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High input, wide output voltage range linear regulators

Valentin-Ioan Maranescu[1], Cătălin D. Căleanu[1], Corneliu I. Toma[2]

Abstract – This paper proposes a method to obtain a high input voltage stabilizer by connecting adjustable voltage regulators in series. Wide output voltage range, maintaining maximum current was obtained without secondary breakdown risks. A method to equal distribute the power dissipation on series regulators was proposed leading to an extended equivalent safe operating area.

Keywords: voltage regulator, wide voltage range, safe operating area (SOA), thermal transfer.

I. INTRODUCTION

Integrated voltage regulators (VR) are common electronic devices present in almost all applications. VR offer constant voltages in conditions of input voltage variations and/or load current variations. Since they were first designed, three pins VR are the most used, due to their good performances and minimum number of external components requirement [1],[2]. Although a large variety of three pins VR exists, with fixed or adjustable output voltages, voltage regulators with inputs over 40V are hard to integrate due secondary breakdown risk of theirs pass element [3],[4],[5]. Adjustable high input stabilizers, with wide output voltage range are demanded for laboratory power supplies applications.

A method to extend the input voltage range for a voltage stabilizer is to add an element in series with the voltage regulator input. This element can be a simple wattage resistor, a bipolar transistor or even a voltage regulator. Using a resistor instead of a regulator will have the disadvantage that the voltage drop across it depends on the load current. A minimum load current is required in this case to avoid stress over datasheet maximum input voltage V_{IMAX} of the regulator. Fig.1. present a solution recommended by producers in theirs datasheets [6]. Connected in series with a preregulation transistor or a voltage regulator is possible to set a fixed voltage drop across output regulator. The line regulation is improved due to the constant input voltage of the output VR set by the preregulator. This solution will increase the input voltage range only with the fixed voltage drop set across the output regulator. The efficiency of this solution is optimum just if the output voltage is fixed or adjustable in a narrow range, in this case, the voltage drop across both regulators can be set almost equal, and the integrated protections [5] will start to work simultaneously. Except the fixed or narrow output voltage range, the equivalent safe operating area (SOA) of the stabilizer will gain just a small improvement, depending on preregulation element SOA. In the case of using a preregulation transistor, no protections to short circuit, overheating, or secondary breakdown will be available for it, requiring supplementary circuitry.

In this paper, we propose a solution to series interconnect two VR in order to increase the maximum input voltage V_{IMAX} of the stabilizer, and extended in the same time the output voltage range, without to reduce maximum load current, providing an efficient use of theirs SOA in all input and load conditions.

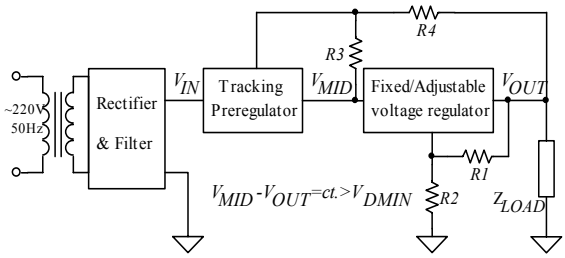

Fig.1. High input voltage range
stabilizer using a tracking preregulator

II. EXTENDED RANGE ADJUSTABLE VOLTAGE REGULATOR

Our proposal to extend to maximum both input and output voltage range of the stabilizer is presented in fig.2. It has the main advantage that keeps both the output VR and input VR with equal voltage drop across in the case of input voltage variations, or load variations. Voltages drop across each regulator are kept equal even when output voltage is adjusted, leading always to equal power dissipations on both VR. Because both input VR and output VR, adjust

[1] Facultatea de Electronică şi Telecomunicaţii, Departamentul Electronică Aplicată
Bd. V. Pârvan nr. 2, Timişoara, 300223 e-mail: valentin.maranescu@etc.upt.ro, catalin.caleanu@etc.upt.ro
[2] Facultatea de Electronică şi Telecomunicaţii, Departamentul Comunicaţii
Bd. V. Pârvan nr. 2,Timişoara, 300223 e-mail: corneliu.toma@etc.upt.ro

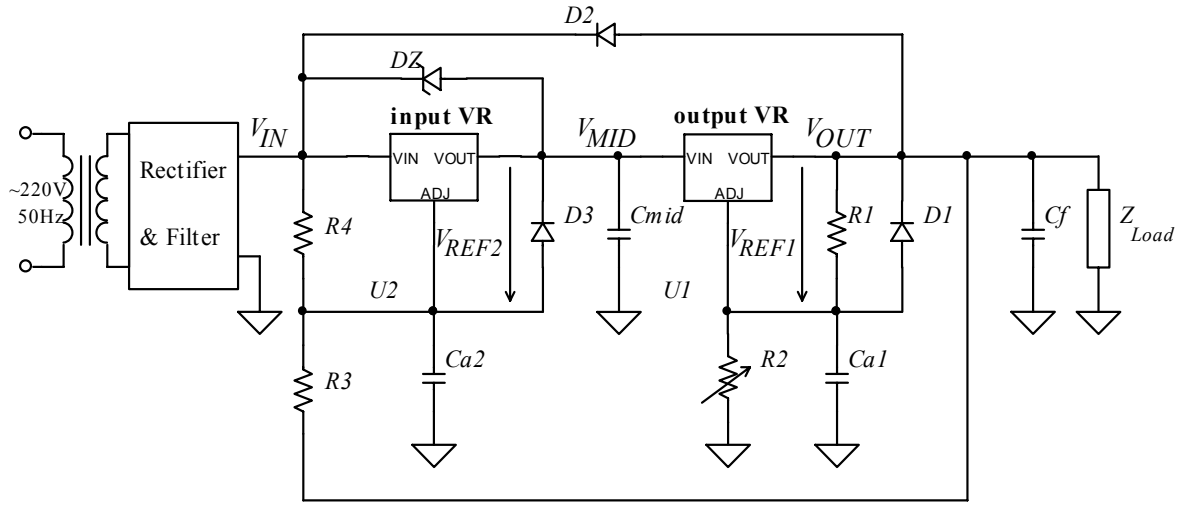

Fig.2. High input, high output voltage range - series regulators.

their input to output voltage drop when stabilizer output voltage is adjusted, twice the maximum output range compared with a single VR supply is obtained. This is an advantage compared with solutions using fixed voltage drop across output VR, where the maximum output voltage range is increased just with fixed voltage drop set across output VR, which usually is set with a few volts over minimum voltage drop V_{DMIN} to keep "cold" the output VR.

To achieve an equalization of the voltage drop across series regulators, the adjusting pin of the preregulator is biased from a resistive divider powered by input to output voltage difference $V_{IN,OUT}$ of the stabilizer. Neglecting adjusting pin current, the common net voltage V_{MID} is:

$$V_{MID} = k \cdot V_{IN} + (1-k) \cdot V_{OUT} + V_{REF2} \qquad (1)$$

Where V_{REF2}=1.25V represents the most usual value of the reference voltage within an adjustable regulator, and k the division ratio of input to output voltage at the adjusting pin of the input VR:

$$k = \frac{R3}{R3 + R4} \qquad (2)$$

Then, the voltage drops across pass element within regulators are:

$$V_{IN,MID} = (1-k) \cdot (V_{IN} - V_{OUT}) - V_{REF2} \qquad (3)$$

$$V_{MID,OUT} = k \cdot (V_{IN} - V_{OUT}) + V_{REF2} \qquad (4)$$

For an efficient use of the SOA for both regulators, these voltage drops must be set equally especially for maximum input voltage and lowest output voltage values, this situation representing the case of maximum power dissipation on regulators at maximum current load. The theoretical optimum value for k is obtained equalizing voltage drop across regulators in (3) and (4) for worst-case input and output conditions, resulting in:

$$k_{opt} = \frac{1}{2} - \frac{V_{REF2}}{V_{IN,MAX} - V_{OUT,MIN}} \qquad (5)$$

When choosing *R3* and *R4* to set k value, using equations (2) and (4), we must consider the V_{REF2} value factory dispersion, and the tolerances of resistors within divider. The minimum worst-case value of k must be greater than k_{opt}. To avoid the need of a minimum load current, and to improve regulator efficiency [7], *R3* and *R4* must not sink a current lager than adjusting resistors of the output regulator, this involving the following condition:

$$R3 + R4 > R1 \cdot \frac{V_{IN,MAX} - V_{OUT,MIN}}{V_{REF1}} \qquad (6)$$

To keep always voltages drop across regulators equal, the output VR must be the one that control the input VR. For the safety of the supply, the situation must be under control even when regulators reach theirs SOA margin. Voltage regulators present a decrease of the maximum limiting current as a function of voltage drop, to keep pass element in its SOA [4]. To be sure that output regulator will be first that limit the current, the voltage drop across it must be set slightly larger (with a few volts) than the voltage drop across the input regulator, by setting minimum worst-case k slightly over k_{opt}.

In the case of maximum current I_{MAX} values dispersion, it is possible for an overload that the input regulator to be the first that limit the current, resulting in an increase of its voltage drop. To prevent unbalancing the regulators voltage drops with the risks of theirs pass element breakdown, a breakdown diode *DZ* will limit the voltage drop across input VR.

The breakdown voltage of this diode must half of the maximum input to output voltage drop of the stabilizer, value that must be under V_{IMAX}. Protection diodes *D1* and *D2* will prevent reverse biasing of the regulators when having a large capacitive load at the output and input is short-circuited or fast discharged. Diode *D3* will prevent reverse biasing of the input VR.

Capacitors *Ca1*, *Ca2*, *Cmid* will help to improve response to input transients, and *Cf* will improve response to load transient [6].

By equally distribute power dissipation on regulators, the stabilizer equivalent SOA increases almost twice, keeping same I_{MAX}, but for an extended voltage range. In fig 3. the results obtained with SPICE [8] simulation for the new equivalent SOA are plotted. The area between V_{DMIN} and $2*V_{DMIN}$ will be lost, because the new equivalent voltage drop is twice as in the case of a single voltage regulator. Defining:

$$r(V_{IN,OUT}) = \frac{I_{OUT,MAX}(seriesVR)}{I_{OUT,MAX}(singleVR)} \qquad (7)$$

where $I_{OUT,MAX}(seriesVR)$ and $I_{OUT,MAX}(singleVR)$, represent maximum output currents at voltage $V_{IN,OUT}$ for series respective single VR. It can be observed from SOA simulations that this ratio becames greater than unity for $V_{IN,OUT}$ range where single VR output current is limited to keep power dissipation to a maximum value. As we state in a previous paper sing series pass elements configurations [9], series VR lead to an improvement of SOA at high voltage input range compared with a single regulator. Around V_{IMAX}, a maximum improvement for the value of *Iout*max was achieved. The new line regulation *LINREG* is worst compared with fixed drop voltage across output regulator solution, being reduced to *LINREG* of a single VR.

III. THERMAL TRANSFER

The voltage regulators will use a common heat sink with one of the regulators isolated from the heat sink because of series connection. The input regulator has a larger temperature margin due to its slightly smaller power dissipation. This will be a reason to choose to isolate the input VR from the heat sink, helping also to equalize the junction temperatures. The equivalent schematic with electrical lumped elements is presented in fig.4.a). In order to obtain equal junction temperature, the electrical isolation of the input VR can be compensated by unbalancing the power dissipation on voltage regulators. The condition to obtain equal junction temperatures is:

$$Pd1\cdot(Rjc1+Rcs1)=Pd2\cdot(Rjc2+Rcs2) \quad (8)$$

where P_{D1}, P_{D2} are power dissipations on output respective input VR, and R_{JC1}, R_{JC2} - junction to case thermal resistances, R_{CS1}, R_{CS2} - case to sink thermal resistances of output respective input VR using a common heat sink with R_S thermal resistance, in ambient temperature *Ta*. In the case of input VR heat sink isolation, R_{CS2} will include thermal resistance of the isolation. If VR have identical cases, then $R_{JC1}=R_{JC2}=R_{JC}$, $R_{CS1}=R_{CS}$, $R_{CS2}=R_{CS}+R_{IS}$. By replacing $P_{D1}=V_{MID,OUT}\cdot I_{OUT}$, $P_{D2}= V_{IN,MID}\cdot I_{OUT}$ in eq.(8), we obtain the relationship between thermal resistances and voltage drop across regulators that lead to equal junction temperatures:

$$\frac{V_{MID,OUT}}{V_{IN,MID}} = \frac{R_{JC}+R_{CS}+R_{IS}}{R_{JC}+R_{CS}} \qquad (9)$$

In the case of equal junction temperatures, the equivalent thermal schematic will have thermal resistances connected in parallel, as presented in fig.4.b). This is thermally equivalent with increasing

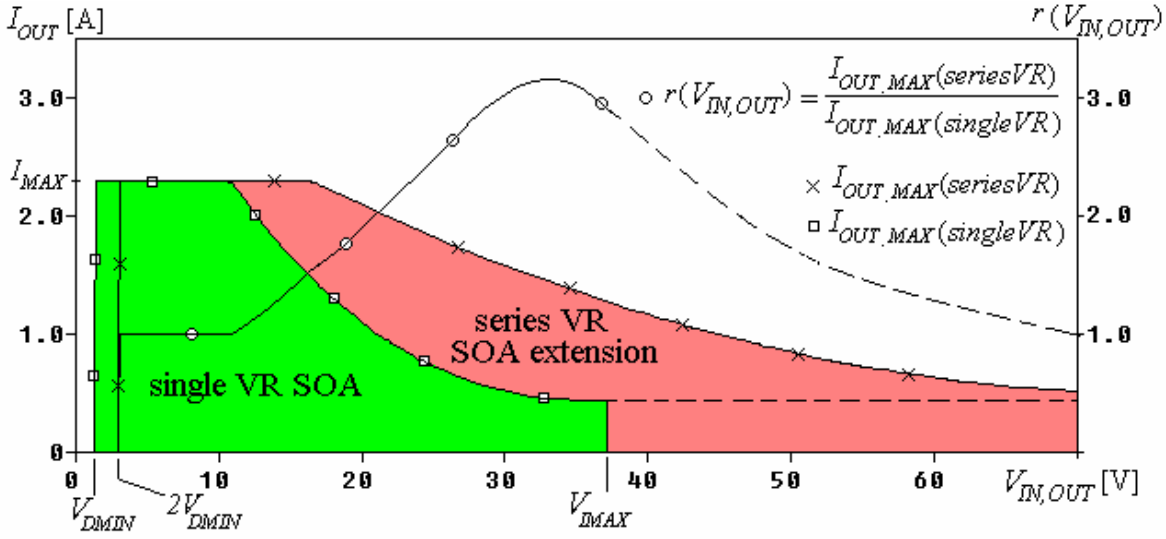

Fig.3. Simulated equivalent SOA extension for series voltages regulators

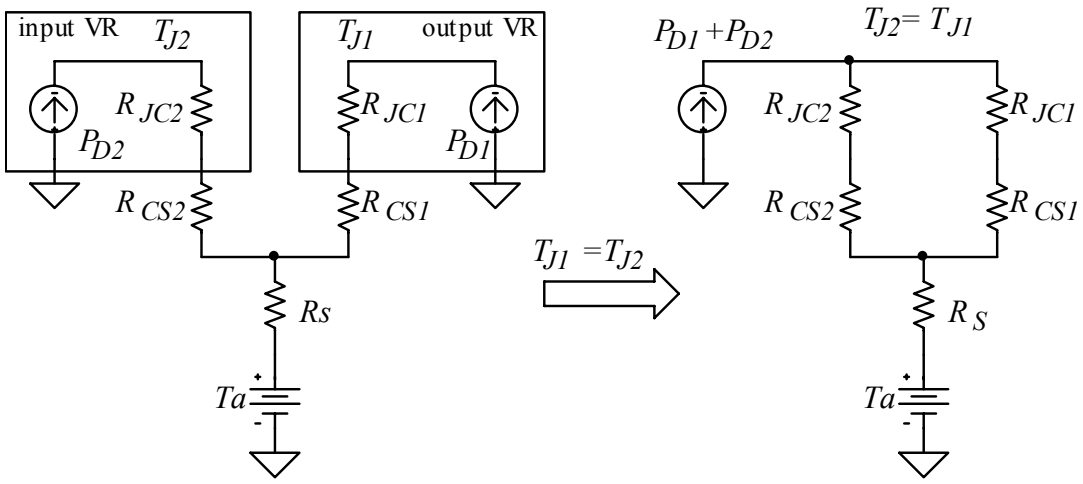

Fig.4. Equivalent thermal schematic with lumped elements for series regulators sharing same heat sink.
a) $T_{J1} \neq T_{J2}$ b) $T_{J1}=T_{J2}$

twice the area used to transfer the heat from junctions to sink. If we compare heat transfer at equal total power dissipation, series VR are more efficient than a single VR, by reducing junction's temperatures in similar line and load conditions.

From eq. (9), we conclude that equal voltage drop and equal junction's temperatures are possible just if thermal paths of both regulators are identical, leading also to an optimum thermal transfer. If VR have low R_{JC} cases, then by isolating one VR, strong unbalanced voltages drop are needed to equalize junction temperature. For voltage unbalanced voltages drop, the maximum input voltage range must be lower to protect against breakdown the input VR [3]. Low R_{JC} involve a tradeoff between equalizing junction temperatures or voltage drop across VR.

IV. CONCLUSIONS

High input voltage, wide output voltage range stabilizer was achieved by series connecting two voltage regulators, and equally distribute voltage drop across them. Solution can obtain optimum thermal transfer for identical thermal paths for both regulators. Having identical thermal paths, proposed solution lead to maximum input voltage range being twice the range of a single VR, in this case the equivalent SOA of proposed stabilizer representing twice the SOA of each regulator. As disadvantages of our proposal, we mention the increasing of V_{DMIN} to $2*V_{DMIN}$, and a low extension of the SOA for low thermal resistance cases, when tradeoffs between input voltage range maximum current at high voltage drops are demanded.

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