

HS7067/HS7107 7 Amp, Multimode, High Efficiency Switching Regulator

General Description

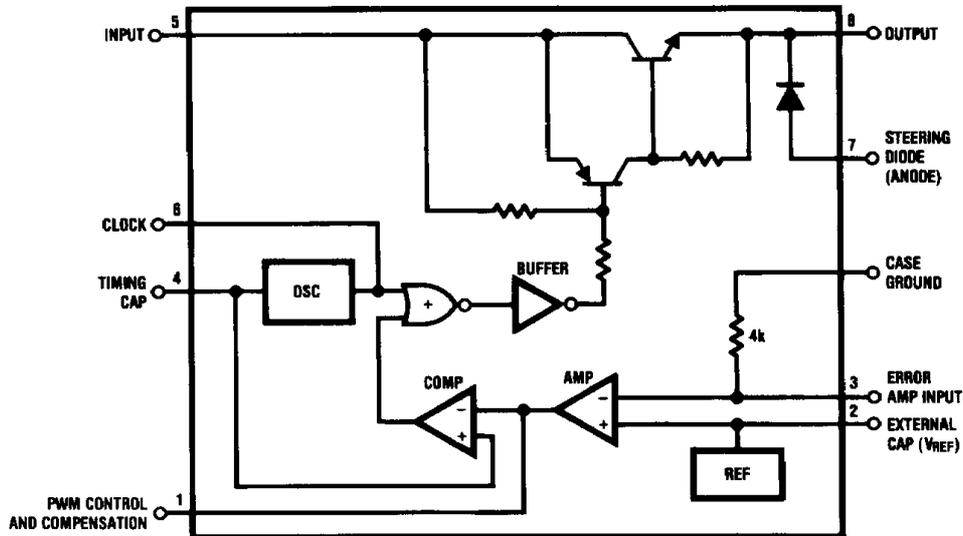
The HS7067/HS7107 is a hybrid high efficiency switching regulator with high output current capability. The device is housed in a standard TO-3 package containing a temperature compensated voltage reference, a pulse-width modulator with programmable oscillator frequency, error amplifier, high current, high voltage output switch and steering diode. The HS7067/HS7107 operates in a step-down, inverting, as well as in a transformer-coupled mode.

The HS7067/HS7107 can supply up to 7A of continuous output current over a wide range of input and output voltages.

Features

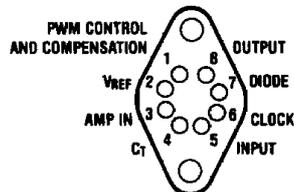
- HS7067—10V to 60V input
- HS7107—10V to 100V input
- 7A continuous output current
- Step-down, inverting, and transformer-coupled operation
- Frequency adjustable to 200 kHz
- High-efficiency (> 75%)
- Standard 8-pin TO-3 package

Block and Connection Diagrams



TL/K/6746-1

Metal Can Package



TL/K/6746-2

Top View

Case is ground

Order Number HS7067CK, HS7067K,
HS7107CK or HS7107K
See NS Package Number K08A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

V_{IN} , Input Voltage		T_A , Operating Temperature Range	
HS7067	65V	HS7067C/7107C	-25°C to +85°C
HS7107	105V	HS7067/7107	-55°C to +125°C
I_{OUT} , Output Current	8A	T_{STG} , Storage Temperature Range	-65°C to +150°C
T_J , Operating Temperature	150°C	$V_R(V_{8-7})$, Steering Diode Reverse Voltage	105V
P_D , Internal Power Dissipation	25W	$I_D(I_{7-8})$, Steering Diode Forward Current	8A

Electrical Characteristics $T_C = 25^\circ\text{C}$, $V_{IN} = 20\text{V}$ (unless otherwise specified)

Symbol	Parameter	Conditions	Min	Typ	Max	Units	
$V_{IN}-V_{OUT}$	Min V_{IN}/V_{OUT} Differential	HS7067	$10\text{V} \leq V_{IN} \leq V_{IN(\text{MAX})}$ $I_{OUT} = 2\text{A}$ (Note 6)		3.0		V
		HS7107			3.0		V
V_S	Switch Saturation Voltage	$I_C = 7.0\text{A}$, $V_{IN} = 10\text{V}$	HS7107		1.6	TBD	V
			HS7607			1.9	V
		$I_C = 2.0\text{A}$, $V_{IN} = 10\text{V}$			1.0		V
V_F	Steering Diode On Voltage	$I_D = 7.0\text{A}$	HS7107		1.3	TBD	V
			HS7607		1.7	TBD	V
		$I_D = 2.0\text{A}$			0.9		V
V_{IN}	Supply Voltage Range (Note 7)	HS7067	$T_{MIN} \leq T_A \leq T_{MAX}$	10		60	V
		HS7107	$T_{MIN} \leq T_A \leq T_{MAX}$	10		100	V
I_R	Steering Diode Reverse Current	$V_R = 100\text{V}$			60	μA	
I_Q	Quiescent Current (Note 3)	0% Duty Cycle ($V_3 = 3.0\text{V}$)		6		mA	
		100% Duty Cycle ($V_3 = 0\text{V}$)		26		mA	
V_2	Reference Voltage on Pin 2	$T_{MIN} \leq T_A \leq T_{MAX}$	2.3	2.5	2.7	V	
$V_{CLK H}$	Clock Output High	$I_{CLK} = -750 \mu\text{A}$	1.2	1.6		V	
$V_{CLK L}$	Clock Output Low	$I_{CLK} = 80 \mu\text{A}$			0.9	V	
ΔV_2	Line Regulation of Reference Voltage on Pin 2	$V_{MIN} \leq V_{IN} \leq V_{MAX}$		5		mV	
R_A	Resistance on Pin 3 to Ground	(Note 4)		4.0		k Ω	
V_{OUT}	Feedback Resistor R_f Tol. $\pm 1\%$	HS7107		4	TBD	%	
		HS7067			9	%	
V_4	Voltage Swing—Pin 4			3.0		V	
I_4	Charging Current—Pin 4			330		μA	
I_{CLK}	Clock Input Current — Pin 6	$V_{CLK} = 3.5\text{V}$		1.75	4	mA	
t_r	Transistor Current Rise Time	$I_O = 2.0\text{A}$ (Note 6)		70		ns	
		$I_O = 7.0\text{A}$ (Note 6)		120		ns	
t_f	Transistor Current Fall Time	$I_O = 2.0\text{A}$ (Note 6)		100		ns	
		$I_O = 7.0\text{A}$ (Note 6)		160		ns	
t_s	Diode Storage Time	$I_O = 7.0\text{A}$ (Note 6)		120		ns	
t_d	Delay Time	$I_O = 7.0\text{A}$ (Note 6)		600		ns	
f_{MAX}	Max Clock Frequency	(Note 5)			200	kHz	

Electrical Characteristics $T_C = 25^\circ\text{C}$, $V_{IN} = 20\text{V}$ (unless otherwise specified) (Continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
Z _{PIN 1}	Impedance at Pin 1	(Note 6)		5		MΩ
η	Efficiency	$V_{OUT} = 5\text{V}$ $I_{OUT} = 1\text{A}$ $f_O = 25\text{ kHz (Note 6)}$		80		%
		$f_O = 200\text{ kHz (Note 5)}$		70		%
θ _{JC}	Thermal Resistance	(Note 1)		4.0		°C/W

Note 1: θ_{JA} is typically 35°C/W for natural convection cooling.

Note 2: V_{OUT} and I_{OUT} refer to the output DC voltage and output current of a switching supply after the output LC filter as shown in Figure 1.

Note 3: Quiescent current depends on the duty cycle of the switching translator.

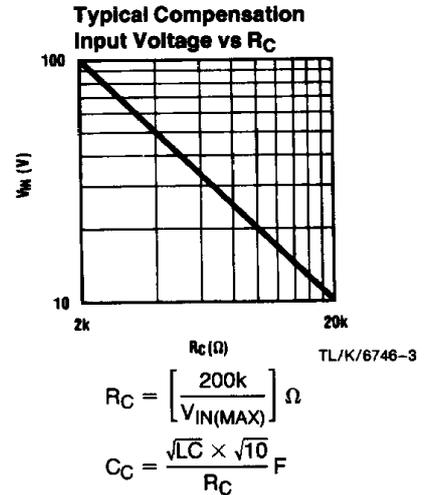
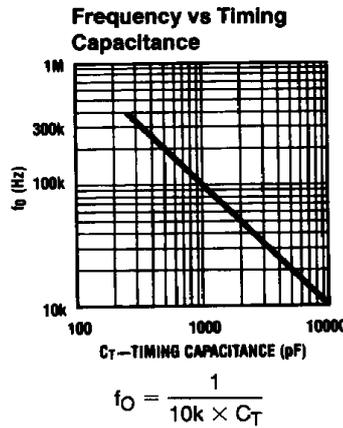
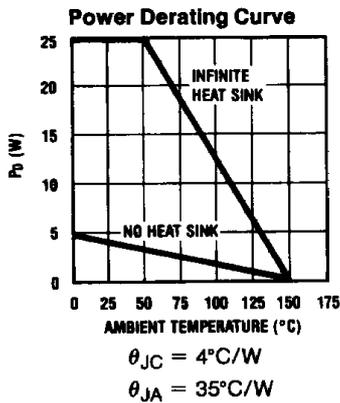
Note 4: This test includes the input bias current of the error amplifier.

Note 5: Circuit configured as shown in Figure 1.

Note 6: These parameters are not tested. They are given for informational purposes only.

Note 7: Functionally tested at limits only (pass-fail).

Typical Performance Characteristics



Typical Applications

THE BUCK CONVERTER (Step Down)

The buck converter is the most common application in switching-power conversion. It allows to step down a voltage with a minimum of components and a maximum of efficiency (for further information on the theory of operation of a buck converter, see AN-343).

f _O	25 kHz	200 kHz
L	86 μH	21 μH
C _T	0.0039 μF	330 pF
C _C	0.2 μF	0.068 μF
R _f	4 kΩ	4 kΩ
R _C	5.7 kΩ	5.7 kΩ
C _{OUT}	1500 μF	680 μF

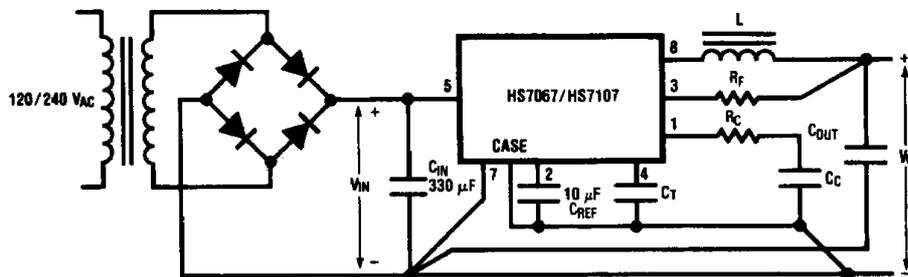
V_{IN} = 10V to 35V

V_{OUT} = 5V

I_{OUT} = 1A to 6A

Load Regulation = 40 mV

Line Regulation = 5 mV



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Typical Applications (Continued)

Design equations:

Following are the design equations for a buck converter application using the HS 7107/7067:

$$C_T = \frac{1}{10^4 \times f_o}$$

$$L_{MIN} = \frac{(V_{IN(MAX)} - V_O) V_O}{V_{IN(MAX)} \times f_o \times \Delta I} \quad (\text{Note 7, 9})$$

$$C_{MIN} = \frac{\Delta I}{4 f_o (e_o - \Delta I \times ESR)} \quad (\text{Note 8, 9})$$

$$C_C = \frac{\sqrt{10 LC}}{R_C}$$

$$R_C = \frac{2 \times 10^5}{V_{IN(MAX)}}$$

$$R_f = 4k \left(\frac{V_O - 2.5}{2.5} \right) \Omega$$

Note 7: L_{MIN} is the minimum value of output filter inductance, L, for stable operation.

Note 8: C_{MIN} is the minimum value of output filter capacitance, C, necessary to achieve an output ripple voltage, e_o . ESR is the Effective Series Resistance of the output filter capacitor, C, at the operating frequency, f_o .

Note 9: ΔI = Peak to Peak Ripple current through the inductor and the capacitor. $\frac{\Delta I}{2} < I_{O MIN}$ and $\frac{\Delta I}{2} < 7 - I_{O MAX}$.

Efficiency Equations

Since high efficiency is the principal advantage of switched-mode power conversion, switching regulator losses are an important design concern. Losses and efficiency of a buck converter can be calculated with the following equations.

Note: Pin 7 is grounded; I_O = average output current at pin 8

Switching Period (T)

$$T = \frac{1}{f_o} = t_{ON} + t_{OFF}$$

Duty Cycle (D)

$$D = \frac{t_{ON}}{t_{ON} + t_{OFF}} = \frac{V_O + V_F}{V_{IN} - V_S + V_F}$$

Transistor DC Losses (P_T)

$$P_T = V_S \times I_O \times D$$

Transistor Switching Losses (P_S)

$$P_S = (V_{IN} + V_F) \times I_O \times \frac{(t_r + t_f + 2t_s) f_o}{2}$$

Capacitor Losses (P_C)

$$P_C = ESR \times \left(\frac{V_O (T - DT)}{4L} \right)^2$$

Diode DC Losses (P_D)

$$P_D = V_f \times I_O \times (1 - D)$$

Drive Circuit Losses (P_{DL})

$$P_{DL} = 0.02 \times V_{IN} \times D$$

Inductor Losses (P_L)

$$P_L = I_O^2 \times R_L \quad (\text{DC winding resistance})$$

Power Output (P_O)

$$P_O = \frac{(V_{IN} - V_S) t_{ON} - (V_F) t_{OFF}}{t_{ON} + t_{OFF}} \times I_O$$

Efficiency (η)

$$\eta = \frac{P_O}{P_{IN}} = \frac{P_O}{P_O + P_T + P_S + P_D + P_{DL} + P_L + P_C}$$

TRANSFORMER COUPLED CONVERTERS

In addition to the implementation of a buck converter, the HS 7107/7067 can be used in various transformer coupled configurations. They can be used in various topologies such as: step-up, step-down, inverter, multiple outputs and isolated converters.

There are basically two different methods in implementing transformer coupled converters: the flyback and the forward topology

The Flyback Principle

Figure 1 shows a functional diagram of a flyback converter. Depending on the turn ratio N_2/N_1 and the feedback voltage, it can be implemented as a step-down or step-up converter.

When the switch is on, the current (I_p) flows through the primary winding creating a magnetic flux in the core and storing the energy. At this time, the voltage at the secondary keeps the same polarity (with respect to the dotted terminals), the diode is off and no current flows through it. When the switch is off, the voltage at the secondary and primary becomes reversed and the diode turns-on (I_d). The stored energy is then transferred to the load and the output filter capacitor. The energy stored in the capacitor will supply the load current during the next turn-on.

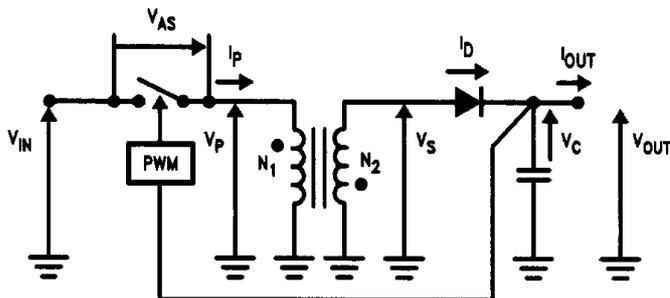
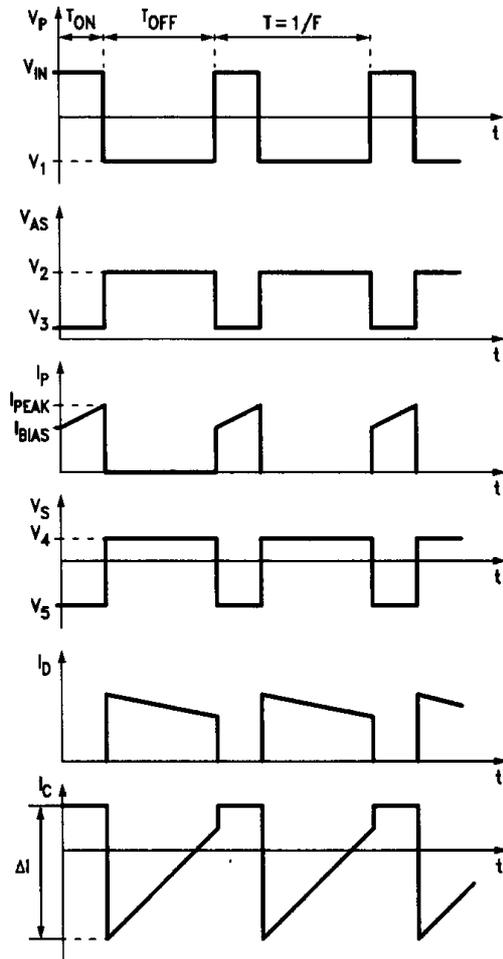


FIGURE 1. Typical Flyback Functional Diagram

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Typical Applications (Continued)

- V_p = Voltage at primary
- V_{as} = Voltage across the switch
- V_s = Voltage at the secondary
- I_p = Current at primary
- I_d = Current through diode
- I_c = Current through output cap
- I_{out} = Output current of the converter
- Δi = Ripple current
- D = $T_{on}/(T_{off} + T_{on})$
- F = Switching frequency
- V_{df} = Forward voltage drop of the diode
- $V_1 = V_{out} \times N_1/N_2$ $V_2 = V_{in} + V_{out} N_1/N_2$
- V_3 = Saturation voltage of the switch
- $V_4 = V_{out} + V_{df}$ $V_5 = V_{in} \times N_2/N_1$



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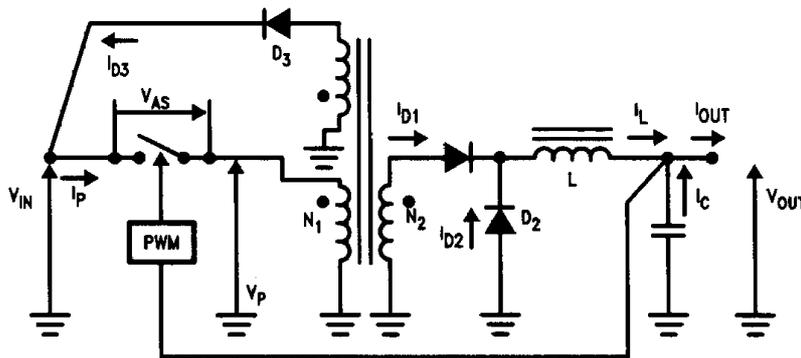
FIGURE 2. Typical Flyback Waveforms

The load current is not supplied directly by the input source when the switch is on, but only by the energy stored in the output capacitor. The output voltage is monitored by the feedback loop which controls the duty cycle (D) through the PWM (Pulse Width Modulator) which in turn, modulates the amount of energy being transferred from the input to the output. *Figure 2* shows the waveforms of a continuous mode flyback converter (primary current I_p is DC biased).

The Forward Principle

The forward converter is a little more complex and requires more components than the flyback, but the output ripple voltage is smaller. *Figure 3* shows a simplified diagram of a forward converter.

When the switch turns-on, a voltage $V_5 = V_1 \times N_2/N_1$ appears at the secondary of the transformer. The diode D_2



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FIGURE 3. Typical Forward Functional Diagram

Typical Applications (Continued)

is off while D_1 turns-on, allowing the current to flow through the inductor L (I_{d1} and I_L), storing energy in its core, and supplying the load current (I_{out}) and the capacitor current (I_C) at the same time. When the switch turns-off, the magnetic energy stored in the core of the inductor creates a current (I_{d2}) which flows through the diode D_2 . The load current I_{out} therefore, equals to $I_{d2} + I_C$.

During the "off" time of the switch, some residual magnetism will stay in the core of the transformer and has to be removed before the next cycle, so that it does not accumulate, leading to core saturation.

A demagnetizing winding is used to "dump" the residual energy back to the input or output of the converter. The

functional principle of the demagnetizing winding is similar to the flyback in the sense that, during the turn-off time, the residual magnetism will generate a reverse voltage at the demagnetizing winding (with respect to the dotted terminals) turning on the diode D_3 .

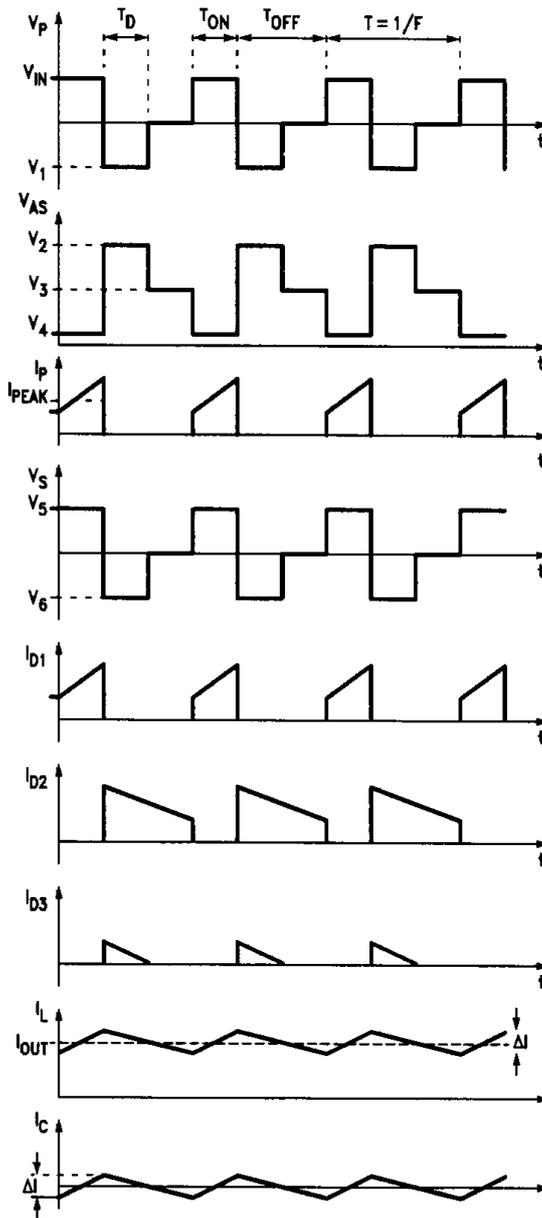
In the forward mode, when the switch is off, the load current is supplied by the energy stored in the output capacitor and the choke inductor but when the switch is on, it is supplied by the input source through the transformer. This accounts for the lower output ripple voltage.

The output voltage is monitored by the feedback loop, which controls the duty cycle through the PWM, which in turn modulates the amount of energy being transferred from the input to the output.

- V_p = Voltage at primary
- V_{as} = Voltage across the switch
- V_s = Voltage at secondary
- I_p = Current at primary
- I_{d1} = Current through diode D_1
- I_{d2} = Current through diode D_2
- I_{d3} = Current through diode D_3
- I_L = Current through inductor L
- I_C = Current through output cap
- I_{out} = Output current of the converter
- Δ_1 = Ripple current
- F = Switching frequency
- D = $T_{on} / (T_{off} + T_{on})$
- $V_1 = V_{in} \times N_1/N_3$ $V_3 = V_{in}$
- $V_2 = V_{in} + V_1$
- V_4 = Saturation voltage of the switch
- $V_5 = V_{in} \times N_2/N_1$ $V_6 = V_{in} \times N_2/N_3$

Figure 4 shows the waveforms of the forward converter.

When the switch is off, $V_{as} = V_{in} + (V_{in} \times N_1/N_3)$ during the demagnetization time (T_D) and then, drops to $V_{as} = V_{in}$ as indicated in Figure 4.



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FIGURE 4. Typical Forward Waveforms

Typical Applications (Continued)

With both flyback and forward topologies, it is possible to design an inverting converter by using an external op-amp (Figure 5).

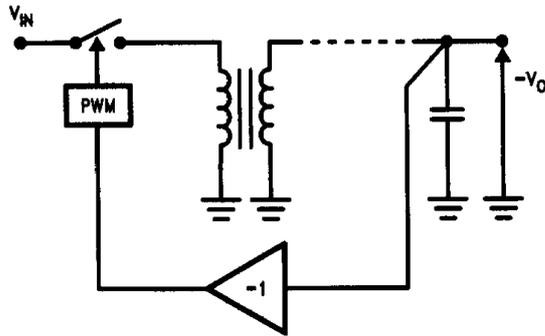


FIGURE 5

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Flyback Step-Up Application

Figure 6 shows flyback converter in a step-up mode where an input voltage of +12V to +30V will be converted into a regulated output voltage of +50V.

Performance Data

Parameter	Conditions	Result
Efficiency	$V_{out} = 50V @ 300\text{ mA}$ $V_{in} = 15V$	82%
Line Regulation	$V_{out} = 50V @ 300\text{ mA}$ $12V \leq V_{in} \leq 30V$	0.2%
Load Regulation	$V_{in} = 15V$ $V_{out} = 50V$ $50\text{ mA} \leq I_{out} \leq 300\text{ mA}$	0.2%

Isolated Flyback Converter

Figure 7 shows an isolated flyback converter using a sense winding for feedback. Although, in practice the line regulation is acceptable, the load regulation can be marginal if the coupling between the windings is poor. However, the sense winding cannot detect any ohmic voltage drop in the main output so, a heavier gauge wire should be used to reduce this regulation error. Also, the sense winding will not sense the non-linear voltage drop across the diode, and this accounts for most of the load regulation inaccuracy. Therefore, the sense winding method is only recommended for applications where load variations are small.

Figure 7 shows an isolated flyback converter with an output of 5V at 2A. The input voltage range is from +10V to +40V. The output can be adjusted to +5V by using the 5 k Ω trimpot.

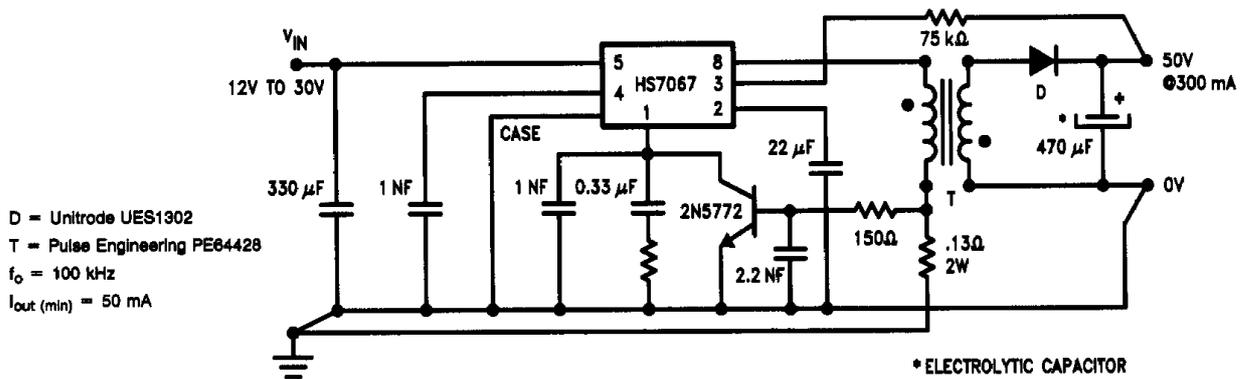
Performance Data

Parameter	Conditions	Result
Efficiency	$V_{out} = 5V @ 2A$ $V_{in} = 30V$	75%
Line Regulation	$V_{out} = 5V @ 2A$ $10V \leq V_{in} \leq 40V$	5%
Load Regulation	$V_{in} = 30V$ $1A \leq I_{out} \leq 2A$	7%

Isolated Forward Converter

As described previously, forward converters exhibit lower output ripple voltage and the opto-coupler feedback scheme provides good regulation as well as input to output isolation.

An opto-coupler feedback is usually difficult to implement because the transfer function of the opto-coupler is non-linear, the current transfer ratio changes with time and temperature and also from one unit to another. Figure 8 shows the circuit diagram of a 5V @ 3A power converter with an input voltage range of +14V to +30V using an isolated forward topology.



D = Unitrode UES1302
T = Pulse Engineering PE64428
 $f_o = 100\text{ kHz}$
 $I_{out (min)} = 50\text{ mA}$

*ELECTROLYTIC CAPACITOR

TL/K/6746-11

A 12V to 60V input Voltage Range is possible by replacing the HS7067 with a HS7107. The converter will operate in a discontinuous mode above 30V with a 300 mA load (the transformer's secondary current drops to zero before the switch turns on) and therefore, may generate more switching noise.

FIGURE 6. Flyback Step-Up Converter

Typical Applications (Continued)

- D₁ = International Rectifier 50SQ060
 - D₂ = 1N4148
 - I_{out (min)} = 1A
 - f_O = 100 kHz
 - T = Transformer made of a core Fenoxcube 1811PA2503B7
 - Primary = 8 turns with 5 strands #29
 - Secondary = 6 turns with 15 strands #30
 - Sense = 25 turns with 1 strand #30
- windings should be interleaved in order to improve the coupling and regulation.

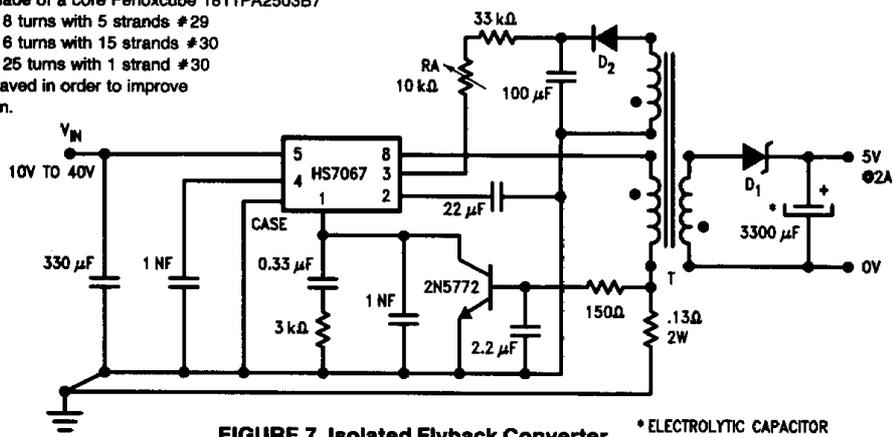


FIGURE 7. Isolated Flyback Converter

* ELECTROLYTIC CAPACITOR

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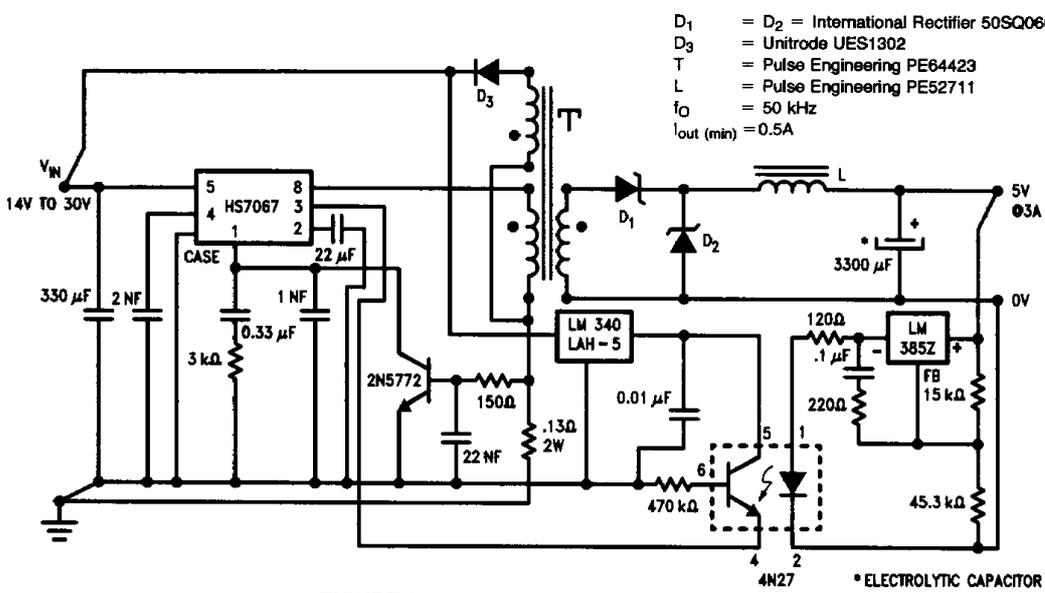
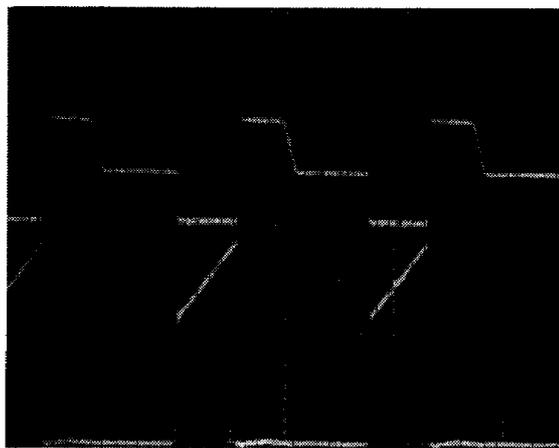


FIGURE 8a. Isolated Forward Converter

* ELECTROLYTIC CAPACITOR

TL/K/6746-13



TL/K/6746-9

Figure 8b shows the typical forward converter waveforms in continuous mode which can be observed using the circuit from Figure 8a. Top waveform is the voltage across the switch (20V/div). Bottom waveform is the current throughout the switch (1A/div). Horizontal Scale = 5 μs/div. V_{in} = 20V; V_{out} = 5V @ 3A.

Figure 8b.

Typical Applications (Continued)

An LM 385z (adjustable reference) is used as a comparator and error amplifier. This reference always wants to maintain 1.2V between pins 1 and 2 and will draw as much current as necessary from the opto-coupler to achieve this. Therefore, the feedback loop is virtually independent of the gain of the opto-coupler.

Performance Data

Parameter	Conditions	Result
Efficiency	$V_{out} = 5V @ 3A$ $V_{in} = 30V$	78%
Line Regulation	$V_{out} = 5V @ 3A$ $14V \leq V_{in} \leq 30V$	0.1%
Load Regulation	$V_{out} = 5V$ $V_{in} = 20V$ $0.5A \leq I_{out} \leq 3A$	0.1%

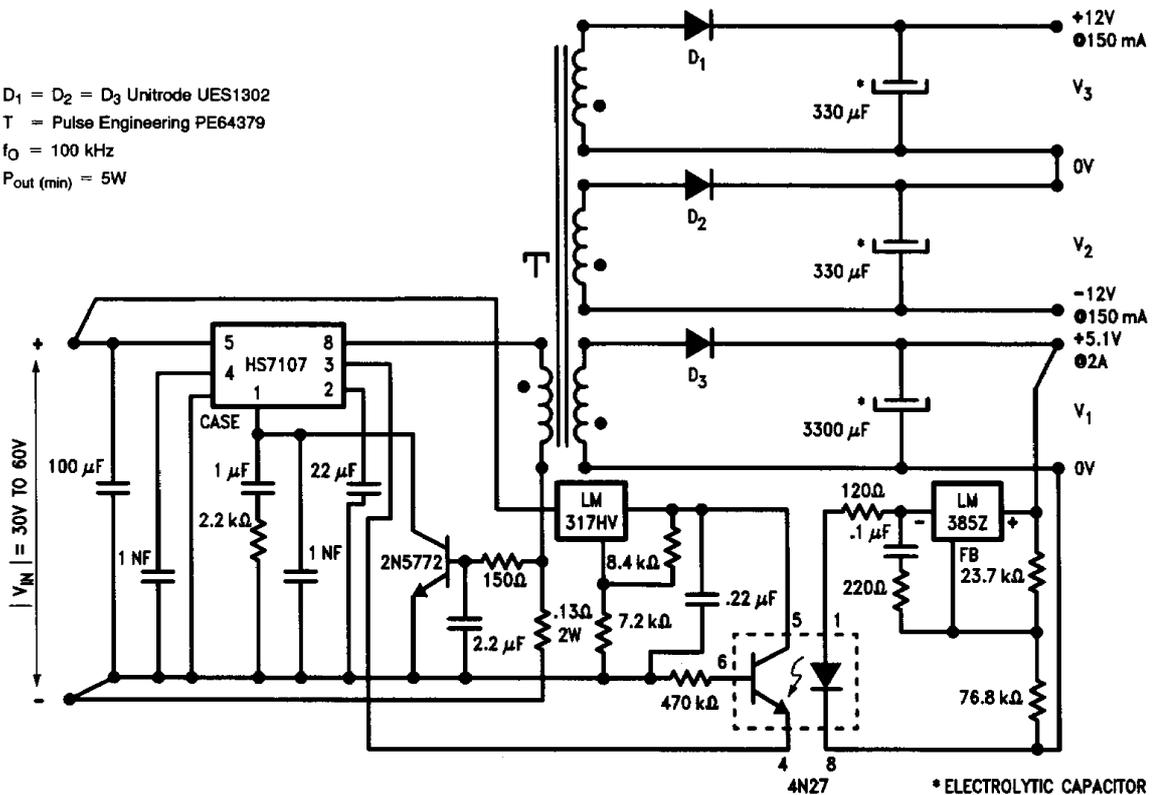
Isolated Telecom Converter

Figure 9 shows an isolated triple output converter which will transform a positive or negative input voltage of 32V to 60V to an uncommitted triple output of +12V, -12V, and 5V, which may be later referenced to the system ground. This converter is ideal for a step down converter of high positive voltage or high negative voltage such as -48V used in telecom circuits.

Performance Data

Parameter	Conditions	Result
Efficiency	$V_1 = 5.1V @ 2A$ $V_2 = -12V @ 150 mA$ $V_3 = 12V @ 100 mA$ $ V_{in} = 48V$	62%
Line Regulation on Main Secondary	$40V \leq V_{in} \leq 60V$ $V_1 = 5.1V @ 2A$ $V_2 = -12V @ 150 mA$ $V_3 = +12V @ 150 mA$	0.8%
Load Regulation on Main Secondary	$ V_{in} = 48V$ $V_1 = 5.1V$ $V_2 = 12V @ 150 mA$ $V_3 = 12V @ 150 mA$ $0.5 \leq I_{out} \leq 2A$	1%
Load Regulation on 12V Secondary for Simultaneous Load Changes	$ V_{in} = 48V$ $V_1 = 5.1V @ 2A$ $V_2 = -12V$ $V_3 = 12V$ $75 mA \leq I_{out} \leq 150 mA$	5%

$D_1 = D_2 = D_3$ Unitorde UES1302
 T = Pulse Engineering PE64379
 $f_0 = 100 kHz$
 $P_{out (min)} = 5W$



Note 10: An input voltage of -10V to -30V may cause the transformer to operate at a higher temperature at full load.

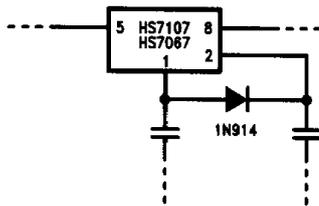
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FIGURE 9. Telecom Flyback Converter

Application Hints

DUTY CYCLE LIMITING

In a flyback converter, the error amplifier sees 0V at the output of the converter during the initial turn-on, and forces the duty cycle to 100% until it sees the output voltage rising to the final value; but no voltage will appear if the switch does not turn off (see flyback principle). The result is that the core will saturate, reducing the effective impedance of the transformer to about 0Ω , and destroying the pass transistor. To prevent this, the duty cycle must be limited to a value at which the core does not saturate. A diode connected between pins 1 and 2 (Figure 10), will limit the duty cycle to about 80%.



TL/K/6746-15

FIGURE 10. Duty Cycle Limiting Circuit

SOFT START

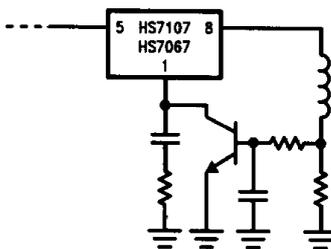
For any converter, connecting a large capacitor (20 to 200 μF) between pin 2 and the case is recommended to allow the reference voltage to slowly reach its final value after start-up. This allows the HS 7067/7107 to start-up smoothly and minimizes the inrush current. The time constant can be calculated by:

$$T = 10^3 \times C$$

It is always a good practice to incorporate soft start and duty cycle limiting when designing a switching power converter, especially when a current limit circuitry is not utilized.

CURRENT LIMIT

The schematic in Figure 11 shows how to protect the pass transistor against excessive current, by sensing the current through a series resistor, and shorting the PWM control voltage at pin 1 to ground, using transistor 2N5772 (this is made possible by the 5 M Ω output impedance of the error amplifier), which will cause the pass transistor to turn off.



TL/K/6746-16

FIGURE 11. Current Limit Circuitry

The sense resistor should be a low inductance type, otherwise the series inductance creates a high impedance at transients and activates the shutdown circuitry. If such a resistor cannot be found, a 0.1 μF capacitor connected in parallel with it will compensate the series inductance.

When such a circuitry is used, the duty cycle limiting diode becomes optional, but the soft start capacitor should still be at least 10 μF .

DECOUPLING AND GROUNDING

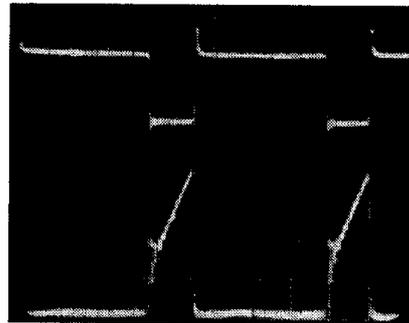
Special attention should be given to the decoupling of the HS 7107/7067 itself at the input (pin 5), where the capacitor must be at least 100 μF and connected as close to the device as possible. Large switching spikes at the input of the pass transistor can cause breakdown of the junction and destroy the device. (See Figure 12.)

The waveform at the top of the picture represents the voltage across the switch of a typical BUCK (step down) converter. When the switch is turned off, the current in the inductor falls to zero (see waveform at the bottom) and a switching spike occurs across the switch. This spike can reach several tens of volts on top of the normally expected voltage across the switch and lead to stress on the device if the overall voltage exceeds the maximum rating.

The picture below shows a spike of about ten volts with a 330 μF capacitor of average quality.

VOLTAGE ACROSS
PIN 5 & PIN 8

CURRENT
THROUGH
SWITCH



VERTICAL SCALE: 20 VOLTS/DIV
HORIZONTAL SCALE: 2 μS /DIV

TL/K/6746-17

FIGURE 12

The reference voltage (pin 2) must be decoupled with at least 10 μF and the compensation network (pin 1) should be decoupled with a ceramic capacitor of 1 nF to 10 nF. Switching noise on the reference voltage pin (pin 2) or on the compensation pin (pin 1) can create different types of oscillations and instabilities.

Because of the high current and high voltage capability of the HS 7107/7067 a single point grounding or, at least a grounding where the force ground is separated from the circuit ground, is highly recommended.

Ordering Information (Transformers and Inductors)

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