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A RADIATION-HARDENED LOW-DROPOUT VOLTAGE REGULATOR FOR LHC AND SPACE APPLICATIONS.

G. Bonna(1), A. Imbruglia (1), H. Duperray (3), P. Jarron (2), F. Faccio (2), A. Bigga (2), M. Glaser (2), B. Roberts (2)

(1) STMicroelectronics, Catane, Italy
(2) CERN Geneva, Switzerland
(3) STMicroelectronics, Rennes, France

1. Abstract

In the LHC experiments, standard voltage regulators are placed in the detector or in the experimental hall and have to function in a challenging radiation environment. At present, there is not radiation-hardened low-dropout voltage regulator available hardened to total dose and displacement damage. Charged hardrons and neutrons dominate the LHC environment and such particles induce displacement damage in semiconductors severely deteriorating in such a way the performances of voltage regulators manufactured in lightly-doped high-voltage bipolar technologies. In addition total ionizing dose effects contribute to the performances deterioration in a way that is difficult to quantify experimentally due to the presence of Low Dose Rate Effects (LDRE). Based on a previous study of a bipolar radiation-hardened technology presented at the LEB conference in Rome in 1998, a radiation-hardened voltage-regulator has been developed by STMicroelectronics under a CERN RD49 contract. Specifications, performances and radiation response to total dose, neutrons and protons are presented.

2. Device outline

During the last two years at STMicroelectronics Laboratories of Catane the elementary structures of a ST proprietary technology, RHBip1, have been evaluated in its ability at working under irradiation and upgraded. The most relevant results have been presented at the 4th workshop in Rome last year [1]. A qualitative sinthesys is shown in fig.1.

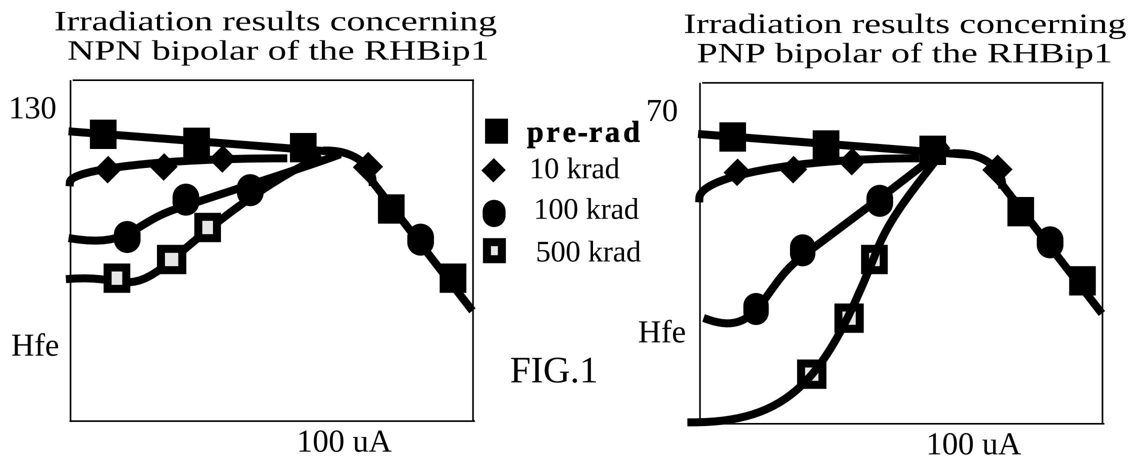


FIG.1

Following the outcomes concerning Total Dose Effects (TDE), Low-Dose Rate Effects (LDRE) and Neutrons, a radiation-hardened voltage regulator able to operate in LHC and Space applications has been developed. The initial target was that of getting a device still able to work after an exposure to a radiation dose of 500 krad with a degradation of the performances of no more than 30 percent compared to the pre-rad condition.

Fig 2 shows an overview of the block schematic.

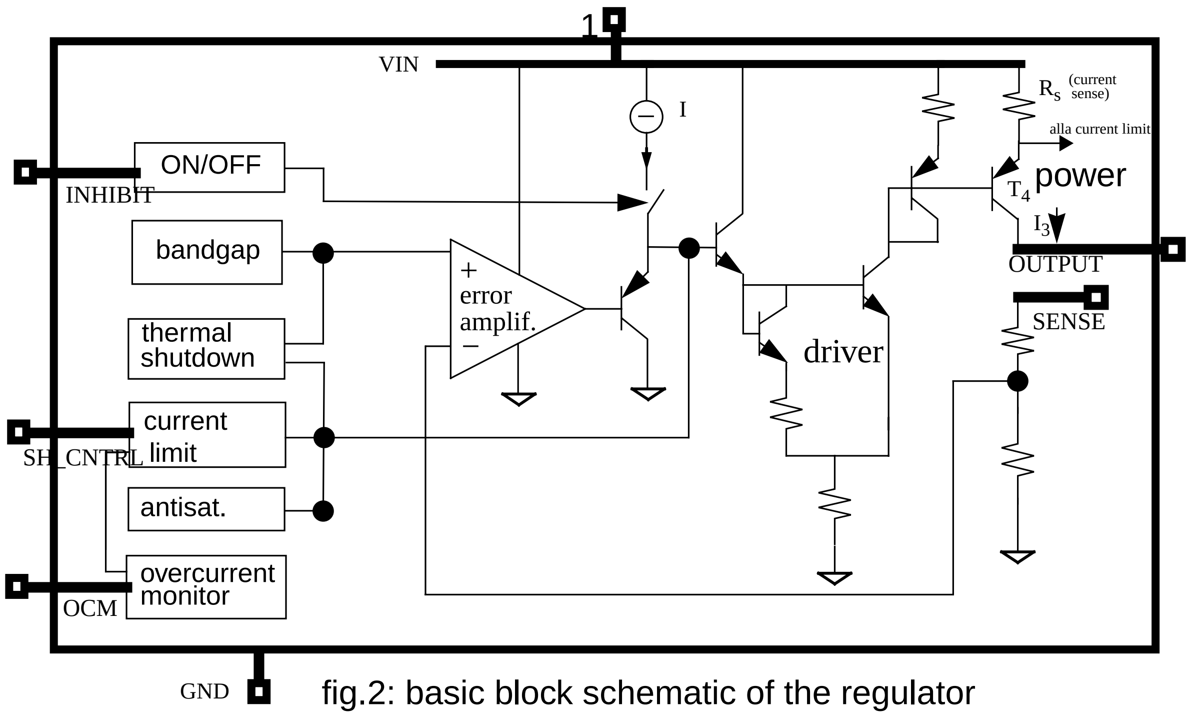


fig.2: basic block schematic of the regulator

Apart from the circuitry usually implemented (feedback regulation loop, thermal and current limit protection, internal voltage reference) it includes among other an overcurrent monitor. This latter operates under the control of the current limit section giving on the pin OCM a voltage level of 0.4 volts whenever this protection intervenes at limiting the current at the OUTPUT pin. Being the OCM pulled-up by an internal resistor to VIN, under normal operating conditions the relative voltage levels are concident.

Others features are:

.possibility of adjusting the short circuit current within 30 % of its typical value by placing an external resistor between the SH_CNTRL and VIN pins;

.a remote sensing, allowing the regulator to function with an the output load far from it;

.possibility of controlling the OFF/ON switching of the device trough an INHIBIT pin.

Even if the general architecture is basically similar to that of a conventional linear regulator, each block has been designed in order to minimize as much as possible the performances degradation under radiation operation. This has been achieved by making use of proper rules during both the schematic and the layout phases, some of them coming from the experimental issues told before and others are in ST proprietary know-how in rad-hard design practice..

An overview of the main target specifications is given in fig. 3.

FIG. 3

Parameter	Test conditions	Min.	Typ	Max	Unit
Output voltage accuracy (Vo)	Iout=5mA, Vin=Vout+2	-2		2	%
Operating input voltage (Vin)	Io=3A	1.25		9.7	V
Current Limit	Adjustable from 1 to 4.5 A	1		4.5	A
Line regulation	Vo+1<Vin<12V		1		%
Load regulation	5mA <Iout<3A, Vin=Vo+1		2		%
Quiescent current (Iq)	Vo+2.3<Vin<12, Iout = 0 mA		2 m		A
	Iout= 3 A		50 m	200m	A
	Vin=Vo+2, OFF mode		50u		A
SVR	Vin=Vo+2, Io=5mA f=120 Hz		60		dB
	f=33 Khz		30		dB
Dropout voltage	Io=1A		0.5		V
	Io=3 A		1.5		V
Inhibit voltage (OFF mode)		2			V
Inhibit voltage (ON mode)				0.8	V
Inhibit input current			10u		A
Output impedance	100 mA DC; 20 mA rms		100m		Ohms
Output noise voltage			400u		Vrms

3. Characterization tests results.

Some of the tests have been performed at CERN laboratories in Geneve. Up to now the responses in terms of line and load regulation have been checked by using the following radiations sources:

.Co-60 up to 1.3 Mrad at ESA-ESTEC
.total dose by X-ray 10 KeV up to 4 Mrad
.neutron fluence up to 10^{13} n/cm^2
.proton fluence up to 5 x 10^{13} p/cm^2

A selection among the most significant results is presented at page 6. All values on y-axis are expressed in percent units with respect to the nominal output voltage.

Others measurements have also been done at ST Catane. They are not set out in this paper because of no concern for an evaluation of the response under radiation.

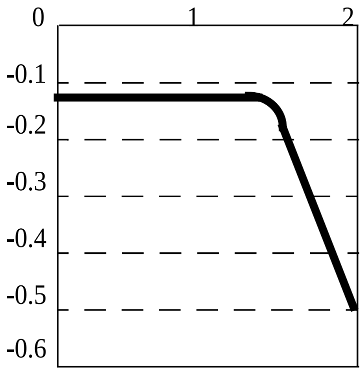
4. Conclusion

So far this first study has demonstrated that this regulators is radiation-hard, as it was designed to be. It survived protons, neutrons and gamma rays with few changes of their line and load regulation graphs. Further study will be done for various biasing conditions, in order to check the variation of other important parameters such as dropout voltage and output noise voltage. Finally, another important investigation will be pursued to different fabrication lots for a quantitative analysis of the parameters spreading.

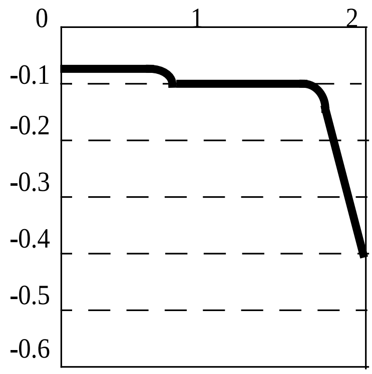
References:

[1] S. Caruso and others - “RHBip1 evaluation to total dose, Low Dose rate and Neutrons for a voltage regulator applications for LHC experiments.” - paper presented at 4th workshop on electr. for LHC experim., Rome, 1998.

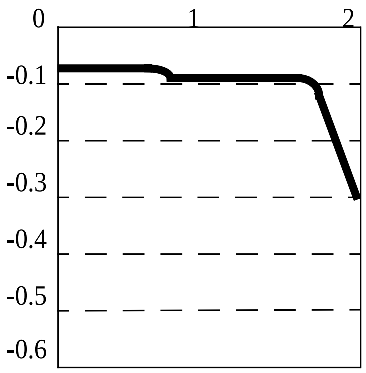
Load regulation before radiation



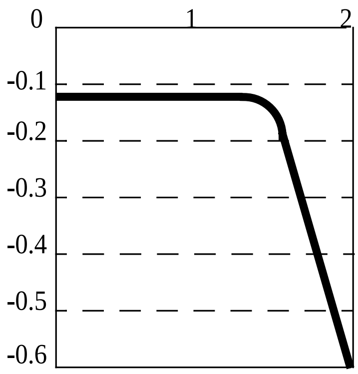
Load regulation after 3.9 Mrad x-rays



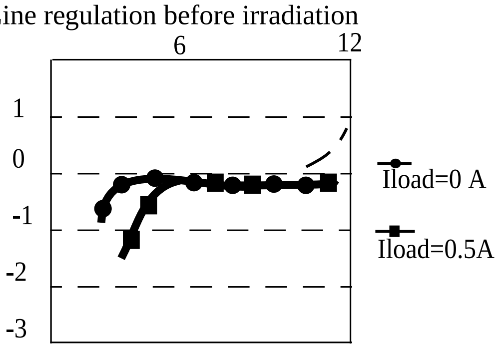
Load regulation after 10^{13} neut./cm^2



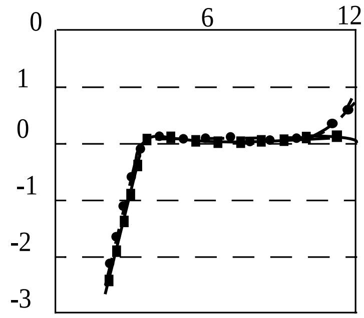
Load regulation after 10^{13} prot/cm^2



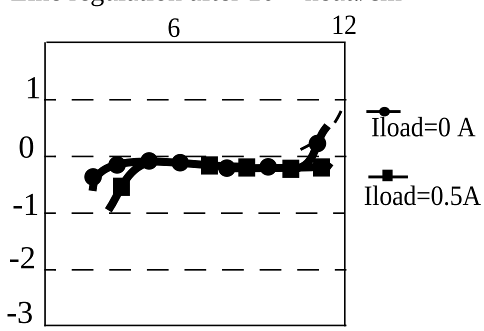
Line regulation before irradiation



Line regulation after 3.9Mrad x-rays



Line regulation after 10^{13} neut./cm^2



Line regulation after 10^{13} prot./cm^2