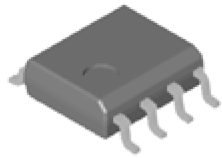
RED2501

LED Controller for LLC converters

Features

- Advanced LED Controller IC for high efficiency low-cost LLC converters with bipolar transistors and integrated PFC
- PSR - +/-5% Primary Side Regulation of LED current and voltage with no Flicker
- 50% duty cycle, variable frequency control of resonant half-bridge
- Automatic dead-time control and capacitive mode protection
- Protection modes:
  - Overload
  - No-Load
  - Over-temperature
  - Control Loop Fault protection
- Low output capacitance allows live LED connection
- Very low output current ripple <5%
- Small SO8 IC package



SO8

Applications

- Single stage PFC LED drivers without flicker
- CC or CV LED drivers 5-40W

Order code

Part Number	Package	Packaging
RED2501AD-TR13	SO8	Tape and reel

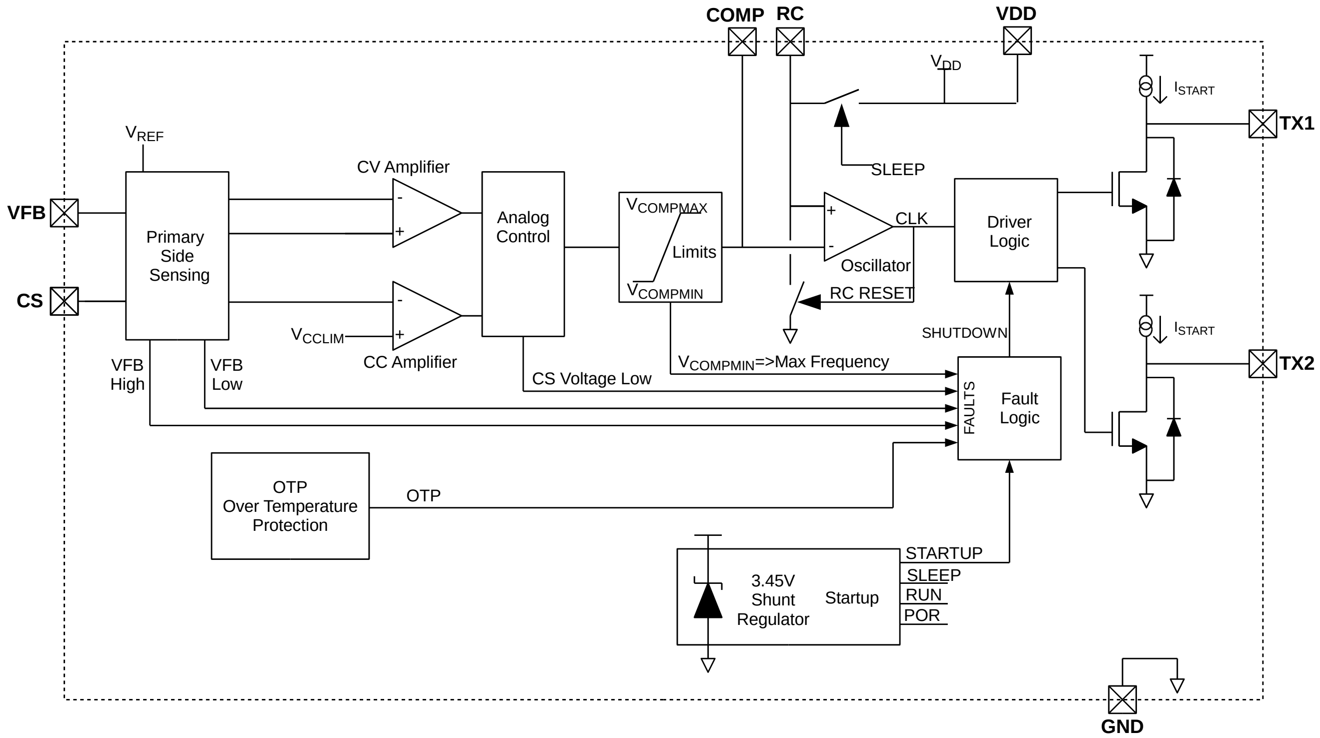


Figure 1: Block diagram

Device Pins

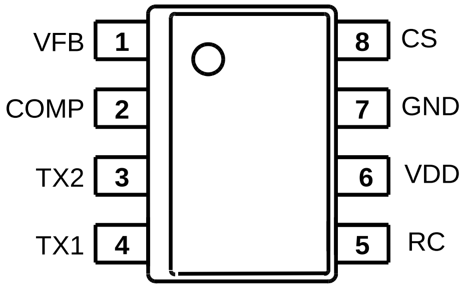


Figure 2: SO8 pin connections (top view)

Pin Functions

Pin #	Name	Function
1	VFB	PSR Feedback input for output voltage regulation. Connect to primary sense winding.
2	COMP	Buffered output of the control amplifiers. A loop compensation network connected between this pin and the VFB input defines CV mode loop response.
3	TX2	Output to control transformer.
4	TX1	Output to control transformer.
5	RC	External RC network sets the minimum [full power] switching frequency.
6	VDD	IC Power Supply pin – nominally 3.45V
7	GND	Chip ground.
8	CS	PSR Current Sense input provides output current regulation and cycle-by-cycle over-current protection. The CS pin is connected to the half-bridge current sense resistor

Typical Application

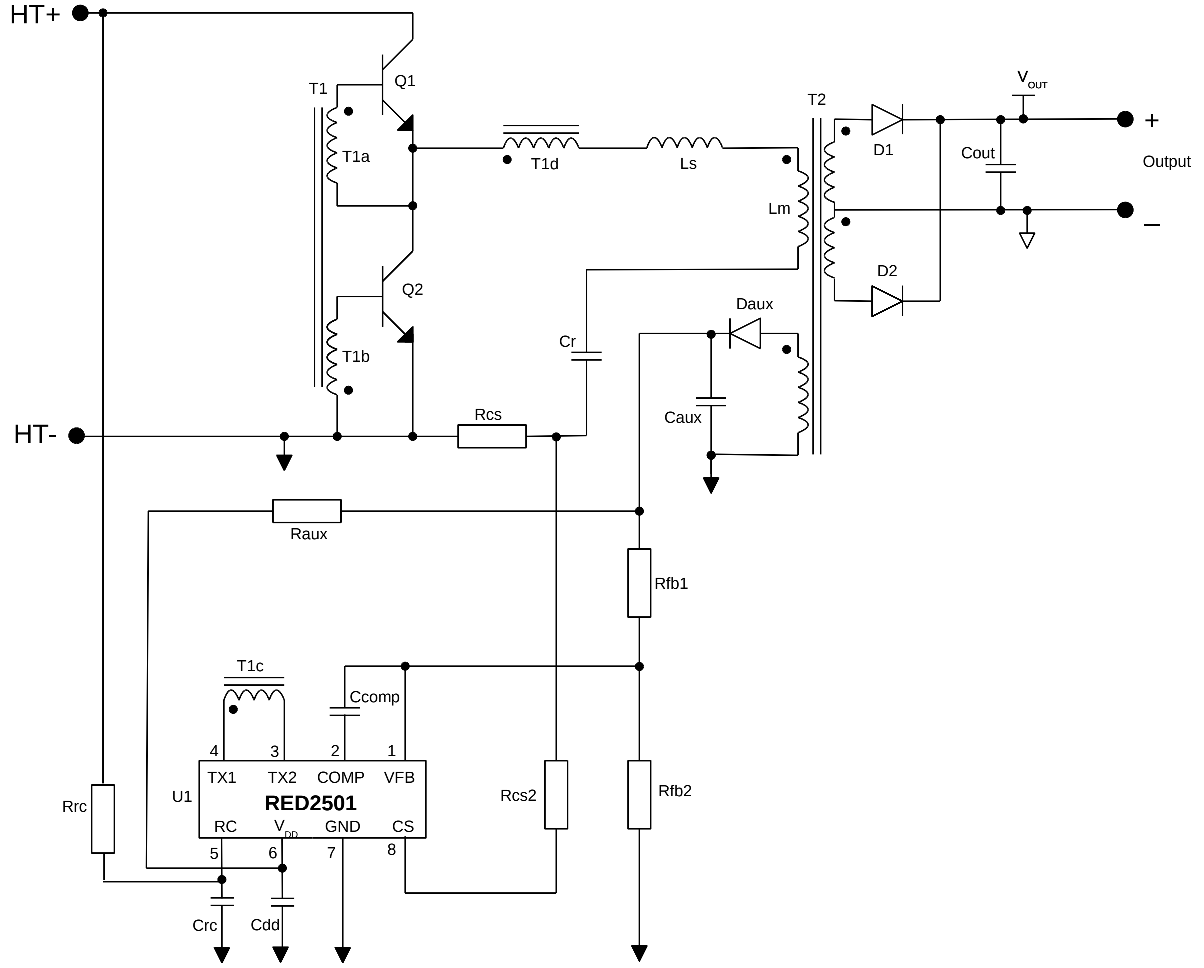


Figure 3: Typical Application Schematic: LLC converter with RED2501 PSR controller

Features

RED2501 is an advanced CMOS control IC for resonant LLC converters. The RED2501 Primary Side Regulation (PSR) control scheme accurately controls the LED current and removes the need for secondary side opto-coupler feedback, reducing cost and complexity.

RED2501 uses the CSOC (Controlled Self-Oscillating Converter) scheme to drive two low-cost bipolar transistors in a half-bridge configuration. RED2501 is optimized to work with RediSem's LLC converter topology with integrated Power Factor Correction.

Please contact RediSem for application design information for LED drivers with PFC.

Accurate Primary Side Regulation

The RED2501 PSR scheme regulates the LED drive current by modulating the converter frequency. Primary side current control enables +/-5% LED current regulation. With the LED disconnected, the RED2501 controls the maximum output voltage and enters fault-mode operation to keep the output voltage from rising and to keep the power consumption low.

Protection Features

There are 5 faults that can cause the IC to enter fault mode:

- VFB pin voltage rises too high (no LED connected)
- VFB pin voltage falls too low (feedback resistor R_{fb1} disconnected)
- CS pin voltage is low (CS pin shorted to GND)
- Overtemperature fault (discussed later)
- Operating frequency rises too high

During these fault conditions, the IC will continually attempt re-starts. Between each re-start attempt there will be 8 dummy re-starts when the IC re-starts while the converter is off.

Additionally, if the output is short-circuit, the auxiliary power to the IC fails and the IC shuts down. From this condition the IC automatically cyclically re-starts until the short-circuit has been removed.

The IC also has an instantaneous cycle-by-cycle over-current protection (OCP) level that will terminate any cycle instantaneously should the current exceed a pre-set level.

Over-temperature Protection

The RED2501 Over-temperature protection (OTP) feature shuts down the controller if the IC temperature exceeds 125°C. The IC will restart the converter when the IC temperature drops by 15°C.

Automatic Dead-Time Control

An important feature of the Controlled Self Oscillating Converter is that the dead-time is controlled naturally. Unlike MOSFET half-bridge converters, it is not necessary to program the dead-time on RED2501. The bipolar switching transistors are turned on correctly through the self-oscillation of the converter and turned off by RED2501. This greatly simplifies the design process and improves the robustness of the LLC converter.

Capacitive Mode Protection

RED2501 includes a capacitive mode protection feature which prevents the converter from entering capacitive switching mode on a cycle-by-cycle basis by limiting the minimum frequency. This always ensures the Controlled Self Oscillating Converter continues to oscillate correctly.

IC Operation

Startup, Shutdown and re-start

Figure 4 shows typical startup waveforms for RED2501. In SLEEP mode the IDD current is approximately 8uA ($I_{DDSLEEP}$). Once VDD reaches 3.6V ($V_{DDSTART}$) the IC enters STARTUP mode. During this period of approximately 10ms (512 cycles) Vdd is allowed to drop to 2.4V or rise to 3.6V. This gives time for the application to pull up the output voltage. After this the IC enters RUN mode when the controlled Zener clamp inside the IC regulates the VDD voltage to 3.45V (V_{DDREG}). The IC current is now approximately 0.7mA (I_{DDREG}) plus any excess current required to clamp VDD to 3.45V. If VDD falls below 3.45V (V_{DDREG}) the Zener clamp turns off and I_{DD} reduces to 0.7mA (I_{DDREG}) only. If VDD falls below 3.0V ($V_{DDSLEEP}$), the IC enters SLEEP mode. In this condition I_{DD} reduces to 8uA. ($I_{DDSLEEP}$).

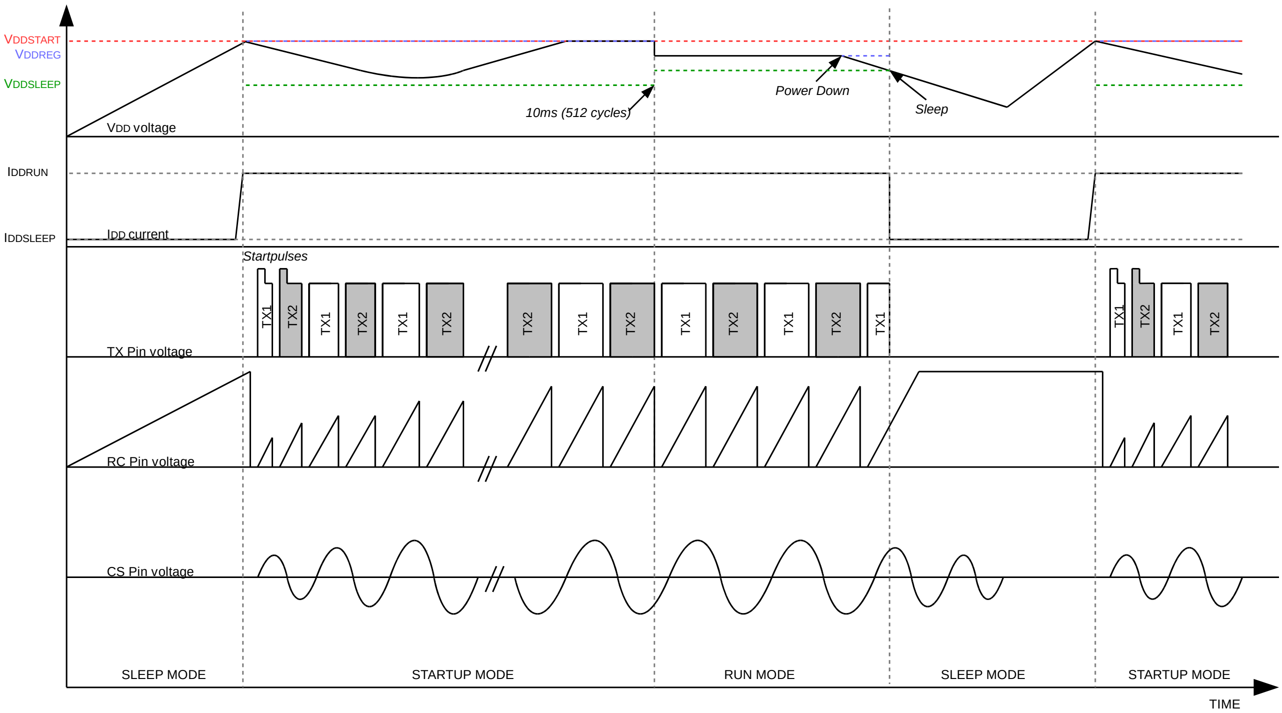


Figure 4: IC Start-up waveforms

Output stage

A diagram of the output stage can be seen in Figure 5. To start the converter oscillating the RED2501 issues start pulses through the TX pins during the first two cycles. These start pulses are 500ns long ($t_{TXSTART}$) and provide 14mA ($I_{TXSTART}$) current pulses from both TX1 and TX2 pins. After this the converter self-oscillates and no longer needs start pulses to maintain oscillation. A low on-state NMOS transistor is used to turn the bipolar transistors off. It is controlled by the oscillator off-time. The NMOS device is turned to pull TX pin low, which switches off the corresponding bipolar transistor in the power converter half-bridge.

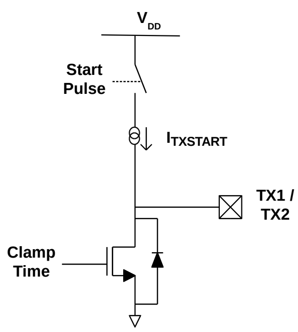


Figure 5: Output Stage

Primary Side Regulation (PSR)

The converter's output current and voltage are estimated by the RED2501 PSR scheme. Inside the IC there are two separate control loops that control the converter output current (in CC mode) and voltage (in CV mode). The RED2501 regulates the output current and voltage by controlling the frequency. A control voltage (V_{COMP}) is fed into the oscillator to give the desired operating frequency. Figure 6 shows how the two current and voltage error amplifiers and their compensation networks are configured for a primary regulated LLC converter.

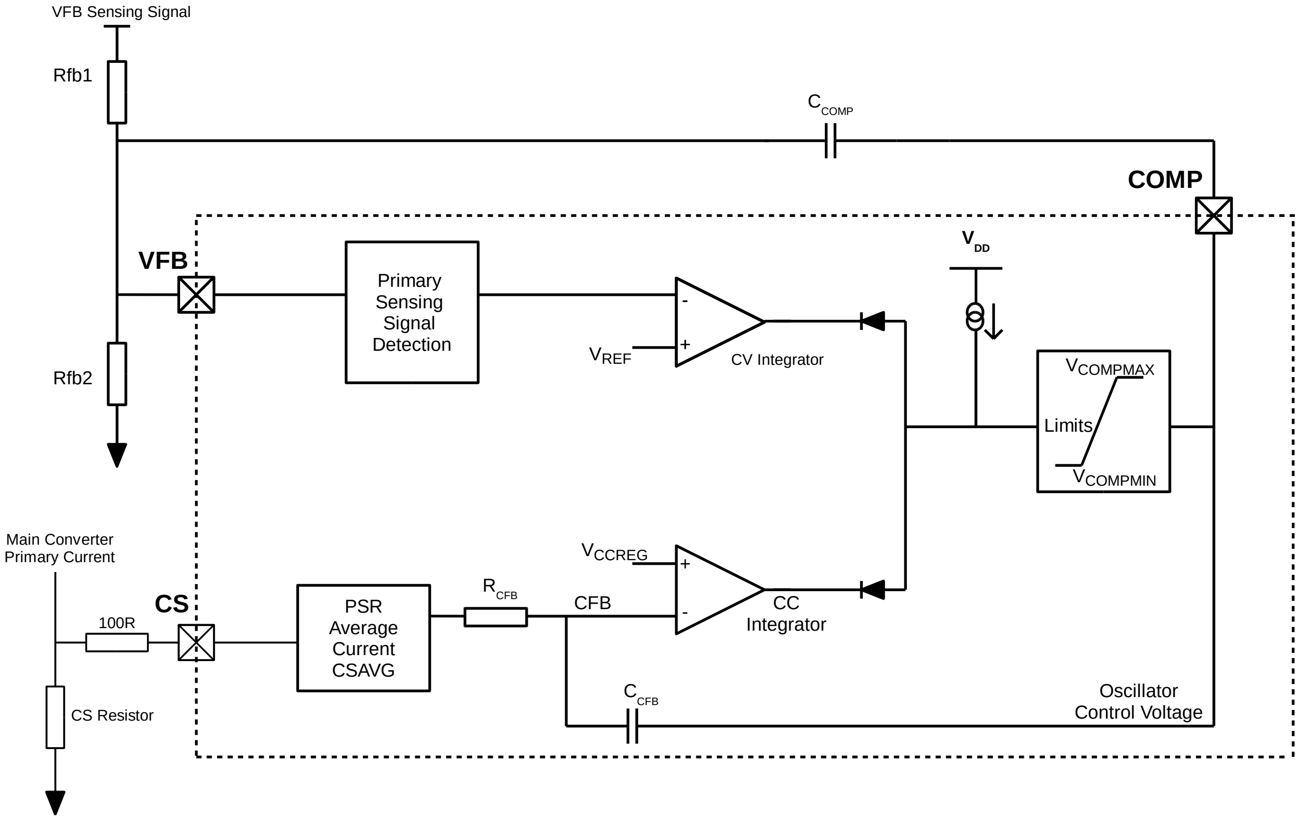


Figure 6: Error Amplifier Circuits

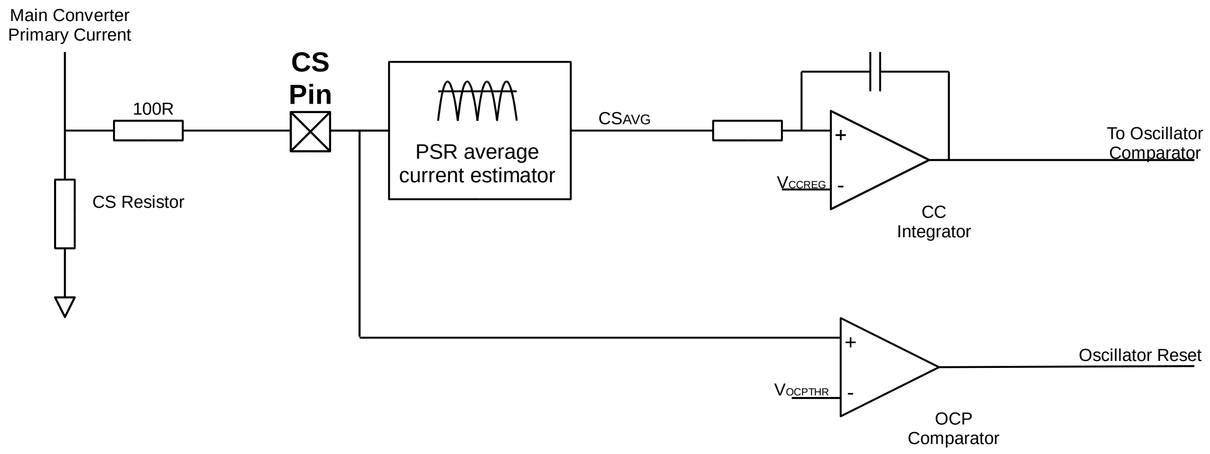


Figure 7: RED2501 Current protection and control circuits

PSR Current Control

Figure 7 shows the two current control methods used in the converter:

1. constant current (CC) regulation;
2. an instantaneous peak current limit (OCP).

PSR Average current estimation

Shown in figure 7 the signal from the CS pin is divided into two different paths. The bottom path provides peak instantaneous over-current protection (OCP) while the PSR Average Current estimation block provides the current regulation (CC) information. The voltage on the CS pin is an AC signal biased around GND. Inside the PSR block this signal is processed to provide a voltage proportional to the average converter output current.

Constant Current Regulation

The CC regulation circuit is shown in Figure 7. CC operation is defined by an internally compensated control loop. This provides a system response time of approximately 300us in a typical application. The average current regulation point, V_{CCREG} is pre-set to 150 mV, referred to the CS pin.

Over Current Protection

Over-Current Protection (OCP) is an instantaneous termination of the current oscillator cycle and the transistor on-time. When a peak voltage greater than +/-500mV (VOCPTHR) is sensed on the CS pin the OCP comparator terminates the current oscillator on-time cycle. The oscillator is reset and the off-time begins resulting in the bipolar transistors turning off and the half-bridge commutating. This is repeated in subsequent cycles whenever the CS voltage exceeds the threshold. However, in a correctly designed converter it should not be possible to trip OCP in normal operation.

PSR Voltage Control

The RED2501 voltage control loop is used to control the maximum LED converter output voltage. The VFB input senses the output voltage from an auxiliary winding on the primary side of the transformer. This signal is conditioned in the PSR block and compared to a voltage reference of 1.2V (V_{REF}) inside the IC. If the voltage exceeds 1.2V RED2501 will enter shutdown.

In a constant current LED application the VFB voltage will normally be below the 1.2V regulation point V_{REF} as the CC control loop determines the COMP voltage. If the LED voltage is too high, or the LED becomes disconnected, the CC loop is not in control and the VFB voltage will rise to the 1.2V V_{REF} control voltage. At that point RED2501 will shut down and enter fault mode, re-starting regularly to check if the fault has been removed

To operate the RED2501 in CV mode as well as CC mode, connect an external feedback network as shown in figure 6 between the COMP and VFB pins. This defines the loop gain and phase for the voltage control loop. RED2501 includes a VFB feedback protection feature that stops the converter if the PSR feedback signal to the VFB pin is lost.

Oscillator

The oscillator (see Figure 8) controls the period of a converter half-cycle. Internal to the IC is an oscillator comparator that compares the voltage on the RC pin to the voltage on the COMP pin. The RC pin has a saw tooth type waveform and the COMP signal should have a steady voltage, inversely proportional to the required frequency.
The COMP pin voltage can vary from 0.55V ($V_{COMPMIN}$) to 2.35V ($V_{COMPMAX}$), resulting in a maximum to minimum frequency ratio of nearly 5x for any input voltage.

The timing capacitor C_{RC} may be chosen within the range 100 – 1000 pF. The recommended type is a 5% COG/NPO capacitor.
The oscillator timing resistor R_{RC} may be connected to either V_{DD} or to the rectified DC bus, V_{HT}. If connected to V_{DD}, the value of R_{RC} may be calculated using following equation.

$$F_{MIN} = \frac{1}{2\left(0.0.8us - R_{RC}.C_{RC}.\ln\left(1 - \frac{2.35}{3.45}\right)\right)}$$

This equation gives the lowest possible operating frequency of the converter.

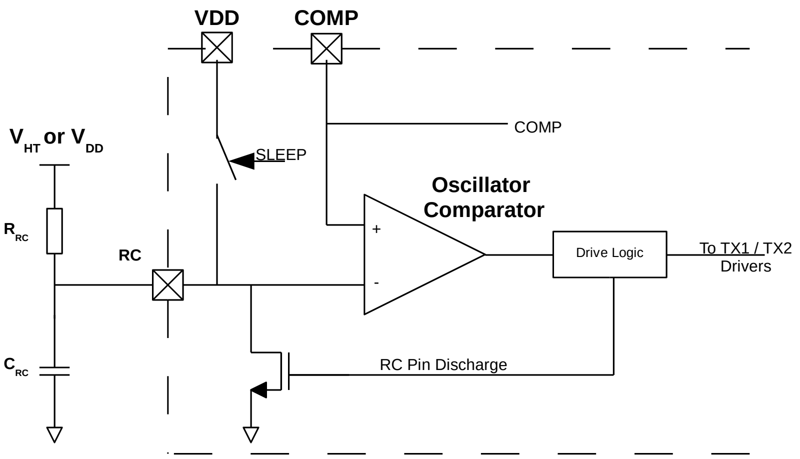


Figure 8: Oscillator circuit

Oscillator Feed-forward Compensation

The oscillator may optionally include feed-forward compensation. Feed-forward compensation is recommended to minimise the line frequency ripple on the output. To apply the feed-forward compensation, the oscillator pull-up resistor R_{RC} is connected to the DC bulk supply V_{HT} instead of V_{DD}. The value may be calculated as a function of the DC bulk voltage using the following equation:

$$F_{MIN} = \frac{1}{2(0.8us + R_{RC}.C_{RC}.2.35/V_{HT})}$$

To assist feed-forward applications, a switch is provided which connects the VDD pin to the RC pin while the controller is in SLEEP. This allows the R_{RC} resistor to pull up the VDD supply for start up.

ABSOLUTE MAXIMUM RATINGS

CAUTION: Permanent damage may result if a device is subjected to operating conditions at or in excess of absolute maximum ratings.

Parameter	Symbol	Condition	Min	Max	Unit
Supply voltage	V_{DD}		-0.5	4.0	V
Supply current	I_{DD}		0	10	mA
Input/output voltages	V_{IO}		-0.5	V_{DD} + 0.5	V
Input/output currents	I_{IO}		-10	10	mA
Junction temperature	T_J	T_{J_MAX} limited by OTP (T_{OTPS_MAX})	-20	+135	°C
Storage temperature	T_P		-20	+125	°C
Lead temperature	T_L	Soldering, 10 s		260	°C
ESD withstand		Human body model, JESD22-A114		2	kV
		Capacitive Discharge Model		500	V

NORMAL OPERATING CONDITIONS

Unless otherwise stated, electrical characteristics are defined over the range of normal operating conditions. Functionality and performance is not defined when a device is subjected to conditions outside this range and device reliability may be compromised.

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Minimum supply current	I_{DDMIN}		0.8	1.0	1.2	mA
Junction temperature	T_J		-20	25	125	°C

ELECTRICAL CHARACTERISTICS

Unless otherwise stated:

- Min and Max electrical characteristics apply over normal operating conditions.
- Typical electrical characteristics apply at $T_J = T_{J(TYP)}$ and $I_{DD} = I_{DDREG(TYP)}$.
- The chip is operating in RUN mode.
- Voltages are specified relative to the GND pin.

VDD Pin

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Supply voltage	$V_{DDSTART}$	To enter RUN mode	3.2	3.6	4.0	V
	V_{DDREG}	$I_{DD} < I_{DDSHUNT}$	3.3	3.45	3.6	V
	$V_{DDSLEEP}$	To enter SLEEP mode	2.8	3.0	3.2	V
Supply current	I_{DDREG}	In RUN mode, $VDD < VDD_{REG}$		0.7	0.8	mA
	$I_{DDSLEEP}$	In SLEEP mode		8	12	µA
	$I_{DDSHUNT}$	VDD shunt regulator max current			8	mA

VFB Pin

Parameter	Symbol	Condition	Min	Typ	Max	Unit
VFB threshold voltage	V_{REF}	T_J= 0°C to 85°C, V_{DD}=3.45V	1.15	1.20	1.25	V

CS Pin

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Constant current regulation	V_{CCREG}	DC CS signal. T_J= 0°C to 85°C	146	150	154	mV
Instantaneous over-current protection threshold	VOCPTHR			500		mV

RC Pin

Parameter	Symbol	Condition	Min	Typ	Max	Unit
External capacitor range	C_{RC}		100		1000	pF
Oscillator Frequency Variation	$\Delta F_{RC}/F_{RC}$	T_J= -0°C to 85°C, C_{RC}=330pF, V_{DD}=3.45V, V_{COMP}= $V_{COMPMAX}$			4	%
Oscillator reset time	T_{RCRST}			0.7		µs

COMP Pin

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Source/Sink current	I_{COMP}		-40		+40	µA
Maximum COMP voltage	$V_{COMPMAX}$	V_{DD}=3.45V		2.35		V
Minimum COMP voltage	$V_{COMPMIN}$	V_{DD}=3.45V		0.55		V

TX1, TX2 Pins

Parameter	Symbol	Condition	Min	Typ	Max	Unit
On-state resistance	R_{TXON}			1.5	2	Ω
TX pin clamp current	$I_{TXCLAMP}$	TX pin frequency >30kHz			800	mA
Start-pulse output current	$I_{TXSTART}$	TX pin voltage 2V		14		mA
Start-pulse width	$T_{TXSTART}$			500		ns

Over-Temperature Protection (OTP)*

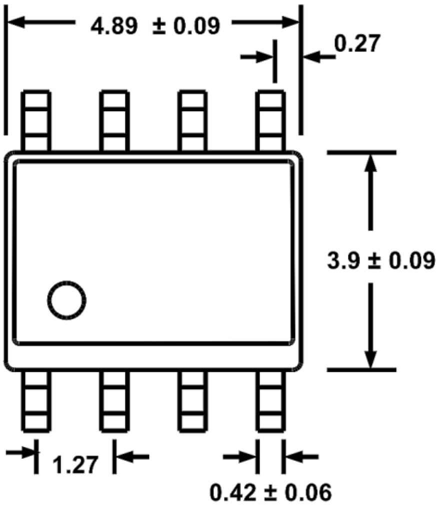
Parameter	Symbol	Condition	Min	Typ	Max	Unit
Over-Temperature Protection threshold	T_{OTPS}	At silicon junction	115	125	135	°C
Over-Temperature Protection reset hysteresis	T_{OTP_HYS}	At silicon junction		15		°C

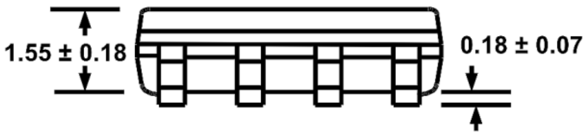
*: *not tested in production*

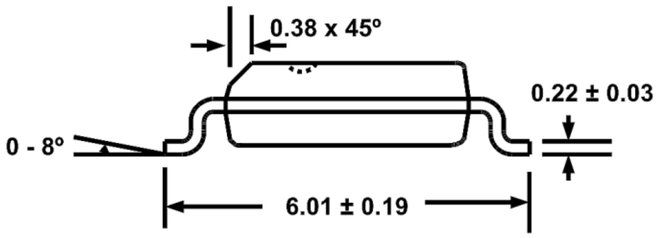
PACKAGE INFORMATION

Package Dimensions

SO8 package dimensions are shown below. All units are in mm.



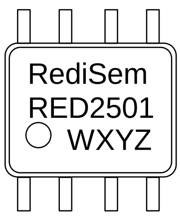




Available packages

Package type	Part number	Moisture Sensitivity Level (MSL)	Packaging
SO8	RED2501AD-TR13	3 (JEDEC J-STD-020)	Tape and reel 2500 / 13" reel

Package Marking



SO8 top-side marking for RED2501

RED2501= Part Number

WXYZ= Lot Code, e.g. AAAA, AAAB

Status

The status of this Datasheet is shown in the footer.

Datasheet Status	Product Status	Definition
Preview	In development	The Datasheet contains target specifications relating to design and development of the described IC product.
Preliminary	In qualification	The Datasheet contains preliminary specifications relating to functionality and performance of the described IC product.
Production	In production	The Datasheet contains specifications relating to functionality and performance of the described IC product which are supported by testing during development and production.

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