ELECTRONIC DESIGNS VERIFICATION BY WORST CASE CIRCUIT ANALYSIS METHOD

Mircea I. Mihaiu*, Gheorghe Grama,**

University of Craiova, Faculty of Automation, Computers and Electronics, Electronics and Instrumentation Department, The Institute for System Analysis- INAS, Craiova*

Abstract: In the papaer is presented the Worst Case Circuit Analysis method for electronic design verification. The method was developed by NASA in years 90 and then was applied to aerospatial, medical and automotive industry. For 3 years University of Craiova and INAS Craiova applied the WCCA method to the automotive industry in colaboration with a large US company. First we present the advanteges and disadvanteges of the WCCA metdods, then is presented a comparaison between the usual methods EVA, RSS and Monte Carlo . Finaly an example is presented and a step by step method for applying WCCA method.

Keywords: Wost Case Circuit Analysis, Electronic Design Verification, Increase the realiability.

1. WORST CASE CIRCUIT ANALYSIS- THE NEW METHOD FOR DESIGNS VERIFICATION

Worst case circuit analysis (WCCA) is a technique which, by accounting for components variability determines circuit performance under a worst case scenario, i.e., under extreme environmental or operating conditions. Environmental conditions are defined as external stress applied to each circuit component, and can include temperature humidity or radiation. Operating conditions include external electrical inputs, but also consider factor such as components quality level, interaction between parts, and drift due to component aging. The output of a WCCA allows an assessment of actual applied part stress against rated part parameters. WCCA should be considered for all circuitry that is safety and/or financially critical. Performance of a WCCA, and implementation of its results, can help identify design problems and alternatives that can reduce financial, legal and safety risk to the manufacturer, and help ensure satisfactory performance for the customer under virtually all operating conditions.

The methods described for developing a worst-case parts variation database and sensitivity analysis, as well as extreme value analysis (EVA), root-sum-square (RSS), and Monte Carlo analysis for solving circuit equations and combining variables, have become accepted industry standards over the last eight years. In addition to a circuit analysis, a WCCA often includes stress and derating analysis, **Failure Modes and Effects Criticality (FMECA)** and Reliability Prediction (**MTBF**). The **Stress and Derating Analysis** is intended to increase reliability by providing sufficient margin compared to the allowable stress limits. This reduces overstress conditions that may induce failure, and reduces the rate of stress-induced parameter change over life. It determines the maximum applied stress to each component in the system.

A WCCA follows this general form:

- Generate/Obtain circuit model
- Obtain Correlation to validate model
- Determine sensitivity to each component parameter
- Determine component tolerances
- Calculate the variance of each component parameter as sensitivity times absolute tolerance
- Use at least two methods of analysis (eg. hand analysis and SPICE or Saber, SPICE and measured data) to assure the result
- Generate a formal report to convey the information produced.

The design is broken down into the appropriate functional sections. A mathematical model of the circuit is developed and the effects of various part/system tolerances are applied. The circuit's EVA and RSS results are determined for Beginning-of-Life and End-of-Life states. WCCA helps ensure increased product reliability. Benefits from WCCA:

- Assure acceptable operation throughout the entire product life cycle under the most unfavorable combination of anticipated conditions [Worst Case Extreme Value Analysis (EVA)]
- Define Critical Components and Spec. Control Drawing (SCD) Limits
- Provide Acceptance Test Procedure (ATP) Limits
- Define Need for and Range of Select-At-Test (SAT) components
- Improve Reliability through Parts Stress and Derating analysis
- Identify design concerns which during test, alignment, and use could result in circuit damage or premature degradation. WCCA is not a candidate for elimination when there are cost overruns.

2. THE METHODS USED TO PERFORM WORST CASE CIRCUIT ANALYSIS

There are three methods used for WCCA:

- Extreme Value Analysis (EVA)
- Root-Sum-Squared (RSS)
- Monte Carlo Analysis (MCA)

The advantages and disadvantages of the three major WCCA methods are presented in Table 1.

Method	Advantages	Disadvantages
Extreme Value Analysis (EVA)	- Most readily obtainable estimate of worst case performance, - Does not require statistical inputs for circuit parameters - Database need only supply part parameter variation extremes - If circuit passes EVA, it will always function properly	- Pessimistic estimate of circuit worst case performance - If circuits fails, there is insufficient data to assess risk
Root-Sum-Squared (RSS)	-More realistic estimate of worst case performance than EVA - Knowledge of part parameter probability density function (pdf) is not required - Provided a limited degree of risk assessment	- Standard deviation of piece part parameter probability distribution is required - Assumes circuit sensitivities remain constant over range of parameter variability - Assumes circuit performance variability follow a normal distribution
Monte Carlo Analysis (MCA)	-Provide the most realistic estimate of true worst case performance - Provides additional information in support of circuit/ product risk assessment	- Require use of computer - Consume a large amount of CPU time - Require knowledge of part parameter (pdf)

The typical cost of performing a rigorous WCCA is generally less than 1% of the program cost. The cost of not doing the WCCA can cost 100% of the program cost. There are many program failures, which required at the least, major redesigns AFTER completion of qualification testing. This costs enormous amounts of time and money. The worst case analysis is used to demonstrate sufficient operating margins for all operating conditions in electronic circuits.

The WCCA analysis was developed first time by NASA JPL in the years 90 (NASA-90) and then the new method was applied to Aerospatiale industry, medical electronics equipment (Smith 95) and military applications (HAD 200). The first university papers was published in the years 2000 by Berkley laboratory at the Massachusetts Institute of Technology (Blarin 99, Balarin 01). The first book on the field was published in 2000 year (Boyd 99). In the year 2005 the first European standard was published in the field of WCCA (ECSS 05).

3. EXAMPLE OF EVA CIRCUIT SIMULATION

An example of WCCA is applied to 10V Voltage Regulator using PSpice Simulator. The circuit schematic is presented in Fig.1.

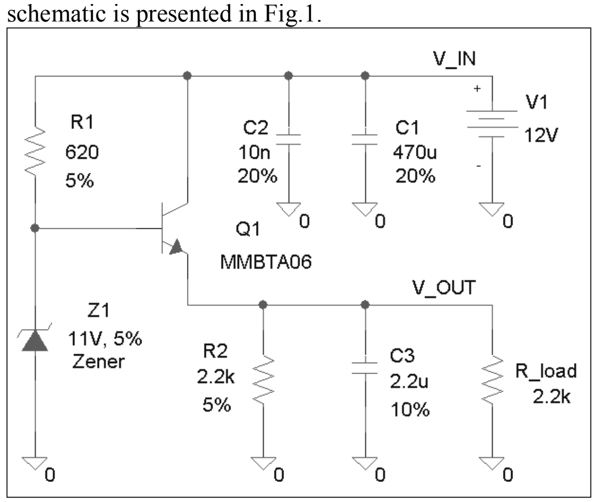

Figure 1

This circuit is an emitter follower supplied by the 12V battery voltage and provides 10V regulated voltage to the output. The output voltage is equal to the reference voltage provided by Z1 minus base emitter voltage of Q1 working in linear region.

Component Description

- Q1 is NPN general-purpose bipolar transistor (MMBTA06) used in emitter follower connection.
- Z1 is 11V, 5% small signal zener diode (BZX84-C11) providing the reference voltage.
- C1 is input filter capacitor.
- C2 is EMI (Electromagnetic Interferences) bypass capacitor.
- C3 is output filter capacitor.
- R1 drive the base of Q1and also limits the current through Z1.
- R2 is output resistor – ensures a collector current of Q1 keeping it in linear region when the load is temporary lost.
- R_load is 2.2k, 10% resistive load.

Assumptions

- We assume ± 10% value variation, including temperature coefficient and aging, for resistors with ± 5% tolerance.
- We assume ± 30% value variation, including temperature coefficient and aging, for ceramic capacitors with ± 10% tolerance.
- We assume ± 40% value variation, including temperature coefficient and aging, for ceramic capacitors with ± 20% tolerance.
- We assume + 25%, -50% value variation, including temperature coefficient and aging, for aluminum capacitors with ±20% tolerance.

Component's Extreme Values:

Param.	Tol.	Nom.	Min.	Max.	Comments
V_IN	-	12V	9V	16V	Cust Spec.
Temp	-	25^0C	-40^0C	105^0C	Cust Spec.
R1	± 10%	620	558	682	-
R2	± 10%	2.2k	1.98k	2.42k	-
R_ load	± 10%	2.2k	1.98k	2.42k	Cust Spec.
C1	+25%, -50%	470uF	235uF	587.5uF	-
C2	± 40%	10nF	6nF	14nF	-
C3	± 30%	2.2uF	1.54uF	2.86uF	-
VZ_Z1	-	11V	9.815V	12.02V	Adj Data.
β_Q1	-	180	70	435	Adj Data.
VBE(on)_Q1	-	680mV	450mV	875mV	Adj Data.

The analysis will have the following requirements:

1. *Calculate the nominal output voltage.*
2. *Calculate the minimum output voltage.*
3. *Calculate the maximum output voltage.*

ANALYSIS:

Operating Point (Nominal Analysis)

1.Calculate the nominal output voltage.

The nominal output voltage is calculated at Temp = 25^0C, and all the components have the nominal values.

V_OUTnom = 10.32V

- Worst Case Analysis (WCA - EVA)

Sensitivity analysis is done by PSpice Simulator.

1.Calculate the minimum output voltage.

Worst case conditions: Temp = -40^0C, V_IN minimum, β_Q1 minimum, VBE(on)_Q1, maximum, R1 maximum, R2 minimum, R_load minimum, VZ_Z1 minimum. All the other component values have no influence.

V_OUTmin = 8.125V *(This value is so low because the Zener diode is out of regulation).*

2.Calculate the maximum output voltage.

Worst case conditions: Temp = 105^0C, V_IN maximum, β_Q1 maximum, VBE(on)_Q1minimum, R1 minimum, R2 maximum, R_load maximum, VZ_Z1 maximum. All the other component values have no influence.

V_OUTmax = 11.57V

3. Conclusions:

The minimum and maximum output voltage values are purely theoretical and hard to achieve in reality. If these values satisfy the customer requirements everything will be fine. If not, the customer could either assume the risk or ask to optimize the circuit with a minimum cost added.

4.WCCA METHOD STEP BY STEP

Performing WCCA means a step by step procedure.

A.The preliminary procedure begin with some review of information and methods.

1. In the first step the analyse must begin with:
- rewiew of requirements
- review of part database
- review of available analysis techniques

2. In the second step it is necesary to identify critical functions where a WCCA must be performed. The inputs of this step are:
- FMECA- Failure Modes Effect Criticality Analysis
- Sneak analysis,
- Fault tree analysis,
- Hazard analysis
- Radiation analysis.

B. The main analyze with WCCA method begin with:

1. Circuit partitioning .Each electronic equipment must be partitioned in functional circuits. For each circuit the inputs and outputs signals are required and the worst case variation of this signals must be presented. Some signals are from other sub circuits.
2. Critical circuit parameter selection. The specification of each component in sub circuits must be analyzed in worst case scenario. A database with the extended specification must be designed.
3. Circuit models and equation. Each component in the sub circuit must be analyzed by EVA, RSS or Monte Carlo methods. First the models of the components must be choose and then the simulation or modeling procedure must begin.

4. Results. The simulation or modeling procedure give us some results. The results must be analyzed to obtain the real values of output signals and compare this signals with conformance signals.
5. Conclusions. After the analyze of the results some conclusion must be done. There are:
- Yes the sub circuit carry out all the specifications or some nonconformance are accepted.
- Not acceptable. The circuit fails to respect the specifications. The circuit must be redesign.
C. The final procedure .Each WCCA ends with a final rapport. In this rapport must be presented all simulation and modeling results with adequate conclusions.

4. CONCLUSIONS

There are many benefits from WCCA:
-Assure acceptable operation throughout the entire product life cycle under the most unfavorable combination of anticipated conditions [Worst Case Extreme Value Analysis (EVA)]
- Define Critical Components and Spec. Control Drawing (SCD) Limits
- Provide Acceptance Test Procedure (ATP) Limits
- Define Need for and Range of Select-At-Test (SAT) components
- Improve Reliability through Parts Stress and Derating analysis
- Identify design concerns which during test, alignment, and use could result in circuit damage or premature degradation.
WCCA helps ensure increased product reliability. This is accomplished through rigorous mathematical and simulation-based models along with hardware correlation. Correlated models are then used to determine part stress margins, and EOL/BOL product operating specifications. A single over-stressed component can cost a company millions of dollars. A thorough Worst Case Analysis can eliminate this from happening.
Can't electrical testing be used as a less expensive an alternative? The answer is generally "No". Testing normally only determines Beginning of Life (BOL) performance. In many cases extended testing needs to be performed with extreme operating conditions such as temperature, voltage, power, etc. in order to determine End-Of-Life (EOL) margins. This can overstress the hardware. Testing is only valid for the measured lot and may vary lot to lot and manufacturer to manufacturer. It requires the parts to be procured PRIOR to completion of the WCCA, which can be Very RISKY!! And it can be very costly if many measurements are required.

REFERENCES

NASA ,JPL, Jet Propulsion Laboratory, (1990) - *Reliability Analyses Handbook*- prepared by Project reliability Group,

Randal. E. Bryant, Lawrence P. Huang, -(1994), *Geometric characterization of series parallel variable resistor networks*-, IEEE, Transaction on Circuits and Systems, I: Fundamental Theory and Applications, 41, pp. 686-698

Design and Evaluation, Inc.,(1995)*, Worst Case Circuit Analysis- One Day Course,*

NASA-STD-8729-1,(1998) -*PLANNING, DEVELOPING AND MANAGING AN EFFECTIVE RELIABILITY AND MAINTAINABILITY (R&M) PROGRAM*,

Walter M. Smith, (1999) -*CIRCUIT ANALYSIS: Worst-Case Circuit Analysis for Electronics parts*-, Medical Electronics Manufacturing,

Felice Balarin,(1999), *Worst-case analysis of discrete systems*-, -Cadence Berkley Laboratories , www.sigda.org

Felice Balarin,(2001), *A STARS in VCC: complementing simulation with worst-case analysis*-, -Cadence Berkley Labs, Berkley , www.sigda.org

Ramazan Gengay, F. Selguk, A. Ulugulyagci,(2001) -*EVIM- A software Package for Extreme Value Analysis in MATLAB*-, Studies in Nonlinear Dynamics&Econometrix, Vol.5, Issue 3,

Headquarter Departments of the Army,(2003) -*RELIABILITY/AVAILABILITY OF ELECTRICAL& MECHANICAL SYSTEM FOR COMMAND, CONTROL, COMMUNICATIONS, COMPUTER, INTELLIGENCE, SURVEILLANCE AND RECONNAISSANCE (C4ISR) FACILITIES-, TECHNICAL MANUAL* tm 5-698-1,

AEI Systems,(2003) *How Worst case Analysis Save Money*, 2003, www.aeng.com/wca.asp

DALLAS Semiconductor &MAXIM,(2003) -*Statistical Circuit Analysis with EXCEL*-, Application notes,

Ron Mancini (Texas Instruments),(2004) -*Worst-case circuit design includes component tolerances*-, EDN,

Reliability Analysis Center (RAC),(2004) -*Worst Case Circuit Analysis(WCCA)*-, RAC, 201, Mill Street, Rome, NY, 13440-6916

European Cooperation for Space Standardization (ECSS), (2005) -*Space product assurance-Worst case circuit performance analysis*-, ECSS-Q-30-01A,

Robert Boyd, (1999) -*Tolerance Analysis of Electron Circuits Using MathCAD*-, CRC Press, ISBN 0849323398