Power BJT Specification for RDFC Applications

Application Note AN-2276

ABSTRACT

This application note provides key parametric requirements of power BJTs suitable for Resonant Discontinuous Forward Converter (RDFC) applications. As the main power switch, the BJT will undergo different stresses in RDFC compared to hard switching topologies such as flyback. Selecting the correct BJT is vital to obtain optimal power supply performance and meet safety requirements.

Further information on the RDFC topology and CamSemi's advanced controller IC's is available at www.camsemi.com.

INTRODUCTION

The Resonant Discontinuous Forward Converter (RDFC) topology with CamSemi's controller IC offers a highly efficient and low cost solution for the replacement of linear power supplies. One of the most significant BOM cost advantages offered by the RDFC solution is the use of a low cost bipolar power transistor for the primary switch, rather than an expensive MOSFET. CamSemi's RDFC controller ICs embody advanced patented techniques for bipolar transistor base drive control.

RDFC Circuit Description

A typical RDFC application circuit is illustrated in Figure 1. The NPN power transistor, Q1, is the main power switching element. It switches in resonant / quasi-resonant mode at high frequency during the operation of the converter. The collector voltage waveform will depend on the converter's operating mode. The RDFC IC controls Q1 through the BAS pin based on the information received through the COL and CS pins.

Collector voltage of Q1 is sensed via the Ccol capacitor during both on and off states. On state voltage sensed via the COL pin is used to control the base current so the transistor is held in quasi-saturation. Off state voltage sensed via the COL pin is used to identify the optimum turn-on timing for Q1 and to define the overall on time of the transistor. When the power supply is operating under load, the on time is fixed at ¾ of the off time.

The CS pin is used to sense the Q1 emitter current, limit the current under overload conditions and reduce the switch duty cycle at light loads.

During the on state, base current is supplied through the AUX pin to the BAS pin. Raux is used to limit the maximum base current.

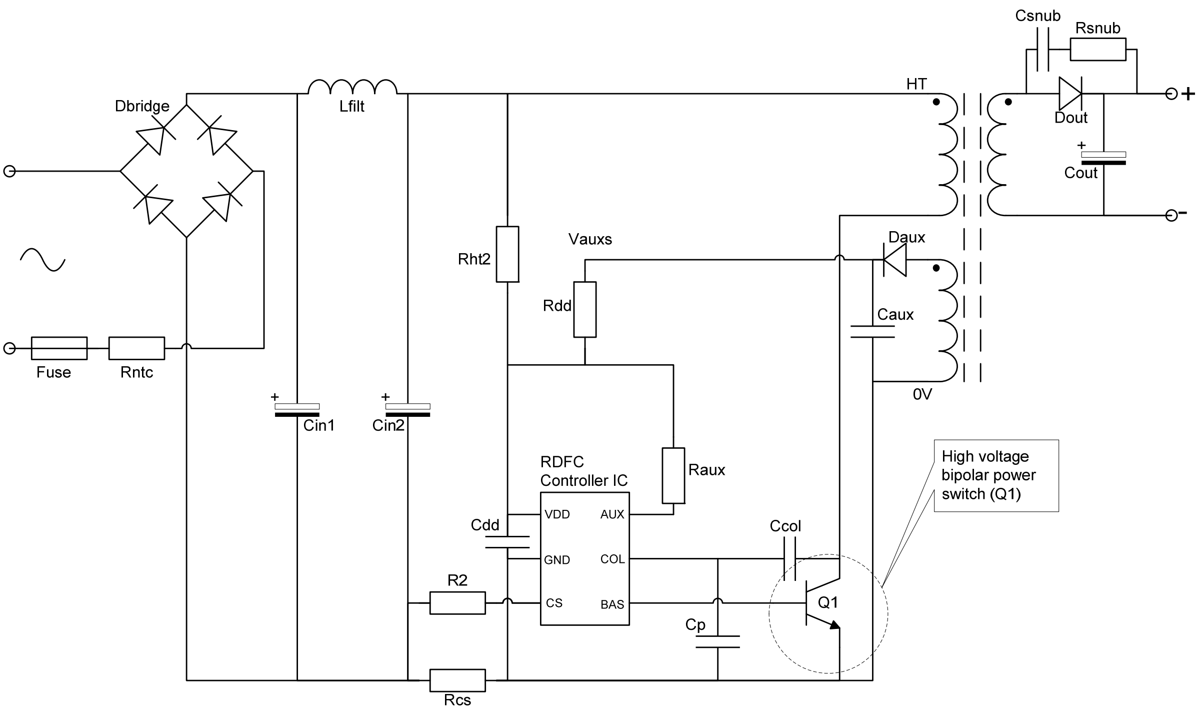

Figure 1: Typical RDFC Application Circuit

Switching Waveforms

Typical Q1 collector voltage and current waveforms in different operating modes are illustrated in Figure 2. In Normal mode, the collector voltage waveform is approximately a half sine wave. Q1 is turned on and off at minimum collector voltage to reduce switching losses. A notable collector voltage step is present during the turn off of Q1 due to the leakage inductance of the transformer.

During Standby mode, Q1 turns on from HT (rectified mains) voltage and turns off at minimum collector voltage.

Under Overload mode, the peak collector current is limited by the RDFC IC. The collector voltage waveform is non-sinusoidal. Turn-on and turn-off transients happen at higher collector voltages.

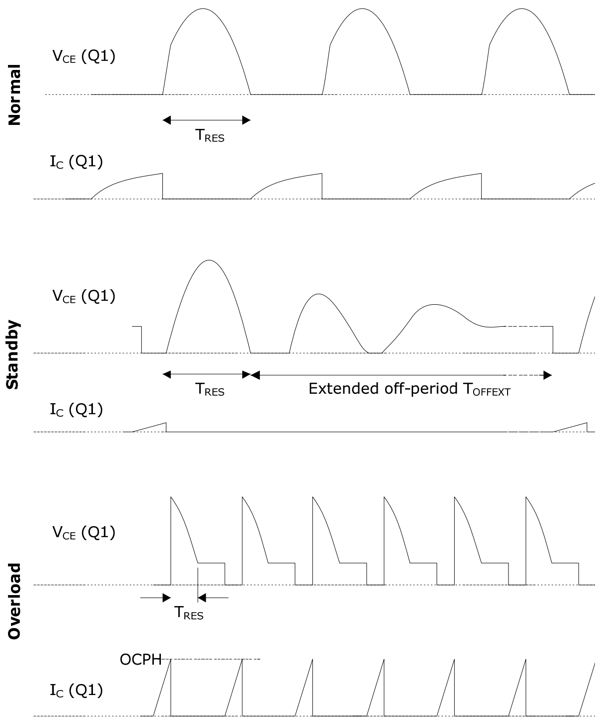

Figure 2: Typical Q1 Collector Voltage (V_{CE}) and Current (I_C) waveforms

TRANSISTOR REQUIREMENTS

As illustrated in Figure 2 the main power switch (Q1) is operated in a significantly different way to a conventional flyback converter power switch. This results in different parametric requirements for suitable power transistors. These requirements are described in detail in the following sub-sections.

Operating Temperature Range

The following ratings and characteristics need to be maintained over the operating temperature range of T_J = -10°C to 125°C in order to guarantee reliable operation of the RDFC circuit.

Collector Voltage Rating (V_{CE})

Peak collector voltage during the off state in RDFC applications will be significantly higher than in flyback applications due to the resonant mode of operation. In order to select the correct collector voltage rating, the following breakdown voltage specifications should be taken into account:

- V_{CEO} - Breakdown voltage under common emitter configuration (where emitter is grounded) with base open circuit
- V_{CBO} - Breakdown voltage under common base configuration (where base is common/grounded) with emitter open circuit
- V_{CES} - Breakdown voltage under common emitter configuration with base shorted to emitter.
- V_{CER} - Breakdown voltage under common emitter configuration with a resistor between base and emitter

Typically $V_{CEO} < V_{CER}^* \approx V_{CES} \approx V_{CBO}$

* For R_{be}< 10kΩ

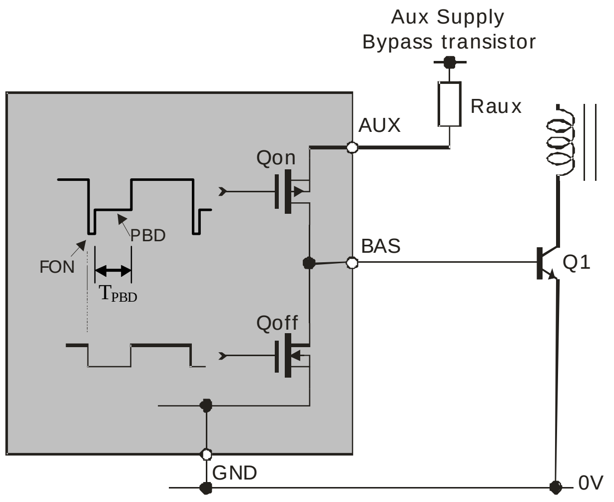

Figure 3: Q1 Base Drive Circuit

The RDFC IC allows switch-off of the transistor with minimum collector voltage and uses a base turn off MOSFET (Q_{OFF} in Figure 3) with an R_{DSON} of typically 5 Ω. Therefore, V_{CER} is the breakdown rating applied to Q1. As V_{CER} is not normally specified in datasheets, the V_{CES} or V_{CBO} rating is used as the allowable worst-case peak collector voltage during the Q1 off state.

Collector Current Rating (I_{C-DC})

The collector current rating of the transistor is selected based on the worst-case peak collector current possible in the target application. This peak collector current is then rounded up to the nearest 0.5 A (or 100 mA for 1 to 6 W RDFC applications) and selected as the collector current rating(I_{C-DC}) of the transistor.

Output Capacitance (C_{OB})

Low output capacitance of Q1 is essential for RDFC applications for two reasons. The resonant frequency of the converter is affected by the output capacitance of Q1. In order to control the resonant frequency tightly using an external capacitor, transistor output capacitance should be minimised. Minimising the output capacitance also allows Q1 to turn-on rapidly. Suitable C_{OB} values are in the 30 to 60 pF range (at V_{CB} = 10 V).

DC Current Gain (h_{FE})

As seen in Figure 3, the Q1 base current will consist of two main parts. The base current is initially forced to a higher value (I_{FON}) to turn-on Q1 rapidly. For the remainder of the on time, the base current (I_{PBD}) is reduced to a lower value while maintaining the on-state collector voltage at a preset target voltage, minimizing turn-off time and consequent losses. It is essential that the minimum h_{FE} is high enough to sustain the required collector current within the available base current from the controller (taking into account the effect of Raux).

h_{FE} is strongly dependant on the collector current, on-state collector voltage and temperature. Typically, h_{FE} is lower at:

- High collector current
- Low collector voltage
- Low temperature

However, manufacturer datasheets usually don't provide comprehensive h_{FE} characteristics. Therefore, extrapolation of available data may be required to predict minimum h_{FE} over the operating range.

The h_{FE} characteristic of the transistor is selected based on the worst-case peak collector current and maximum base current limitation. This ensures BJT quasi-saturation under worst-case on-state conditions. Lower than rated h_{FE} could cause inefficient power conversion and BJT overheating. The on-state collector voltage can be preset using the proportional base drive system in the controller. Setting a lower voltage improves efficiency but decreases the h_{FE} of the transistor and increases storage time. For 700 V V_{CBO} transistors it is normally best to operate around 2-3 V on-state V_{CE}. For transistors with higher V_{CBO} (e.g. 1.2 kV – 1.5 kV) it is recommended to operate around 5 V on-state V_{CE}. It is important to use h_{FE} characteristics relevant to the on-state voltage.

For higher power applications with 115 Vac input line voltage the h_{FE} requirement will be quite demanding.

RBSOA

The Reverse Biased Safe Operating Area (RBSOA) of the transistor is mainly applicable to the Q1 turn off transient. To force turn-off of Q1, Qon is turned off and Qoff is turned on (Figure 3).The collector rises in a fast voltage step due to the leakage inductance of the transformer. There is a significant amount of collector current present during this voltage step as a result of the energy in the leakage inductance and charge storage in Q1. As the base drive is turned off through Qoff (Figure 3) there will be a negative base current present during the turn-off duration. Therefore RBSOA curves for $I_b \leq 0$ or $V_{BE} \geq 0$ V are applicable to RDFC applications.

In RDFC applications, turn-off conditions typically are different from those used to characterise RBSOA in transistor datasheets. Particularly, V_{BE} is not negative during turn off, but also the transistor is operated with minimum excess base charge. It is important that the transformer leakage inductance and collector node capacitance are chosen to limit collector voltage until the transistor collector current has fallen to a low value. An applicable limit for Vce (with I_C) can be judged from a family of RBSOA curves for varying reverse V_{BE}. Where RBSOA data is not available, V_{CEO} may be used as the V_{CE} limit but a conservative margin should be applied.

Storage Time (T_{STG})

Low storage time is required to achieve optimal turn-off switching operation and reduce peak collector voltages in RDFC applications. BJTs with storage times less than 0.5 us (measured under inductive load switching) are recommended for typical RDFC applications. Note that the switching specifications in transistor datasheets are normally under drive conditions and are very different to those used in RDFC applications. Particularly, datasheet tests are carried out under higher base currents and negative V_{BE} at turn-off.

TRANSISTOR SELECTION

The following tables list suitable transistors with key parameters for 115 Vac and 230 Vac RDFC applications, based on the above requirements.

Notes:

- The $I_{C\text{-}DC}$ rating for suitable transistors should be higher than the $I_{C\text{-}DCmin}$ specification in order to achieve the target h_{FEmin} specification at $I_{C\text{-}DCmin}$
- h_{FEmin} is calculated based on the minimum guaranteed I_{BASPBD} specification of 100 mA for CamSemi's C2472 and C2473 products and 22 mA for CamSemi's C2471 product, [1] and [2]

RDFC Controller IC Product	**Application Power Range (W)**	**V_{CBO} (V)**	**V_{CEO} (V)**	**$I_{C\text{-}DCmin}$ (A)**	**h_{FEmin} @ $I_{C\text{-}DCmin}$ & V_{CE} = 2.5 V**	**Package**
C2471	1-3	700	400	0.15	8	TO-92
	4-6	700	400	0.30	15	TO-92/TO-126
C2472 / C2473	7-10	700	400	0.50	5	TO-92/TO-126
	11-20	700	400	1.00	10	TO-126
	21-30	700	400	1.50	15	TO-126/ TO-220
	31-40	700	400	2.00	20	TO-220

Table 1: BJT Specifications for 115 Vac RDFC Applications

RDFC Controller IC Product	**Application Power Range (W)**	**V_{CBO} (V)**	**V_{CEO} (V)**	**$I_{C\text{-}DCmin}$ (A)**	**h_{FEmin} @ $I_{C\text{-}DCmin}$ & V_{CE} = 5 V**	**Package**
C2471	1-3	1400	700	0.10	6	TO-92
	4-6	1400	700	0.15	8	TO-92/TO-126
C2472 / C2473	7-20	1400	700	0.50	5	TO-126
	21-40	1400	700	1.00	10	TO-126
	41-60	1400	700	1.50	15	TO-126/ TO-220

Table 2: BJT Specifications for 230 Vac RDFC Applications

REFERENCES

[1] RDFC C2472, C2473 Product Datasheet (DS-1423), www.camsemi.com/support/datasheets

[2] LPRDFC C2471 Product Datasheet (DS-1639), www.camsemi.com/support/datasheets

[3] RDFC Basic Design Guide (DG-1694), www.camsemi.com/support/designguides

[4] Low Power RDFC Basic Design Guide (DG-2128), www.camsemi.com/support/designguides

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