DATA SHEET
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PRELIMINARY

CM2596-xx series

3A STEP-DOWN VOLTAGE REGULATOR

REPLACEMENT OF:
LM 2596

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GENERAL DESCRIPTION

The CM2596 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving a 3A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, 12V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation, and a fixed-frequency oscillator.

The CM2596 series operates at a switching frequency of 150 kHz thus allowing smaller sized filter components than what would be needed with lower frequency switching regulators. Available in a standard 5-lead TO-220 package with several different lead bend options, and a 5-lead TO-263 surface mount package.

A standard series of inductors are available from several different manufacturers optimized for use with the CM2596 series. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a guaranteed ±4% tolerance on output voltage under specified input voltage and output load conditions, and ±15% on the oscillator frequency. External shutdown is included, featuring typically 80 μA standby current. Self protection features include a two stage frequency reducing current limit for the output switch and an over temperature shutdown for complete protection under fault conditions.

FEATURES

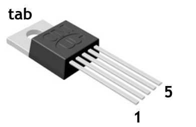
- 3.3V, 5V, 12V, and adjustable output versions
- Adjustable version output voltage range, 1.2V to 37V ±4% max over line and load conditions
- Available in TO-220 and TO-263 packages
- Guaranteed 3A output load current
- Input voltage range up to 40V
- Requires only 4 external components
- Excellent line and load regulation specifications
- 150 kHz fixed frequency internal oscillator
- TTL shutdown capability
- Low power standby mode, I_Q typically 80 μA
- High efficiency
- Uses readily available standard inductors
- Thermal shutdown and current limit protection

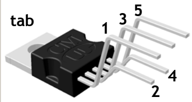
APPLICATIONS

- Simple high-efficiency step-down (buck) regulator
- On-card switching regulators
- Positive to negative converter

PIN DESCRIPTION

CM 2596-xx T CM 2596 T	CM 2596-xx TV CM 2596 TV
TO-220-5	TO-220-5h





IN	OUT	GND	FB	$\overline{ON}$/OFF	GND
1	2	3	4	5	tab

TO-263-5

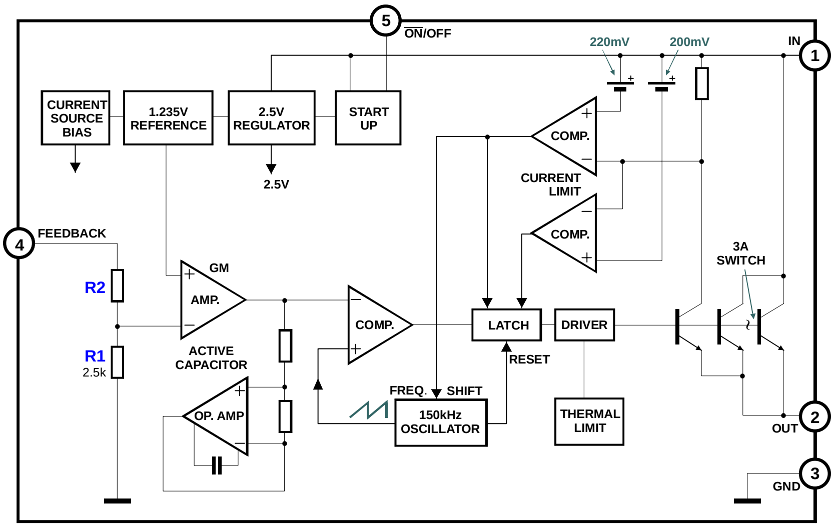
CM 2596-xx S
CM 2596 S

IN	+V_{IN} - this is the positive input supply for the IC switching regulator. A suitable input bypass capacitor must be present at this pin to minimize voltage transients and to supply the switching currents needed by the regulator.
OUT	**OUTPUT** — internal switch. The voltage at this pin switches between (+V_{IN}—V_{SAT}) and approximately -0.5V, with a duty cycle of approximately V_{OUT}/V_{IN}. To minimize coupling to sensitive circuitry, the PC board copper area connected to this pin should be kept to a minimum.
GND	Circuit ground
FB	**FEEDBACK** — senses the regulated output voltage to complete the feedback loop.
$\overline{ON}$/OFF	Allows the switching regulator circuit to be shut down using logic level signals thus dropping the total input supply current to approximately 80µA. Pulling this pin below a threshold voltage of approximately 1.3V turns the regulator on, and pulling this pin above 1.3V (up to a maximum of 25V) shuts the regulator down. If this shutdown feature is not needed, the **$\overline{ON}$/OFF** pin can be wired to the ground pin or it can be left open, in either case the regulator will be in the **ON** condition.

INTERNAL BLOCK DIAGRAM

3.3V ⇨ R2 = 4.2k
5.0V ⇨ R2 = 7.6k
12V ⇨ R2 = 21.8k

ADJ ⇨ R1 = Open
R2 = 0 Ω



ABSOLUTE MAXIMUM RATINGS (NOTE 1)

PARAMETER	VALUE
MAXIMUM SUPPLY VOLTAGE	45V
$\overline{ON}$/OFF PIN INPUT VOLTAGE	-0.3 ≤ V ≤ +25V
FEEDBACK PIN VOLTAGE	-0.3 ≤ V ≤+25V
OUTPUT VOLTAGE TO GROUND (steady state)	-1V
POWER DISSIPATION	Internally limited
STORAGE TEMPERATURE RANGE	-65°C to +150°C
ESD SUSCEPTIBILITY Human Body Model (Note 2)	2 kV
LEAD TEMPERATURE	
TO-220-5	
Vapor Phase (60 Sec.)	+215°C
Infrared (10 Sec.)	+245°C
TO-263-5 (soldering 10 sec.)	+260°C
MAXIMUM JUNCTION TEMPERATURE	+150°C

OPERATING CONDITIONS

PARAMETER	VALUE
TEMPERATURE RANGE	-40°C ≤ T_J ≤ +125°C
SUPPLY VOLTAGE	4.5V to 40V

NOTES:
1. Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.
2. The human body model is a 100 pF capacitor discharged through a 1.5k resistor into each pin.

ELECTRICAL CHARACTERISTICS

SYSTEM PARAMETERS (NOTE 5), TEST CIRCUIT FIGURE 1, 2

CM2596-3.3

SYMBOL	PARAMETER	CONDITIONS	JUNCTION TEMPERATURE (T_J)	LIMITS (NOTES 3, 4) MIN	TYP	MAX	UNIT
V_{OUT}	Output Voltage	$4.75V \le V_{IN} \le 40V$, $0.2A \le I_{LOAD} \le 3A$	25°C	3.168	3.3	3.432	V
			-40°C ÷ +125°C	3.135	–	3.465	
η	Efficiency	V_{IN} =12V, I_{LOAD} =3A	25°C	–	73	–	%

CM2596-5.0

SYMBOL	PARAMETER	CONDITIONS	JUNCTION TEMPERATURE (T_J)	LIMITS (NOTES 3, 4) MIN	TYP	MAX	UNIT
V_{OUT}	Output Voltage	$7.0V \le V_{IN} \le 40V$, $0.2A \le I_{LOAD} \le 3A$	25°C	4.80	5.0	5.20	V
			-40°C ÷ +125°C	4.75	–	5.25	
η	Efficiency	V_{IN} =12V, I_{LOAD} =3A	25°C	–	80	–	%

CM2596-12

SYMBOL	PARAMETER	CONDITIONS	JUNCTION TEMPERATURE (T_J)	LIMITS (NOTES 3, 4) MIN	TYP	MAX	UNIT
V_{OUT}	Output Voltage	$15V \le V_{IN} \le 40V$, $0.2A \le I_{LOAD} \le 3A$	25°C	11.52	12	12.48	V
			-40°C ÷ +125°C	11.40	–	12.60	
η	Efficiency	V_{IN} =12V, V_{OUT} =3V, I_{LOAD} =3A	25°C	–	90	–	%

CM2596-ADJ

SYMBOL	PARAMETER	CONDITIONS	JUNCTION TEMPERATURE (T_J)	LIMITS (NOTES 3, 4) MIN	TYP	MAX	UNIT
V_{OUT}	Output Voltage	V_{OUT} programmed for 3V, $4.5V \le V_{IN} \le 40V$, $0.2A \le I_{LOAD} \le 3A$	25°C	1.193	1.23	1.267	V
			-40°C ÷ +125°C	1.180	–	1.280	
η	Efficiency	V_{IN} =12V, V_{OUT} =3V, I_{LOAD} =3A	25°C	–	73	–	%

ALL OUTPUT VOLTAGE VERSIONS

SPECIFICATIONS WITH STANDARD TYPE FACE ARE FOR T_J = 25°C.
UNLESS OTHERWISE SPECIFIED, V_{IN} = 12V FOR THE 3.3V, 5V, AND ADJUSTABLE VERSION AND V_{IN} = 24V FOR THE 12V VERSION. I_{LOAD} = 500 mA

SYMBOL	PARAMETER	CONDITIONS	JUNCTION TEMPERATURE (T_J)	LIMITS (NOTES 3, 4) MIN	TYP	MAX	UNIT
DEVICE PARAMETERS							
I_B	FEEDBACK BIAS CURRENT	Adjustable Version Only, V_{FB}=1.3V	25°C	–	10	50	nA
			-40°C ÷ +125°C	–	–	100	
F_O	OSCILLATOR FREQUENCY	(NOTE 6)	25°C	127	150	173	kHz
			-40°C ÷ +125°C	110	–	173	
V_{SAT}	SATURATION VOLTAGE	I_{OUT} =3A (NOTES 7, 8)	25°C	–	1.16	1.4	V
			-40°C ÷ +125°C	–	–	1.5	
DC	MAX DUTY CYCLE (ON)	(NOTE 8)	25°C	–	100	–	%
	MIN DUTY CYCLE (OFF)	(NOTE 9)	25°C	–	0	–	
I_{CL}	CURRENT LIMIT	Peak Current (NOTES 7, 8)	25°C	3.6	4.5	6.9	A
			-40°C ÷ +125°C	3.4	–	7.5	
I_L	OUTPUT LEAKAGE CURRENT	OUTPUT = 0V (NOTES 7, 9)	25°C	–	–	50	μA
		OUTPUT = -1V (NOTE 10)		–	2	30	mA
I_Q	QUIESCENT CURRENT	(NOTE 9)		–	5	10	
I_{STBY}	STANDBY QUIESCENT CURRENT	$\overline{ON}$/OFF pin=5V (OFF) (NOTE 10)	25°C	–	80	200	μA
			-40°C ÷ +125°C	–	–	250	
THERMAL RESISTANCE							
θ_{JC}	Junction to Case	TO-220 or TO-263 Package	25°C	–	2	–	^{0}C/W
θ_{JA}	Junction to Ambient	TO-220 Package, (NOTE 11)		–	50	–	
		TO-263 Package, (NOTE 12)		–	50	–	
		TO-263 Package, (NOTE 13)		–	30	–	
		TO-263 Package, (NOTE 14)		–	20	–	
ON/OFF CONTROL (TEST CIRCUIT FIGURE 1)							
V_{IL}	$\overline{ON}$/OFF PIN LOGIC INPUT THRESHOLD VOLTAGE		25°C	–	1.3	–	V
		Low (Regulator ON)	-40°C ÷ +125°C	–	–	0.6	
V_{IH}		High (Regulator OFF)	-40°C ÷ +125°C	2.0	–	–	
I_H	$\overline{ON}$/OFF PIN INPUT CURRENT	V_{LOGIC} =2.5V (Regulator OFF)	25°C	–	5	15	μA
I_L		V_{LOGIC} =0.5V (Regulator ON)		–	0.02	5	

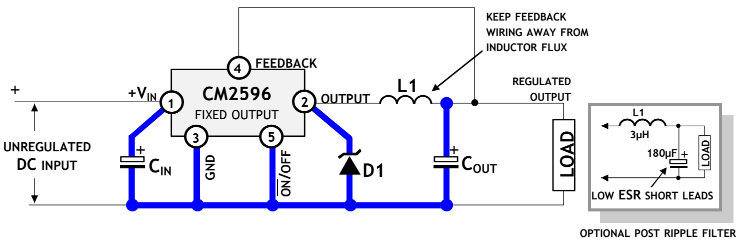
ELECTRICAL CHARACTERISTICS (CONTINUED)

NOTES:

3. Typical numbers are at 25°C and represent the most likely norm.
4. All limits guaranteed at room temperature (standard type face) and at temperature extremes (bold type face). All room temperature limits are 100% production tested. All limits at temperature extremes are guaranteed via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
5. External components such as the catch diode, inductor, input and output capacitors, and voltage programming resistors can affect switching regulator system performance. When the CM2596 is used as shown in the Figure 1 test circuit, system performance will be as shown in system parameters section of Electrical Characteristics.
6. The switching frequency is reduced when the second stage current limit is activated. The amount of reduction is determined by the severity of current overload.
7. No diode, inductor or capacitor connected to output pin.
8. Feedback pin removed from output and connected to 0V to force the output transistor switch ON.
9. Feedback pin removed from output and connected to 12V for the 3.3V, 5V, and the ADJ. version, and 15V for the 12V version, to force the output transistor switch OFF.
10. V_{IN} = 40V.
11. Junction to ambient thermal resistance (no external heat sink) for the TO-220 package mounted vertically, with the leads soldered to a printed circuit board with (1 oz.) copper area of approximately 1 in^2.
12. Junction to ambient thermal resistance with the TO-263 package tab soldered to a single printed circuit board with 0.5 in^2 of (1 oz.) copper area.
13. Junction to ambient thermal resistance with the TO-263 package tab soldered to a single sided printed circuit board with 2.5 in^2 of (1 oz.) copper area.
14. Junction to ambient thermal resistance with the TO-263 package tab soldered to a double sided printed circuit board with 3 in^2 of (1 oz.) copper area on the CM2596S side of the board, and approximately 16 in^2 of copper on the other side of the p-c board. See Application Information in this data sheet.

STANDARD TEST CIRCUITS AND LAYOUT GUIDES

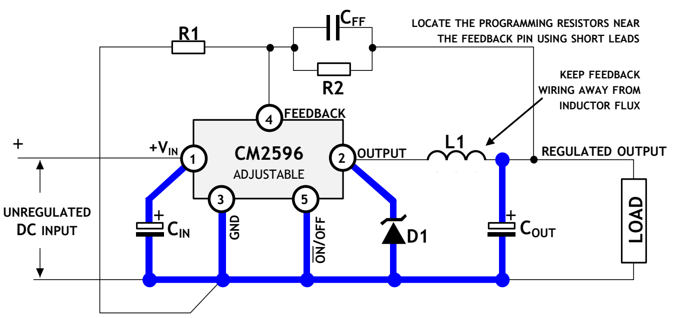
FIGURE 1 FIXED OUTPUT VOLTAGE VERSIONS



HEAVY LINES MUST BE KEPT SHORT AND USE GROUND PLANE CONSTRUCTION FOR BEST RESULTS.

C_{IN} — 470µF, 50V, Aluminum Electrolytic Nichicon «PL Series»
C_{OUT} — 220µF, 25V, Aluminum Electrolytic Nichicon «PL Series»
D1 — 5A, 40V Schottky Rectifer, 1N5825
L1 — 68µH, L38

FIGURE 2 ADJUSTABLE OUTPUT VOLTAGE VERSION



$V_{OUT} = V_{REF}$ (1 + (R2/R1)), were V_{REF} = 1.23V

R2 = R1×((V_{OUT} /V_{REF})-1)

HEAVY LINES MUST BE KEPT SHORT AND USE GROUND PLANE CONSTRUCTION FOR BEST RESULTS.

SELECT R1 TO BE APPROXIMATELY 1kΩ, USE A 1% RESISTOR FOR BEST STABILITY.

C_{IN} — 470µF, 50V, Aluminum Electrolytic Nichicon «PL Series»
C_{OUT} — 220µF, 35V, Aluminum Electrolytic Nichicon «PL Series»
D1 — 5A, 40V Schottky Rectifer, 1N5825
L1 — 68µH, L38
R1 — 1kΩ, 1%
C_{FF} — see Application Information Section

As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance can generate voltage transients which can cause problems. For minimal inductance and ground loops, the wires indicated by heavy lines should be wide printed circuit traces and should be kept as short as possible. For best results, external components should be located as close to the switcher IC as possible using ground plane construction or single point grounding. If open core inductors are used, special care must be taken as to the location and positioning of this type of inductor.

Allowing the inductor flux to intersect sensitive feedback, IC ground path and C_{OUT} wiring can cause problems. When using the adjustable version, special care must be taken as to the location of the feedback resistors and the associated wiring. Physically locate both resistors near the IC, and route the wiring away from the inductor, especially an open core type of inductor. (See application section for more information.)

APPLICATION INFORMATION

EXTERNAL COMPONENTS

INPUT CAPACITOR

C_{IN} — a low ESR aluminum or tantalum bypass capacitor is needed between the input pin and ground pin. It must be located near the regulator using short leads. This capacitor prevents large voltage transients from appearing at the input, and provides the instantaneous current needed each time the switch turns on.

The important parameters for the Input capacitor are the voltage rating and the RMS current rating. Because of the relatively high RMS currents flowing in a buck regulator's input capacitor, this capacitor should be chosen for its RMS current rating rather than its capacitance or voltage ratings, although the capacitance value and voltage rating are directly related to the RMS current rating.

The RMS current rating of a capacitor could be viewed as a capacitor's power rating. The RMS current flowing through the capacitors internal ESR produces power which causes the internal temperature of the capacitor to rise. The RMS current rating of a capacitor is determined by the amount of current required to raise the internal temperature approximately 10°C above an ambient temperature of 105°C. The ability of the capacitor to dissipate this heat to the surrounding air will determine the amount of current the capacitor can safely sustain. Capacitors that are physically large and have a large surface area will typically have higher RMS current ratings. For a given capacitor value, a higher voltage electrolytic capacitor will be physically larger than a lower voltage capacitor, and thus be able to dissipate more heat to the surrounding air, and therefore will have a higher RMS current rating.

The consequences of operating an electrolytic capacitor above the RMS current rating is a shortened operating life. The higher temperature speeds up the evaporation of the capacitor's electrolyte, resulting in eventual failure.

Selecting an input capacitor requires consulting the manufacturers data sheet for maximum allowable RMS ripple current. For a maximum ambient temperature of 40°C, a general guideline would be to select a capacitor with a ripple current rating of approximately 50% of the DC load current. For ambient temperatures up to 70°C, a current rating of 75% of the DC load current would be a good choice for a conservative design. The capacitor voltage rating must be at least 1.25 times greater than the maximum input voltage, and often a much higher voltage capacitor is needed to satisfy the RMS current requirements.

A graph shown in Figure 3 shows the relationship between an electrolytic capacitor value, its voltage rating, and the RMS current it is rated for. These curves were obtained from the Nichicon «PL» series of low ESR, high reliability electrolytic capacitors designed for switching regulator applications. Other capacitor manufacturers offer similar types of capacitors, but always check the capacitor data sheet.

«Standard» electrolytic capacitors typically have much higher ESR numbers, lower RMS current ratings and typically have a shorter operating lifetime. Because of their small size and excellent performance,

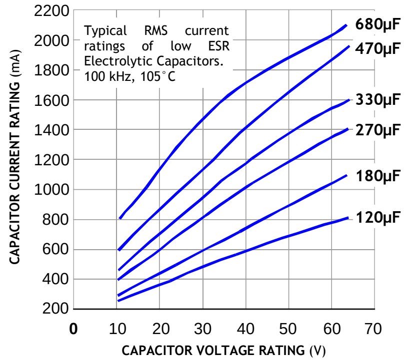


FIGURE 3 RMS CURRENT RATINGS FOR LOW ESR ELECTROLYTIC CAPACITORS (TYPICAL)

surface mount solid tantalum capacitors are often used for input bypassing, but several precautions must be observed. A small percentage of solid tantalum capacitors can short if the inrush current rating is exceeded. This can happen at turn on when the input voltage is suddenly applied, and of course, higher input voltages produce higher inrush currents. Several capacitor manufacturers do a 100% surge current testing on their products to minimize this potential problem. If high turn on currents are expected, it may be necessary to limit this current by adding either some resistance or inductance before the tantalum capacitor, or select a higher voltage capacitor. As with aluminum electrolytic capacitors, the RMS ripple current rating must be sized to the load current.

FEEDFORWARD CAPACITOR

(ADJUSTABLE OUTPUT VOLTAGE VERSION)

C_{FF} — a Feedforward Capacitor **C_{FF}**, shown across R2 in Figure 1 is used when the output voltage is greater than 10V or when **C_{OUT}** has a very low ESR. This capacitor adds lead compensation to the feedback loop and increases the phase margin for better loop stability. For **C_{FF}** selection, see the design procedure section.

OUTPUT CAPACITOR

C_{OUT} — an output capacitor is required to filter the output and provide regulator loop stability. Low impedance or low ESR Electrolytic or solid tantalum capacitors designed for switching regulator applications must be used. When selecting an output capacitor, the important capacitor parameters are: the 100 kHz Equivalent Series Resistance (ESR), the RMS ripple current rating, voltage rating, and capacitance value. For the output capacitor, the ESR value is the most important parameter.

The output capacitor requires an ESR value that has an upper and lower limit. For low output ripple voltage, a low ESR value is needed. This value is determined by the maximum allowable output ripple voltage, typically 1% to 2% of the output voltage. But if the selected capacitor's ESR is extremely low, there is a possibility of an unstable feedback loop, result-

APPLICATION INFORMATION (CONTINUED)

ing in an oscillation at the output. Using the capacitors listed in the tables, or similar types, will provide design solutions under all conditions.

If very low output ripple voltage (less than 15 mV) is required, refer to the section on Output Voltage Ripple and Transients for a post ripple filter.

An aluminum electrolytic capacitor's ESR value is related to the capacitance value and its voltage rating. In most cases, higher voltage electrolytic capacitors have lower ESR values (see Figure 4).

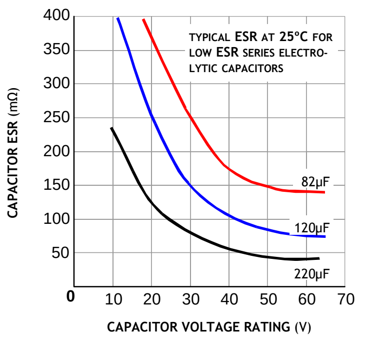


FIGURE 4 CAPACITOR ESR VERSUS CAPACITOR VOLTAGE RATING (TYPICAL LOW ESR ELECTROLYTIC CAPACITOR)

Often, capacitors with much higher voltage ratings may be needed to provide the low ESR values required for low output ripple voltage.

The output capacitor for many different switcher designs often can be satisfied with only three or four different capacitor values and several different voltage ratings.

Electrolytic capacitors are not recommended for temperatures below −25°C. The ESR rises dramatically at cold temperatures and typically rises 3X at −25°C and as much as 10X at −40°C. See curve shown in Figure 5.

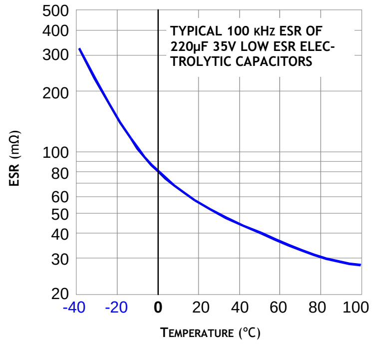


FIGURE 5 CAPACITOR ESR CHANGE VERSUS TEMPERATURE

Solid tantalum capacitors have a much better ESR spec for cold temperatures and are recommended for temperatures below −25°C.

CATCH DIODE

Buck regulators require a diode to provide a return path for the inductor current when the switch turns off. This must be a fast diode and must be located close to the CM2596 using short leads and short printed circuit traces. Because of their very fast switching speed and low forward voltage drop, Schottky diodes provide the best performance, especially in low output voltage applications (5V and lower).

Ultra-fast recovery, or High-Efficiency rectifiers are also a good choice, but some types with an abrupt turnoff characteristic may cause instability or EMI problems. Ultra-fast recovery diodes typically have reverse recovery times of 50 ns or less. Rectifiers such as the 1N5400 series are much too slow and should not be used.

INDUCTOR SELECTION

All switching regulators have two basic modes of operation, continuous and discontinuous. The difference between the two types relates to the inductor current, whether it is flowing continuously, or if it drops to zero for a period of time in the normal switching cycle. Each mode has distinctively different operating characteristics, which can affect the regulators performance and requirements. Most switcher designs will operate in the discontinuous mode when the load current is low.

The CM2596 (or any of the Simple Switcher family) can be used for both continuous or discontinuous modes of operation.

In many cases the preferred mode of operation is the continuous mode. It offers greater output power, lower peak switch, inductor and diode currents, and can have lower output ripple voltage. But it does require larger inductor values to keep the inductor current flowing continuously, especially at low output load currents and/or high input voltages.

When the regulator operates in the continuous mode, an inductor selected will allow a peak-to-peak inductor ripple current to be a certain percentage of the maximum load current. This peak-to-peak inductor ripple current percentage is not fixed, but is allowed to change as different design load currents are selected (see Figure 6).

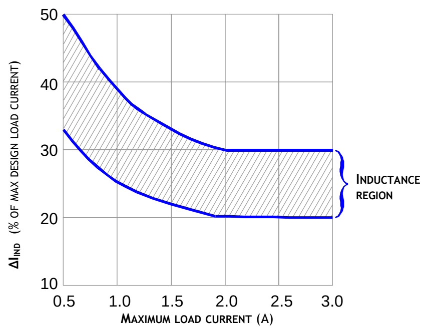


FIGURE 6 PEAK-TO PEAK INDUCTOR RIPPLE CURRENT VERSUS LOAD CURRENT

APPLICATION INFORMATION (CONTINUED)

By allowing the percentage of inductor ripple current to increase for low load currents, the inductor value and size can be kept relatively low.

When operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage), with the average value of this current waveform equal to the DC output load current.

Inductors are available in different styles such as pot core, toroid, E-core, bobbin core, etc., as well as different core materials, such as ferrites and powdered iron. The least expensive, the bobbin, rod or stick core, consists of wire wound on a ferrite bobbin. This type of construction makes for an inexpensive inductor, but since the magnetic flux is not completely contained within the core, it generates more Electro-Magnetic Interference (EMI). This magnetic flux can induce voltages into nearby printed circuit traces, thus causing problems with both the switching regulator operation and nearby sensitive circuitry, and can give incorrect scope readings because of induced voltages in the scope probe. Also see section on Open Core Inductors.

When multiple switching regulators are located on the same PC board, open core magnetics can cause interference between two or more of the regulator circuits, especially at high currents. A toroid or E-core inductor (closed magnetic structure) should be used in these situations.

The inductors listed in the selection chart include ferrite E-core construction for Schott, ferrite bobbin core for Renco and Coilcraft, and powdered iron toroid for Pulse Engineering.

Exceeding an inductor's maximum current rating may cause the inductor to overheat because of the copper wire losses, or the core may saturate. If the inductor begins to saturate, the inductance decreases rapidly and the inductor begins to look mainly resistive (the DC resistance of the winding). This can cause the switch current to rise very rapidly and force the switch into a cycle-by-cycle current limit, thus reducing the DC output load current. This can also result in overheating of the inductor and/or the CM2596. Different inductor types have different saturation characteristics, and this should be kept in mind when selecting an inductor.

The inductor manufacturer's data sheets include current and energy limits to avoid inductor saturation.

DISCONTINUOUS MODE OPERATION

The selection guide chooses inductor values suitable for continuous mode operation, but for low current applications and/or high input voltages, a discontinuous mode design may be a better choice. It would use an inductor that would be physically smaller, and would need only one half to one third the inductance value needed for a continuous mode design.

The peak switch and inductor currents will be higher in a discontinuous design, but at these low load currents (1A and below), the maximum switch current will still be less than the switch current limit.

Discontinuous operation can have voltage waveforms that are considerable different than a continuous design. The output pin (switch) waveform can have some damped sinusoidal ringing present. This ringing is normal for discontinuous operation, and is not caused by feedback loop instabilities. In discontinuous operation, there is a period of time where neither the switch or the diode are conducting, and the inductor current has dropped to zero. During this time, a small amount of energy can circulate between the inductor and the switch/diode parasitic capacitance causing this characteristic ringing.

Normally this ringing is not a problem, unless the amplitude becomes great enough to exceed the input voltage, and even then, there is very little energy present to cause damage.

Different inductor types and/or core materials produce different amounts of this characteristic ringing. Ferrite core inductors have very little core loss and therefore produce the most ringing. The higher core loss of powdered iron inductors produce less ringing. If desired, a series RC could be placed in parallel with the inductor to dampen the ringing.

The computer aided design software Switchers Made Simple (version 4.3) will provide all component values for continuous and discontinuous modes of operation.

OUTPUT VOLTAGE RIPPLE AND TRANSIENTS

The output voltage of a switching power supply operating in the continuous mode will contain a sawtooth ripple voltage at the switcher frequency, and may also contain short voltage spikes at the peaks of the sawtooth waveform.

The output ripple voltage is a function of the inductor sawtooth ripple current and the ESR of the output capacitor. A typical output ripple voltage can range from approximately 0.5% to 3% of the output voltage. To obtain low ripple voltage, the ESR of the output capacitor must be low, however, caution must be exercised when using extremely low ESR capacitors because they can affect the loop stability, resulting in oscillation problems. If very low output ripple voltage is needed (less than 20 mV), a post ripple filter is recommended (see Figure 1). The inductance required is typically between 1 μH and 5 μH, with low DC resistance, to maintain good load regulation. A low ESR output filter capacitor is also required to assure good dynamic load response

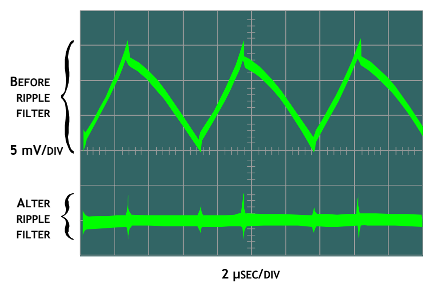


FIGURE 7 POST RIPPLE FILTER WAVEFORM

APPLICATION INFORMATION (CONTINUED)

and ripple reduction. The ESR of this capacitor may be as low as desired, because it is out of the regulator feedback loop. The photo shown in Figure 7 shows a typical output ripple voltage, with and without a post ripple filter.

When observing output ripple with a scope, it is essential that a short, low inductance scope probe ground connection be used. Most scope probe manufacturers provide a special probe terminator which is soldered onto the regulator board, preferable at the output capacitor. This provides a very short scope ground thus eliminating the problems associated with the 3 inch ground lead normally provided with the probe, and provides a much cleaner and more accurate picture of the ripple voltage waveform.

The voltage spikes are caused by the fast switching action of the output switch and the diode, and the parasitic inductance of the output filter capacitor, and its associated wiring. To minimize these voltage spikes, the output capacitor should be designed for switching regulator applications, and the lead lengths must be kept very short. Wiring inductance, stray capacitance, as well as the scope probe used to evaluate these transients, all contribute to the amplitude of these spikes.

When a switching regulator is operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage). For a given input and output voltage, the peak-to-peak amplitude of this inductor current waveform remains constant. As the load current increases or decreases, the entire sawtooth current waveform also rises and falls. The average value (or the center) of this current waveform is equal to the DC load current.

If the load current drops to a low enough level, the bottom of the sawtooth current waveform will reach zero, and the switcher will smoothly change from a continuous to a discontinuous mode of operation. Most switcher designs (irregardless how large the inductor value is) will be forced to run discontinuous if the output is lightly loaded. This is a perfectly acceptable mode of operation.

In a switching regulator design, knowing the value of the peak-to-peak inductor ripple current (ΔI_{IND}) can be useful for determining a number of other circuit parameters. Parameters such as, peak inductor or peak switch current, minimum load current

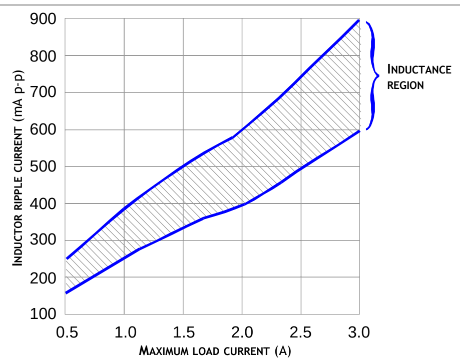


FIGURE 8 PEAK-TO-PEAK INDUCTOR RIPPLE CURRENT VERSUS LOAD CURRENT

before the circuit becomes discontinuous, output ripple voltage and output capacitor ESR can all be calculated from the peak-to-peak ΔI_{IND}. The curve shown in Figure 8 shows the range of (ΔI_{IND}) that can be expected for different load currents. The curve also shows how the peak-to-peak inductor ripple current (ΔI_{IND}) changes as you go from the lower border to the upper border (for a given load current) within an inductance region. The upper border represents a higher input voltage, while the lower border represents a lower input voltage. These curves are only correct for continuous mode of operation, and only if the inductor values are properly selected.

OPEN CORE INDUCTORS

Another possible source of increased output ripple voltage or unstable operation is from an open core inductor. Ferrite bobbin or stick inductors have magnetic lines of flux flowing through the air from one end of the bobbin to the other end.

These magnetic lines of flux will induce a voltage into any wire or PC board copper trace that comes within the inductor's magnetic field. The strength of the magnetic field, the orientation and location of the PC copper trace to the magnetic field, and the distance between the copper trace and the inductor, determine the amount of voltage generated in the copper trace. Another way of looking at this inductive coupling is to consider the PC board copper trace as one turn of a transformer (secondary) with the inductor winding as the primary. Many millivolts can be generated in a copper trace located near an open core inductor which can cause stability problems or high output ripple voltage problems.

If unstable operation is seen, and an open core inductor is used, it's possible that the location of the inductor with respect to other PC traces may be the problem. To determine if this is the problem, temporarily raise the inductor away from the board by several inches and then check circuit operation.

If the circuit now operates correctly, then the magnetic flux from the open core inductor is causing the problem.

Substituting a closed core inductor such as a torroid or E-core will correct the problem, or re-arranging the PC layout may be necessary. Magnetic flux cutting the IC device ground trace, feedback trace, or the positive or negative traces of the output capacitor should be minimized.

Sometimes, locating a trace directly beneath a bobbin inductor will provide good results, provided it is exactly in the center of the inductor (because the induced voltages cancel themselves out), but if it is off center one direction or the other, then problems could arise. If flux problems are present, even the direction of the inductor winding can make a difference in some circuits.

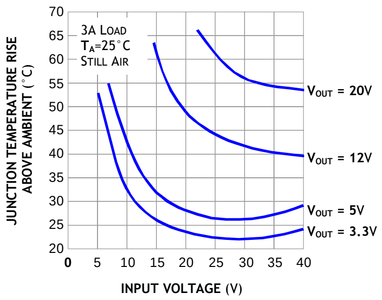
This discussion on open core inductors is not to frighten the user, but to alert the user on what kind of problems to watch out for when using them. Open core bobbin or «stick» inductors are an inexpensive, simple way of making a compact efficient inductor, and they are used by the millions in many different applications.

APPLICATION INFORMATION (CONTINUED)

THERMAL CONSIDERATIONS

The CM2596 is available in two packages, a 5-pin TO-220 (T) and a 5-pin surface mount TO-263 (S).

The TO-220 package needs a heat sink under most conditions. The size of the heatsink depends on the input voltage, the output voltage, the load current and the ambient temperature. The curves in Figure 9 show the CM2596T junction temperature rises above ambient temperature for a 3A load and different input and output voltages. The data for these curves was taken with the CM2596T (TO-220 package) operating as a buck switching regulator in an ambient temperature of 25°C (still air). These temperature rise numbers are all approximate and there are many factors that can affect these temperatures. Higher ambient temperatures require more heat sinking.



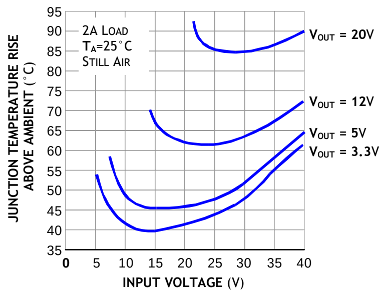
CIRCUIT DATA FOR TEMPERATURE RISE CURVE TO-220 PACKAGE (T)	
CAPACITOR	THROUGH HOLE ELECTROLYTIC
INDUCTOR	THROUGH HOLE, RENCO
DIODE	THROUGH HOLE, 5A 40V, SCHOTTKY
PC BOARD	3 SQUARE INCHES SINGLE SIDED 2 OZ. COOPER (0.0028")

FIGURE 9 JUNCTION TEMPERATURE RISE, TO-220

The TO-263 surface mount package tab is designed to be soldered to the copper on a printed circuit board. The copper and the board are the heat sink for this package and the other heat producing components, such as the catch diode and inductor. The PC board copper area that the package is soldered to should be at least 0.4 in2, and ideally should have 2 or more square inches of 2 oz. (0.0028) in) copper.

Additional copper area improves the thermal characteristics, but with copper areas greater than approximately 6 in2, only small improvements in heat dissipation are realized. If further thermal improvements are needed, double sided, multilayer PC board with large copper areas and/or airflow are recommended.

The curves shown in Figure 10 show the CM2596S (TO-263 package) junction temperature rise above ambient temperature with a 2A load for various input and output voltages. This data was taken with the circuit operating as a buck switching regulator with all components mounted on a PC board to simulate the junction temperature under actual operating conditions. This curve can be used for a quick check for the approximate junction temperature for various conditions, but be aware that there are many factors that can affect the junction temperature. When load currents higher than 2A are used, double sided or multilayer PC boards with large copper areas and/or airflow might be needed, especially for high ambient temperatures and high output voltages.



CIRCUIT DATA FOR TEMPERATURE RISE CURVE TO-263 PACKAGE (S)	
CAPACITOR	SURFACE MOUNT TANTALUM, MOLDED «D» SIZE
INDUCTOR	SURFACE MOUNT, PULSE ENGINEERING, 68µH
DIODE	SURFACE MOUNT, 5A 40V, SCHOTTKY
PC BOARD	9 SQUARE INCHES SINGLE SIDED 2 OZ. COOPER (0.0028")

FIGURE 10 JUNCTION TEMPERATURE RISE, TO-263

For the best thermal performance, wide copper traces and generous amounts of printed circuit board copper should be used in the board layout. (One exception to this is the output (switch) pin, which should not have large areas of copper.) Large areas of copper provide the best transfer of heat (lower thermal resistance) to the surrounding air, and moving air lowers the thermal resistance even further.

Package thermal resistance and junction temperature rise numbers are all approximate, and there are many factors that will affect these numbers. Some of these factors include board size, shape, thickness, position, location, and even board temperature. Other factors are, trace width, total printed circuit copper area, copper thickness, single- or double-sided, multilayer board and the amount of solder on the board. The effectiveness of the PC board to dissipate heat also depends on the size, quantity and spacing of other components on the board, as well as whether the surrounding air is still or moving. Furthermore, some of these components such as the catch diode will add heat to the PC board and the heat can vary as the input voltage changes. For the inductor, depending on the physical size, type of core material and the DC resistance, it could either act as a heat sink taking heat away from the board, or it could add heat to the board.

DELAYED STARTUP

The circuit in Figure 11 uses the the ON/$\overline{OFF}$ pin to provide a time delay between the time the input

APPLICATION INFORMATION (CONTINUED)

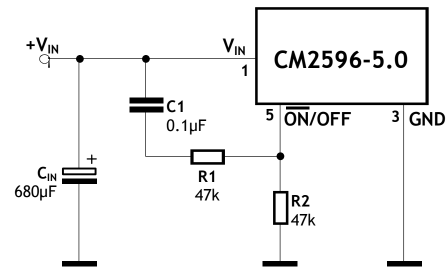


FIGURE 11 DELAYED STARTUP

voltage is applied and the time the output voltage comes up (only the circuitry pertaining to the delayed start up is shown). As the input voltage rises, the charging of capacitor C1 pulls the ON/OFF pin high, keeping the regulator off. Once the input voltage reaches its final value and the capacitor stops charging, and resistor R2 pulls the ON/OFF pin low, thus allowing the circuit to start switching. Resistor R1 is included to limit the maximum voltage applied to the ON/OFF pin (maximum of 25V), reduces power supply noise sensitivity, and also limits the capacitor, C1, discharge current. When high input ripple voltage exists, avoid long delay time, because this ripple can be coupled into the ON/OFF pin and cause problems.

This delayed startup feature is useful in situations where the input power source is limited in the amount of current it can deliver. It allows the input voltage to rise to a higher voltage before the regulator starts operating. Buck regulators require less input current at higher input voltages.

UNDERVOLTAGE LOCKOUT

Some applications require the regulator to remain off until the input voltage reaches a predetermined voltage. An undervoltage lockout feature applied to a buck regulator is shown in Figure 12, while Figure 13 and 14 applies the same feature to an inverting circuit. The circuit in Figure 13 features a constant threshold voltage for turn on and turn off (zener voltage plus approximately one volt). If hysteresis is

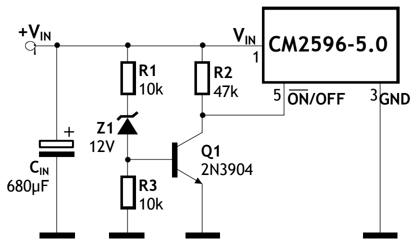
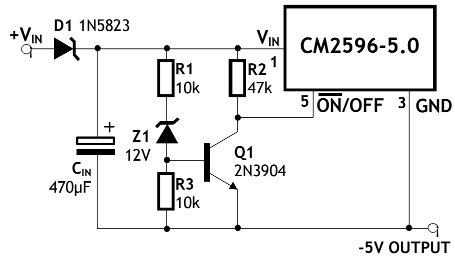


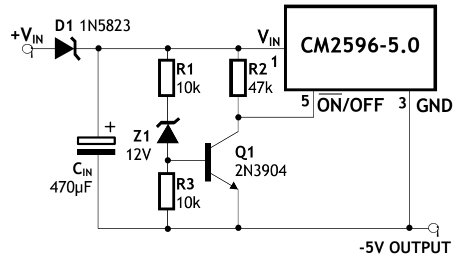
FIGURE 12 UNDERVOLTAGE LOCKOUT FOR BUCK REGULATOR



This circuit has an ON/OFF threshold of approximately 13V.

FIGURE 13 UNDERVOLTAGE LOCKOUT FOR INVERTING REGULATOR

needed, the circuit in Figure 14 has a turn ON voltage which is different than the turn OFF voltage. The amount of hysteresis is approximately equal to the value of the output voltage.



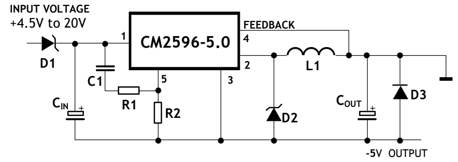
THIS CIRCUIT HAS HYSTERESIS
REGULATOR STARTS SWITCHING AT V_{IN} = 13V
REGULATOR STOPS SWITCHING AT V_{IN} = 8V

FIGURE 14 UNDERVOLTAGE LOCKOUT WITH HYSTERESIS FOR INVERTING REGULATOR

If zener voltages greater than 25V are used, an additional 47 kΩ resistor is needed from the ON/OFF pin to the ground pin to stay within the 25V maximum limit of the ON/OFF pin.

INVERTING REGULATOR

The circuit in Figure 15 converts a positive input voltage to a negative output voltage with a common ground. The circuit operates by bootstrapping the regulator's ground pin to the negative output voltage, then grounding the feedback pin, the regulator senses the inverted output voltage and regulates it.



C_{IN} = 470µF × 50V
C_{OUT} = 220µF × 25V
C1 = 0.1µF
R1 = 47 k
R2 = 47 k
D1 = 1N5823
D2 = 1N5825
D3 = 1N5400
L1 = 33 µH

FIGURE 15 INVERTING -5V REGULATOR WITH DELAYED STARTUP

APPLICATION INFORMATION (CONTINUED)

This example uses the CM2596-5.0 to generate a -5V output, but other output voltages are possible by selecting other output voltage versions, including the adjustable version. Since this regulator topology can produce an output voltage that is either greater than or less than the input voltage, the maximum output current greatly depends on both the input and output voltage. The curve shown in Figure 16 provides a guide as to the amount of output load current possible for the different input and output

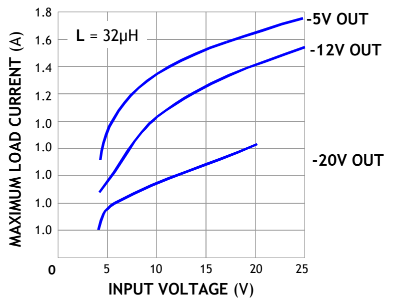


FIGURE 16 INVERTING REGULATOR TYPICAL LOAD CURRENT

voltage conditions. The maximum voltage appearing across the regulator is the absolute sum of the input and output voltage, and this must be limited to a maximum of 40V. For example, when converting +20V to -12V, the regulator would see 32V between the input pin and ground pin. The CM2596 has a maximum input voltage spec of 40V.

Additional diodes are required in this regulator configuration.

Diode D1 is used to isolate input voltage ripple or noise from coupling through the C_{IN} capacitor to the output, under light or no load conditions. Also, this diode isolation changes the topology to closley resemble a buck configuration thus providing good closed loop stability. A Schottky diode is recommended for low input voltages, (because of its lower voltage drop) but for higher input voltages, a fast recovery diode could be used.

Without diode D3, when the input voltage is first applied, the charging current of C_{IN} can pull the output positive by several volts for a short period of time. Adding D3 prevents the output from going positive by more than a diode voltage.

Because of differences in the operation of the inverting regulator, the standard design procedure is not used to select the inductor value. In the majority of designs, a 33 µH, 3.5A inductor is the best choice. Capacitor selection can also be narrowed down to just a few values.

Using the values shown in Figure 15 will provide good results in the majority of inverting designs. This type of inverting regulator can require relatively large amounts of input current when starting up, even with light loads. Input currents as high as the CM2596 current limit (approx 4.5A) are needed for at least 2 ms or more, until the output reaches its nominal output voltage. The actual time depends on the output voltage and the size of the output capacitor. Input power sources that are current limited or sources that can not deliver these currents without getting loaded down, may not work correctly. Because of the relatively high startup currents required by the inverting topology, the delayed startup feature (C1, R1 and R2) shown in Figure 15 is recommended. By delaying the regulator startup, the input capacitor is allowed to charge up to a higher voltage before the switcher begins operating. A portion of the high input current needed for startup is now supplied by the input capacitor (C_{IN}). For severe start up conditions, the input capacitor can be made much larger than normal.

INVERTING REGULATOR SHUTDOWN METHODS

To use the $\overline{ON}$/OFF pin in a standard buck configuration is simple, pull it below 1.3V (at 25°C, referenced to ground) to turn regulator ON, pull it above 1.3V to shut the regulator OFF. With the inverting configuration, some level shifting is required, because the ground pin of the regulator is no longer at ground, but is now setting at the negative output voltage level. Two different shutdown methods for inverting regulators are shown in Figure 17 and 18.

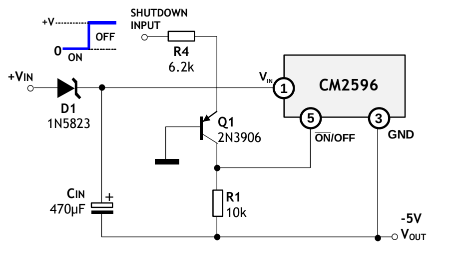


FIGURE 17 INVERTING REGULATOR GROUND REFERENCED SHUTDOWN

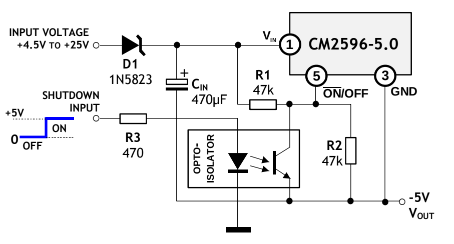
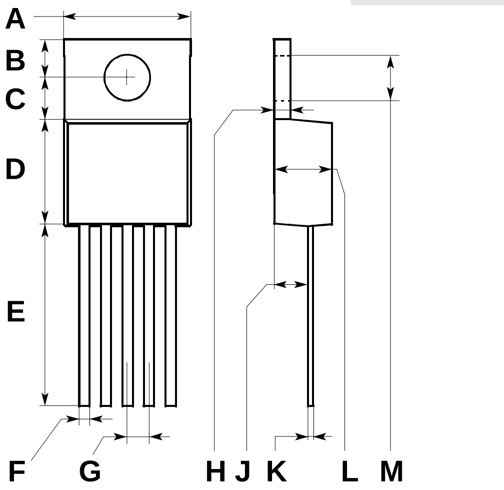


FIGURE 18 INVERTING REGULATOR GROUND REFERENCED SHUTDOWN USING OPTO DEVICE

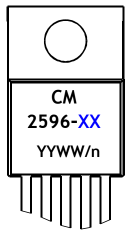
PHYSICAL DIMENSIONS AND MARKING DIAGRAM

TO-220-5



	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	9.85	10.15	0.388	0.400
B	2.59	2.89	0.102	0.114
C	3.56		0.140	
D	8.20	8.60	0.323	0.339
E	13.50	13.90	0.531	0.547
F	0.71	0.91	0.028	0.036
G	1.70		0.067	
H	1.17	1.37	0.046	0.054
J	2.52	2.82	0.099	0.111
K	0.31	0.53	0.012	0.021
L	4.47	4.67	0.176	0.184
M	3.79	3.89	0.149	0.153

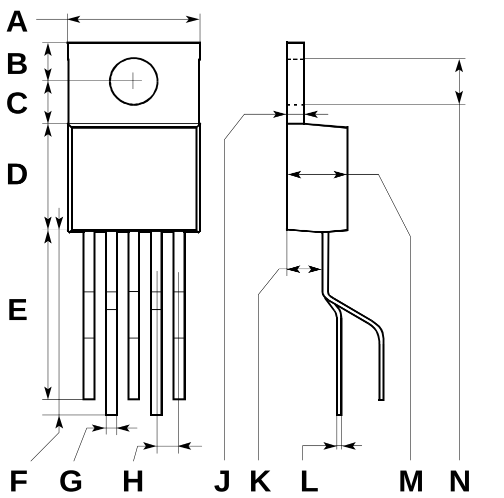
TO-220 (5 leads)



XX – see page 14, table «Ordering Information»

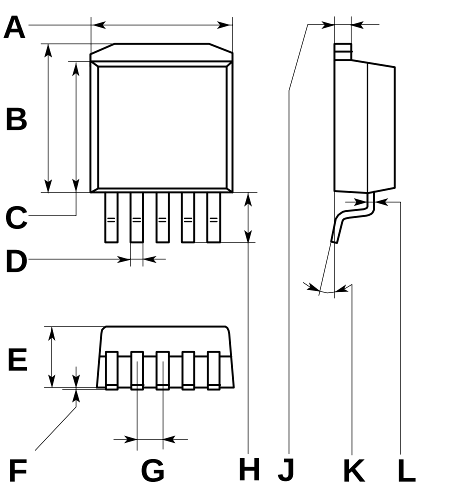
YY – Year
WW – Work Week
n – assembly location

TO-220-5h



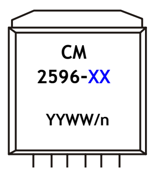
	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	10.01	10.31	0.394	0.406
B	2.59	2.89	0.102	0.114
C	3.56		0.140	
D	8.90	9.30	0.350	0.366
E	8.95	9.25	0.352	0.364
F	9.75	10.05	0.384	0.395
G	0.71	0.91	0.028	0.036
H	1.70		0.067	
J	1.17	1.37	0.046	0.054
K	2.52	2.82	0.099	0.111
L	0.31	0.53	0.012	0.021
M	4.47	4.67	0.176	0.184
N	3.79	3.89	0.149	0.153

TO-263-5



	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	10.01	10.31	0.394	0.406
B	9.76	10.36	0.384	0.408
C	8.20	8.60	0.323	0.339
D	0.71	0.91	0.028	0.036
E	4.47	4.67	0.176	0.184
F	0	0.15	0	0.006
G	1.70		0.067	
H	5.08	5.48	0.200	0.216
J	1.17	1.37	0.046	0.054
K	0°	3°	0°	3°
L	0.31	0.53	0.012	0.021

TO-263 (5 leads)



XX – see page 14, table «Ordering Information»

YY – Year
WW – Work Week
n – assembly location

ORDERING INFORMATION

ORDERING NUMBER	OUTPUT VOLTAGE	PACKAGE	OPERATING TEMPERATURE	SHIPPING
CM2596 T	Adjustable	TO-220-5	0ºC to +70°C	50 pcs/Tube
CM2596- **33** T	3.3V			
CM2596- **50** T	5.0V			
CM2596- **12** T	12.0V			
CM2596 TV	Adjustable	TO-220-5h		
CM2596- **33** TV	3.3V			
CM2596- **50** TV	5.0V			
CM2596- **12** TV	12.0V			
CM2596 S	Adjustable	TO-263-5		50 pcs/Tube 50 pcs/Rail 800 pcs/Reel
CM2596- **33** S	3.3V			
CM2596- **50** S	5.0V			
CM2596- **12** S	12.0V			

NOTE: The form of packing is stipulated in the contract.

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