SPICE Modeling of Neutron Displacement Damage in Bipolar Amplifier

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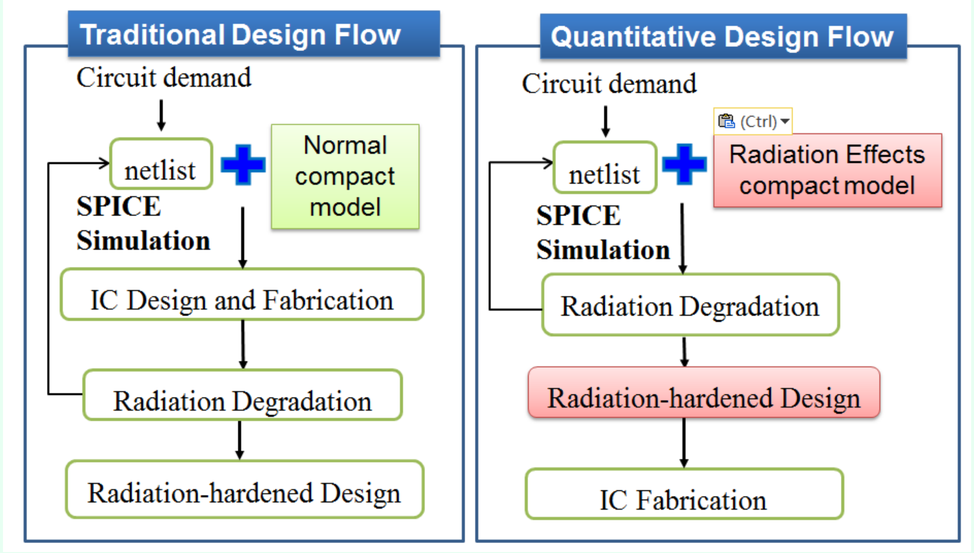
Introduction

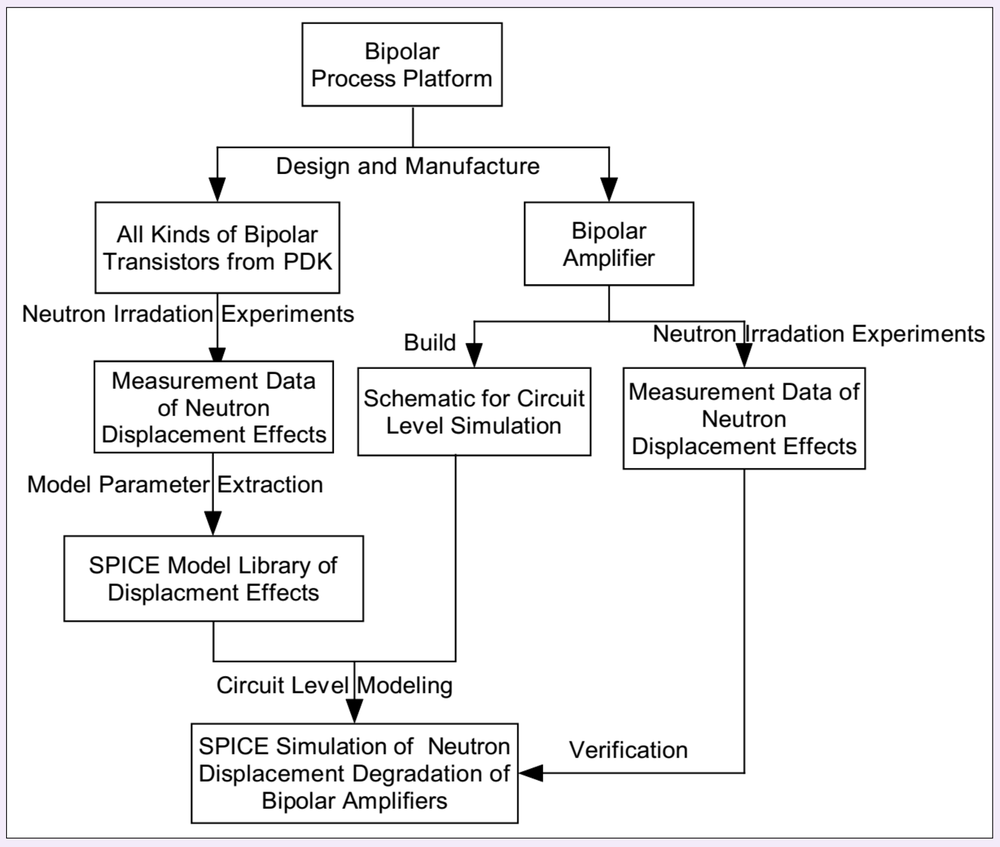
It is very essential to predict the circuit's performance under irradiation based on SPICE simulation prior to their fabrication.



Our work: circuit modeling method of neutron displacement effects in bipolar analog integrated circuits was developed.

Modeling Methods and Simulation Results

SPICE modeling flow and methods:



Bipolar process platform:

- WX40 technology by ANALOG FOUNDRIES, Chongqing, China
- 32 types of bipolar transistors in PDK totally, including VNPN, SPNP, LPNP

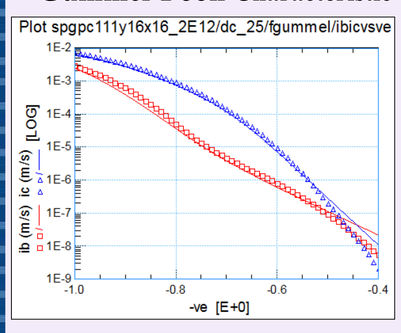
Model framework:

- Gummel-Poon (GP) model is selected for the development of neutron displacement effects SPICE compact model.

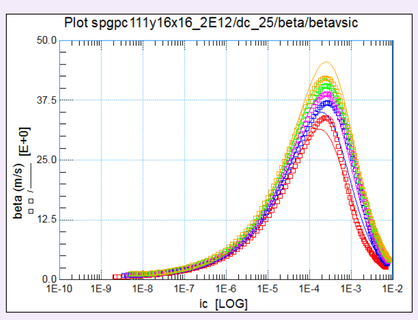
Measuring method of electrical characteristics and corresponding extracted model parameters of the transistors exposed to neutrons:

Electrical Characteristic	Testing Method	Extracted parameter
Gummel-Poon Characteristic	BC shorted to ground, testing IB and IC vs VE	BF, IS, ISE, IKF, NF, NE, NKF, RE, RB
Gain Characteristic	B grounded, VC fixed, testing IC, IB vs VE	BF, ISE, IKF， VAF, NE, NKF, RE, RB, RC
Forward Early Characteristic	E grounded, VB fixed, testing IC vs VC	IS, IKF, VAF, NF, NE, NKF, RE, RB

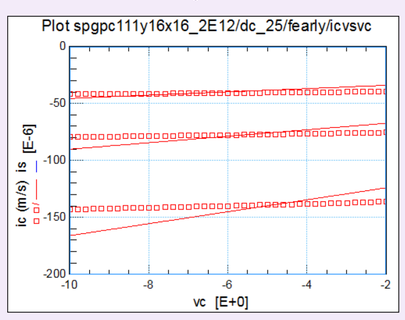
Gummel-Poon Characteristic



Gain Characteristic

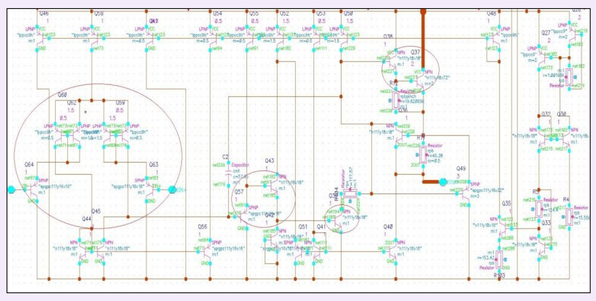


Forward Early Characteristic



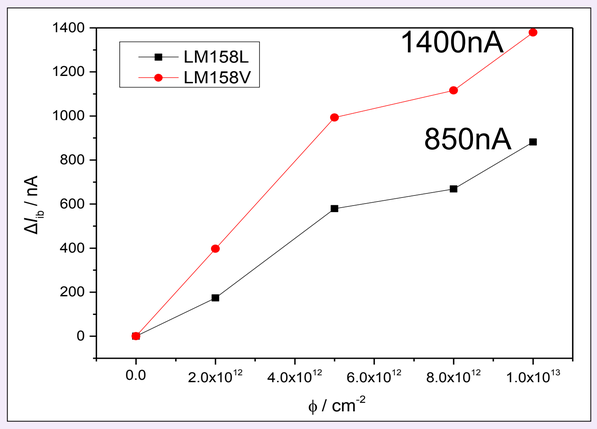
Modeling Methods and Simulation Results

Schematic of LM158V and LM158L bipolar amplifiers for SPICE simulation:



Only input transistors are different for 2 types of amplifiers, other transistors are identical.

Input transistor	LM158V amplifier	LM158L amplifier
Q1 Q2	spgpc111y16x16	lppcc9
	SPNP	LPNP



Simulation results:

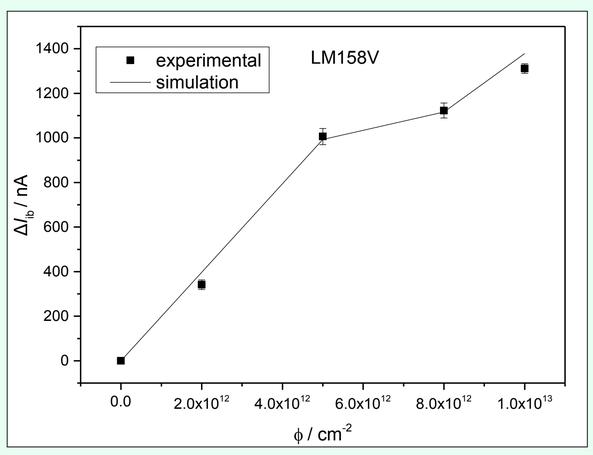
- With the increase of neutron fluence, the input bias current degradation of the amplifiers increase monotonously.
- LM158V degrades more severely than LM158L (about 1.65 times).

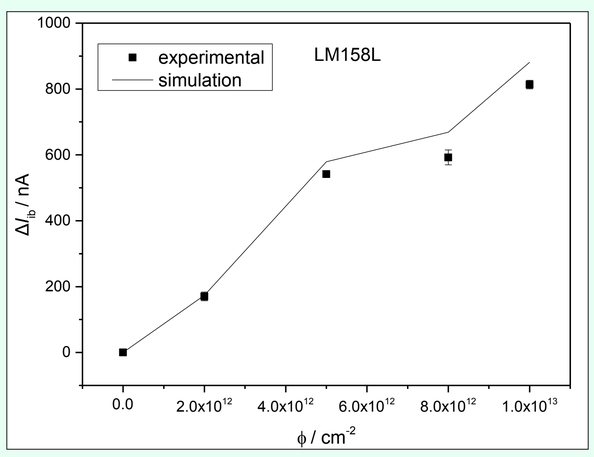
Experimental Verification

Neutron Irradiation Experiments for LM158V and LM158L bipolar amplifiers at Xi'an Pulsed Reactor (XAPR):

Item	Condition
Neutron Fluence (cm^{-2})	2.0×10^{12} cm^{-2}, 4.0×10^{12} cm^{-2}, 6.0×10^{12} cm^{-2}, 8.0×10^{12} cm^{-2} and 1.0×10^{13} cm^{-2} consistent with the simulation condition
Number of Samples	more than 6 at each neutron fluence
Bias Condition	all pins shorted without electrical bias
Measurement after exposure	input bias current of each amplifier sample

The average value and standard deviation of input bias current degradation of all the samples was calculated to make a comparison with SPICE simulation results:





The RMS error between simulation and experimental results is within 16.4%.

As the simulation predicted, LM158V with SPNP input transistor degrades more severely than LM158L LPNP input transistor.

Summary

SPICE modeling method of neutron displacement degradation in bipolar amplifiers is developed based on neutron displacement effects SPICE model library for bipolar transistors from PDK. For LM158L and LM158V amplifiers with LPNP and SPNP input transistors respectively, the SPICE simulation results well predicts the degradation performance exposed to neutrons with different fluence, and the RMS error between SPICE simulation and experimental results is within 16.4%.