8	Induction type constant current circuit 	In this circuit, the load is connected on the collector side of transistor Q in circuit 7 above. In this case, the load floats from GND, but the HA17431 cathode current is not superimposed on I_L, so that I_L can be kept small (1 mA or less is possible). The constant current value is the same as for circuit 7 above: $I_L \cong \frac{2.5\ V}{R_S}$ [A]

7.2 Design Guide for AC-DC SMPS (Switching Mode Power Supply)

7.2.1 Use of Shunt Regulator in Transformer Secondary Side Control

This example is applicable to both forward transformers and flyback transformers. A shunt regulator is used on the secondary side as an error amplifier, and feedback to the primary side is provided via a photocoupler.

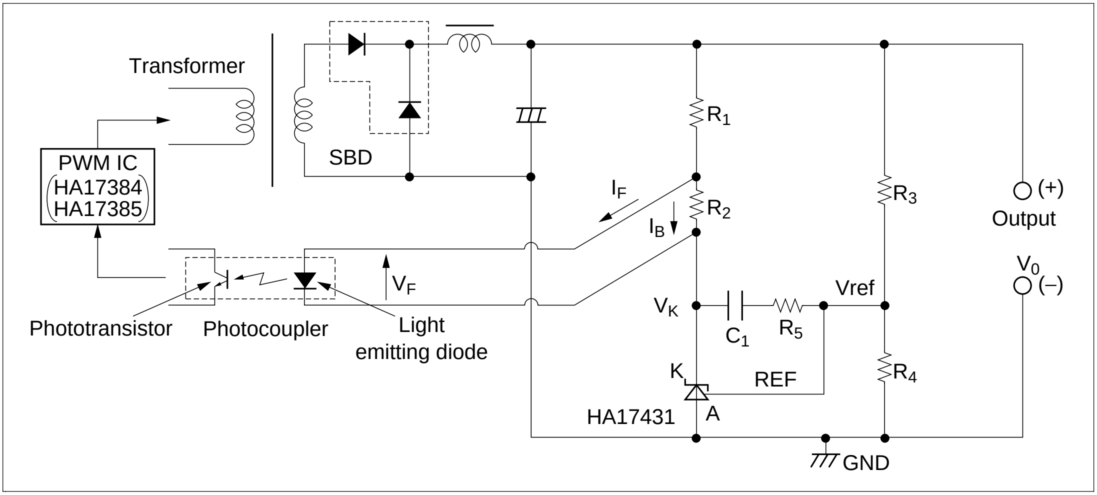


Figure 7.2 Typical Shunt Regulator/Error Amplifier

7.2.2 Determination of External Constants for the Shunt Regulator

DC Characteristic Determination: In figure 7.2, R_1 and R_2 are protection resistor for the light emitting diode in the photocoupler, and R2 is a bypass resistor to feed I_K minimum, and these are determined as shown below. The photocoupler specification should be obtained separately from the manufacturer. Using the parameters in figure 7.2, the following formulas are obtained:

$$R_1 = \frac{V_0 - V_F - V_K}{I_F + I_B}\ ,\ R_2 = \frac{V_F}{I_B}$$

V_K is the HA17431 operating voltage, and is set at around 3 V, taking into account a margin for fluctuation. R_2 is the current shunt resistance for the light emitting diode, in which a bias current I_B of around 1/5 I_F flows.

Next, the output voltage can be determined by R_3 and R_4, and the following formula is obtained:

$$V_0 = \frac{R_3 + R_4}{R_4} \times \text{Vref, Vref} = 2.5\text{ V Typ}$$

The absolute values of R_3 and R_4 are determined by the HA17431 reference input current Iref and the AC characteristics described in the next section. The Iref value is around 3.8 µA typ.
(V version: 2 µA typ)

AC Characteristic Determination: This refers to the determination of the gain frequency characteristic of the shunt regulator as an error amplifier. Taking the configuration in figure 7.2, the error amplifier characteristic is as shown in figure 7.3.

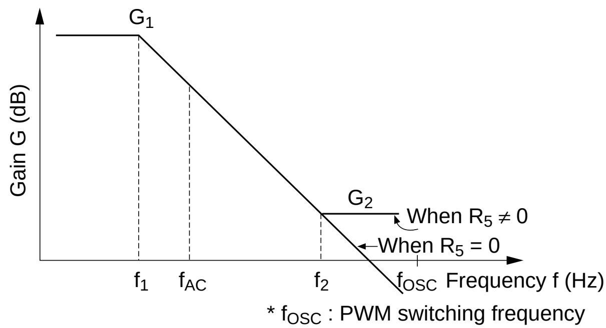


Figure 7.3 HA17431 Error Amplification Characteristic

In figure 7.3, the following formulas are obtained:

Gain

$G_1 = G_0 \approx 50$ dB (determined by shunt regulator)

$$G_2 = \frac{R_5}{R_3}$$

Corner frequencies

$f_1 = 1/(2\pi\ C_1\ G_0\ R_3)$

$f_2 = 1/(2\pi\ C_1\ R_5)$

G_0 is the shunt regulator open-loop gain; this is given by the reciprocal of the reference voltage fluctuation $\Delta Vref/\Delta V_{KA}$, and is approximately 50 dB.

7.2.3 Practical Example

Consider the example of a photocoupler, with an internal light emitting diode V_F = 1.05 V and I_F = 2.5 mA, power supply output voltage V_2 = 5 V, and bias resistance R_2 current of approximately 1/5 I_F at 0.5 mA. If the shunt regulator V_K = 3 V, the following values are found.

$$R_1 = \frac{5V - 1.05V - 3V}{2.5mA + 0.5mA} = 317(\Omega)\ (330\Omega \text{ from E24 series})$$

$$R_2 = \frac{1.05V}{0.5mA} = 2.1(k\Omega)\ (2.2k\Omega \text{ from E24 series})$$

Next, assume that $R_3 = R_4 = 10\ k\Omega$. This gives a 5 V output. If $R_5 = 3.3\ k\Omega$ and $C_1 = 0.022\ \mu F$, the following values are found.

$$G_2 = 3.3\ k\Omega / 10\ k\Omega = 0.33 \text{ times } (-10\ dB)$$

$$f_1 = 1/(2 \times \pi \times 0.022\ \mu F \times 316 \text{ times} \times 10\ k\Omega) = 2.3\ (Hz)$$

$$f_2 = 1/(2 \times \pi \times 0.022\ \mu F \times 3.3\ k\Omega) = 2.2\ (kHz)$$

7.3 Circuit Example AC-DC SMPS

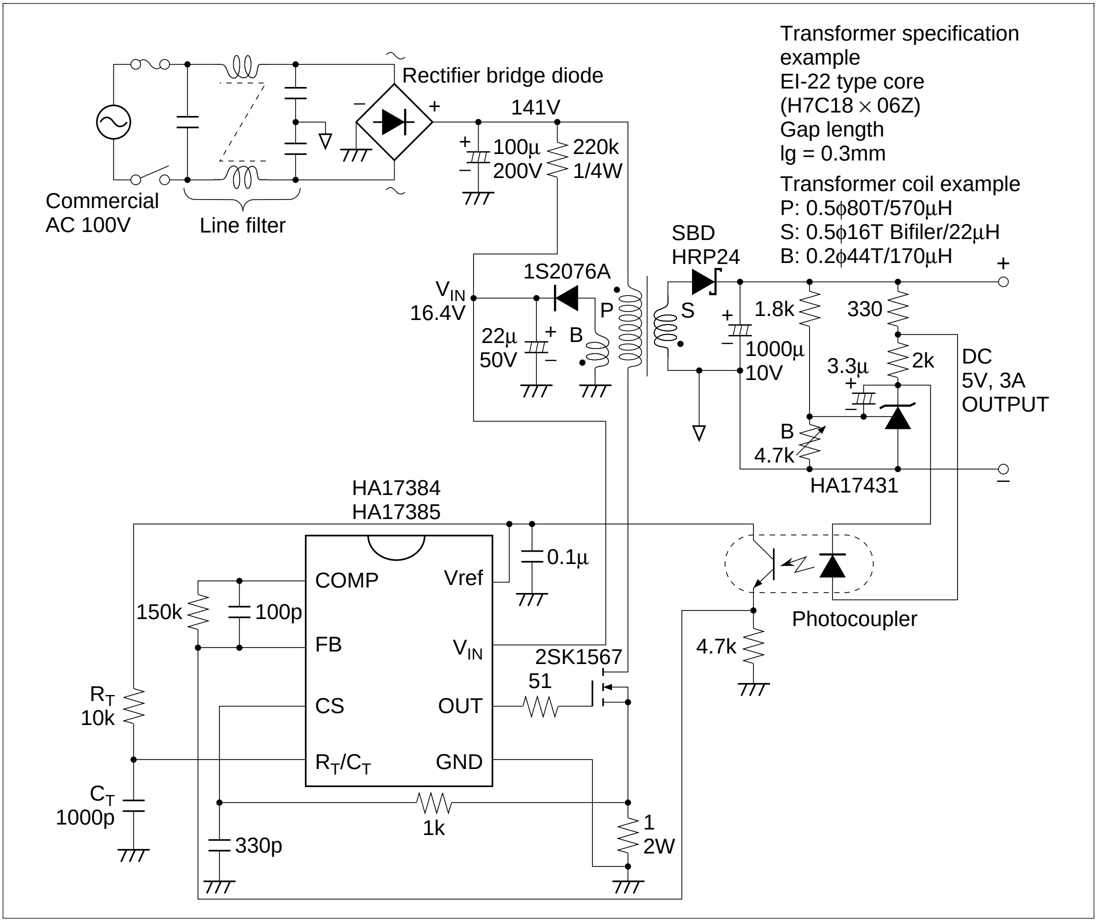


Figure 7.4 Circuit Example AC-DC SMPS

HA17431 Series Shunt Regulators
Application Note

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