Application Note

AN-06002

***Version:* 1.2**

***15-Nov-2010* (Modified)**

Voltage regulator short-circuit protection and associated potential startup issue

I Introduction

In order to protect serial voltage regulators against short-circuit events, most of them are internally protected in order to limit the short-circuit current. Basically, the short circuit protection is activated when the current exceeds a maximum limit (named "foldback" current, I_{FB}). At the short-circuit condition, the current is internally limited to I_{SC}. Depending on these two current limits, there exist cases where such regulator could not start correctly in specific conditions, namely when it is used with an opposite voltage regulator in dual voltage application.

The case of a positive voltage regulator will be considered hereafter. Obviously, the case of a negative regulator is dual.

II Related documents

AN-06016: *"Selecting correct CISSOID regulator depending on your application"*

III Linear regulator with current limiting protection.

A typical linear voltage regulator architecture basically includes a voltage reference, a large pass transistor, a feedback amplifier and a short-circuit protection. The short-circuit protection is mostly characterized by two limit current values:

- The maximum current before activation of protection (also called the fold-back current I_{FB}).
- The short-circuit current (I_{SC})

Note that a regulator is usually specified to be functional up to a current level I_{max}. Between I_{max} and I_{FB}, the regulator could be functional but out of specifications (bad line and/or load regulation). Also, the actual value of I_{FB} is usually very dependent on the regulator dropout, temperature, process variations, …

IV Regulator DC operating point vs. load

Figure 1 sketches typical voltage regulator DC output voltage characteristics with I_{SC} either smaller (1), equivalent (2) or larger (3) than I_{FB}.

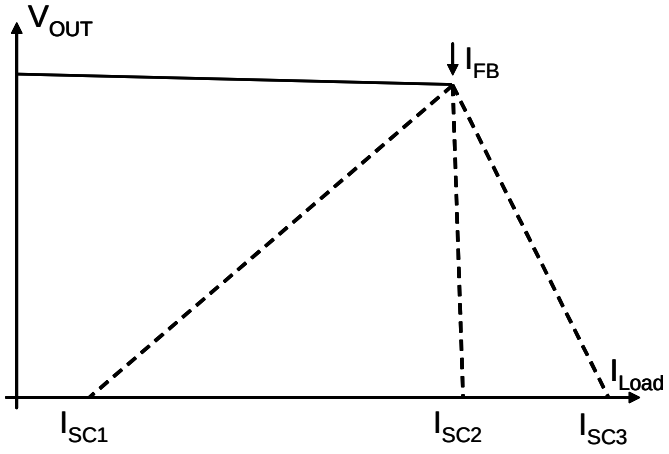

Figure 1: Typical serial regulator DC characteristic with short-circuit protection level lower, equivalent or higher than the foldback current I_{FB}.

Figure 2 depicts a typical linear DC generic load, consisting in a resistive load in parallel with an ideal current source.

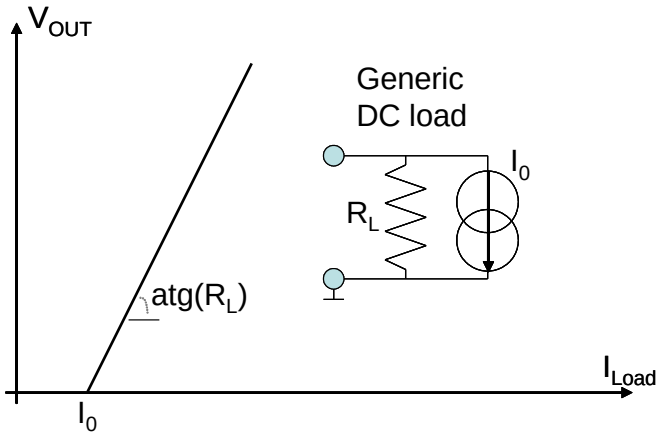

Figure 2: Generic DC load characteristic, consisting in a resistive part in parallel with an ideal current source part.

In figure 1, we have only considered the positive voltage part of the regulator DC characteristic. To be correct, the negative voltage part should also be considered! This is often not considered, leading to unexpected behavior when using such regulator in dual (positive and negative) voltage applications. Figure 3 sketches two typical cases for this usually not considered DC part. These cases show that the current can be lower than I_{SC} for slightly negative output voltage. It also shows that the current can increase very quickly when the output voltage becomes more and more negative.

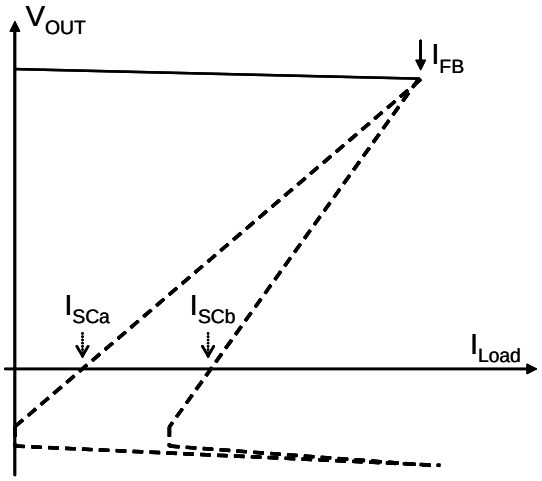

Figure 3: Example of 2 different regulator's DC characteristics.
We now consider also negative V_{out}.

The intersection of DC curves of figure 2 and 3 gives the actual DC point for a fixed load. If more than one intersection occurs, then the actual operating point cannot be guaranteed! (it will mostly depends on transients effects). Figure 4 sketches such intersection between figures 2 and 3. Depending on regulator load, one, two or even three stable operating points could be obtained. The actual intercept point will then depend on transient effects during start-up (capacitors, supply voltage ramp, …).

In practice, for protection purposes, voltage regulators used in dual voltage application are accompanied by external grounded reverse biased diodes on their output node. The effect of such a diode is that the regulator DC characteristic of figure 4 must only be considered down to about -0.7V (or less if Schottky diode is used). In some cases, this diode can reduce the number of DC stable point from three to one.

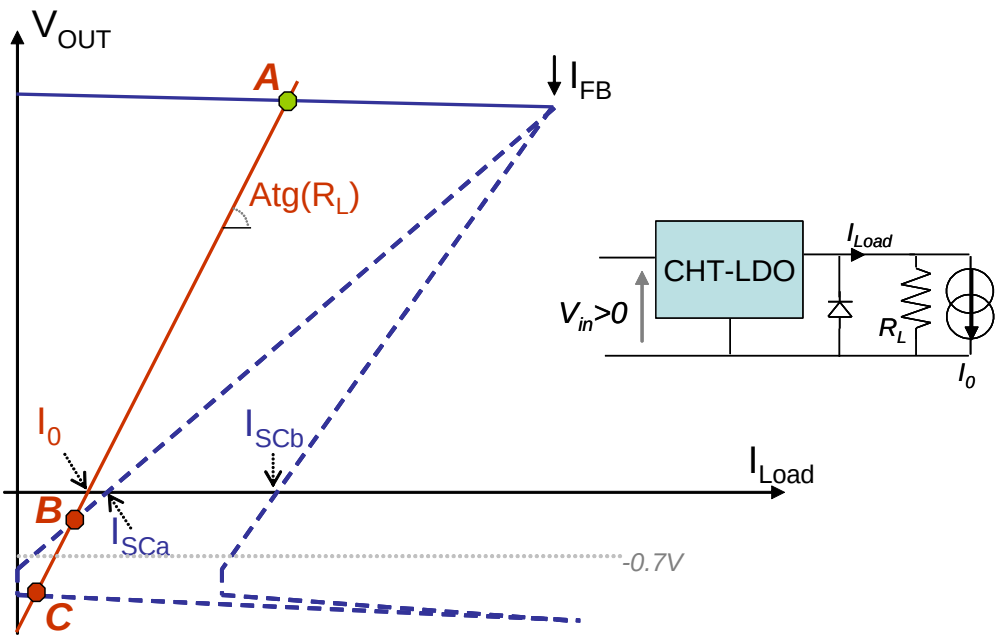

Figure 4: DC locus of:

- *Voltage regulator, with 2 different short-circuit current limits: Isc_a or Isc_b*
- *Generic load (resistive + current source) + reverse protection diode*

In first case (Isc_a), 3 stable points exist (A, B, C).
Note that point (C) should not be considered if a reverse diode is used.

In the second case (Isc_b), only 1 stable point (A) exists.

V General considerations for correct startup

The main requirements for correct startup can be extracted from figure 4, depending on the load and the short-circuit protection value.

V.1 Single supply applications

We consider here that the positive voltage regulator output voltage can only be zero or positive, i.e. that it exists nowhere in the system a negative supply able to force the output of

the positive regulator to a negative voltage. In such case, the negative part of figure 4 can be neglected, reducing the number of possible stable points to one or two.

From the positive part only of figure 4, it is easy to see or extrapolate that:

- For a pure resistive load R_L (i.e. I_0=0), it exists one and only one stable point, regardless the (positive) value of the short-circuit protection level. This means that after some transient, such regulator with such load will always reach its right operating point. A voltage regulator with a low short-circuit current (Isc_a) is a good choice for such a load as it leads to minimum energy losses in case of short-circuit, also avoiding thermal shutdown or destruction due to self-heating.
- If an ideal current source (I_0) load exists in parallel with a resistive load, two stable points exist if $I_0>I_{SC}$. As result, a regulator driving a load that includes a large current source must have a short-circuit current protection level I_{SC} large enough to guarantee its correct startup.

V.2 Dual supply applications

We consider here that besides R_L and I_0 of figure 4, the positive voltage regulator load can also have a **direct** current path to an external negative supply (V_N<0) towards a resistive load R_D (figure 5). It is called “direct” if this current path does not cross the ground node. It can easily be demonstrated that these three current paths (towards I_0, R_L and R_D) can be simplified to two equivalent current paths, I_{Equ} and R_{Equ}, defined as

- $I_{Equ}=I_0-V_N/R_D$
- $R_{Equ}=R_L//R_D$

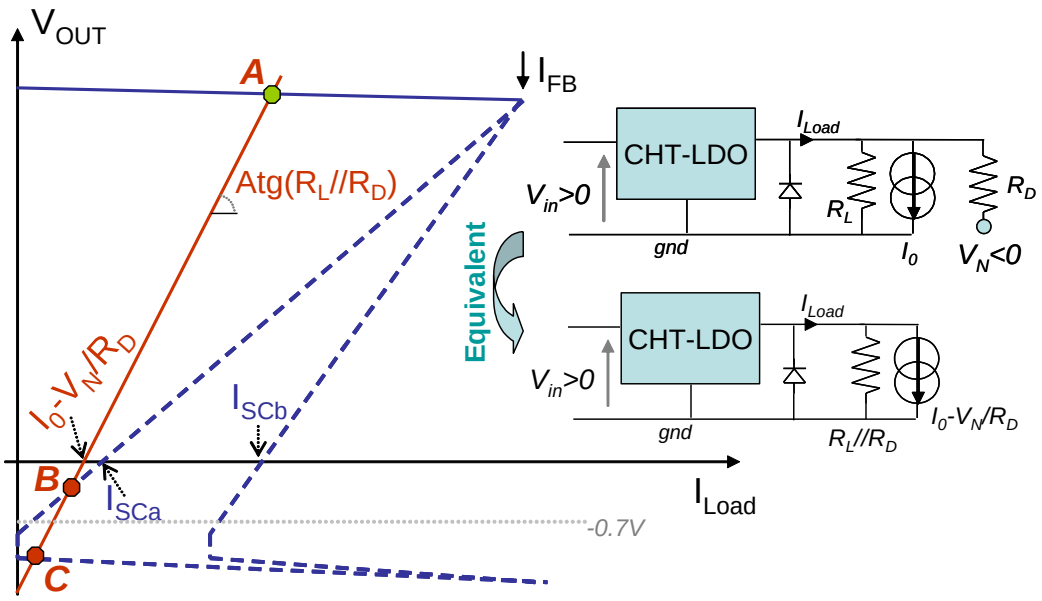

Figure 5: DC locus for a positive voltage regulator with a generic load to ground and an additional direct resistive (R_D) path to an external negative voltage (V_N).

If we assume a constant (negative) V_N, the direct current path through R_D acts like an IDEAL current source as V_N/R_D appears in the equivalent current source relation.

We can conclude that such a regulator, whose output node has a direct current path to a negative supply voltage, could have several DC stable operating points if the regulator short-circuit protection level (I_{SC}) is smaller than I_0-V_N/R_D (with $V_N<0$).

Note that if such regulator is used in a symmetrical voltage setup with only a resistive current path to ground (R_L), then this regulator will always correctly start. This is in fact equivalent to the "single supply" case, as this regulator does not see any opposite voltage. In this case, a regulator with a small short-circuit current (I_{sc}) is the best choice.

VI Regulator choice depending on application load

As explained in the previous section, if the regulator load is only resistive (i.e. no current source load) and if the regulator output has no resistive load connected directly to an oppo-

site voltage, then a regulator presenting a low short-circuit current value is the best choice. Otherwise, in order to guarantee correct startup and/or correct recovering after a short-circuit event, a regulator with higher short-circuit protection value is required.

For each, positive and negative voltage regulator, CISSOID has developed two different versions of voltage regulators, mainly differing on their short-circuit current value.

Refer to CISSOID's application note **AN-06016**

"Selecting correct CISSOID regulator depending on your application"

VII Contact & Ordering

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VIII Disclaimer