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Worst Case Circuit Analysis (WCCA) White Paper

Worst case circuit analysis (WCCA) is a technique which, by accounting for component variability, determines circuit performance under a worst case scenario, i.e., under extreme environmental or operating conditions. Environmental conditions are defined as external stresses applied to each circuit component, and can include temperature, humidity or radiation. Operating conditions include external electrical inputs, but must also consider factors such as component quality level, interaction between parts, and drift due to component aging. The output of a WCCA allows an assessment of actual applied part stresses against rated part parameters. This can help ensure sufficient part stress derating to meet design requirements. 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 risks to the manufacturer, and help ensure satisfactory performance for the customer under virtually all operating conditions. The advantages and disadvantages of the three major WCCA methods are presented in Table 1. A capacitor example is shown in Table 2. The WCCA process is outlined in Table 3.

One of the most critical steps involved in completing a meaningful WCCA is the development of a part characteristic database. This database contains a composite of information necessary for quantifying sources of component parameter variation. Once these sources have been identified, the database can be used to calculate worst case component drift for critical parameters. Quantifying the contribution of environmental effects on component variability (as will be illustrated in an example) is also a critical step in the development of a WCCA. A number of starting places can be used to establish random and biased contributions to variability. They maybe summarized as:

- Company data (historical test data from other products, or special test programs)
- Vendor data (documentation of test conditions, sample size, number of lots, etc., is needed)
- Military specifications (tend to be very conservative)
- Outside sources (e.g., Jet Propulsion Lab for radiation data)

Actual field performance indicates that components tend to drift beyond initial tolerance levels. The magnitude of component tolerance variation is dependent on a variety of sources, as illustrated in Table 4. When conducting a worst case circuit performance analysis, the key elements to be examined within the system are dependent upon the intended function of the circuit. Critical timing of digital circuits, transfer functions of filtering networks, and characteristics of amplifiers are examples of circuit performance elements. Table 5 describes those parameters which should be analyzed in a worst case performance analysis for digital and analog circuits.

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Methodology

Part statistics are based on two types of component variation: random and bias. Random variation is not predictable in direction. Bias, however, is predictable given known inputs. All sources of component variation can be grouped into one of these effects. The effects are subsequently combined to give an overall indication of part variability. Addition of individual random and biased variables is as follows:

- Bias Effects – Added Algebraically
- Random Effects – Root Sum Squared (±3σ limits of a normally distributed population)

Determination of the minimum and maximum limits of component value due to drift is as follows:

$$\text{Worst Case Minimum} = \text{Nominal Value} - (\text{Nominal Value} \times \Sigma\,|\,\text{Negative Biases}\,|\,) - \left(\text{Nominal Value} \times \sqrt{\Sigma\,(\text{Random Effects})^2}\right)$$

$$\text{Worst Case Maximum} = \text{Nominal Value} + (\text{Nominal Value} \times \Sigma\,|\,\text{Positive Biases}\,|\,) + \left(\text{Nominal Value} \times \sqrt{\Sigma\,(\text{Random Effects})^2}\right)$$

Table 1. WCCA Analysis Methods

Method	Advantages	Disadvantages
Extreme Value Analysis (EVA)	• Most readily obtainable estimate of worst case performance (best initial WCCA approach) • Does not require statistical inputs for circuit parameters (easiest to apply) • Database need only supply part parameter variation extremes (easiest to apply) • If circuit passes EVA, it will always function properly (high confidence for critical production applications)	• Pessimistic estimate of circuit worst case performance • If circuit fails, there is insufficient data to assess risk (modify circuit to meet EVA requirements, or apply RSS or MCA for less conservatism)
Root-Sum-Squared (RSS)	• More realistic estimate of worst case performance than EVA • Knowledge of part parameter probability density function (pdf) is not required • Provides a limited degree of risk assessment (% of units to pass or fail)	• Standard deviation (σ) of piece part parameter probability distribution is required • Assumes circuit sensitivities remain constant over range of parameter variability • Assumes circuit performance variability follows a normal distribution
Monte Carlo Analysis (MCA)	• Provides the most realistic estimate of true worst case performance • Provides additional information in support of circuit/product risk assessment	• Requires use of computer • Consumes a large amount of CPU time • Requires knowledge of part parameter pdf

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Calculation of Capacitor Minimum and Maximum Values

The following example illustrates a representative calculation for determining the worst case minimum and maximum values for a 1200 μF CLR capacitor. These parameters are used to determine the potential resultant effect of CLR capacitor drift on circuit applications.

Table 2. Capacitor Example

Parameters: Capacitance	**Bias (%)**		**Random (%)**
	Neg.	**Pos.**	
Initial Tolerance at 25°C	--	--	20
Low Temp. (-20°C)	28	--	--
High Temp. (+80°C)	--	17	--
Other-Envt's (Hard Vacuum)	20	--	--
Radiation (10KR, 10^{13} N/cm^2)	--	12	--
Aging	--	--	10
TOTAL VARIATION	48	29	$\sqrt{(20)^2 + (10)^2} = 22.4$

where:

Worst Case Minimum = - 48 - 22.4 = -70.4%
Worst Case Maximum = + 29 + 22.4 = +51.4%
Worst Case Minimum Capacitance = $1200\mu f - 1200\mu f\,(\,|-.48| + .224) = 355.2\mu f$
Worst Case Maximum Capacitance = $1200\mu f + 1200\mu f\,(\,|+.29| + .224) = 1816.8\mu f$

Table 3. Worst Case Circuit Analysis Process

Action	**Rationale**
Determine Analysis Approach	• Full analysis vs. circuit partitioning to critical functions • Define the circuitry to be analyzed (analog, digital, etc.) • Determine availability of component data • Identify the tools available to support the analysis
Obtain the Data • Performance Requirements and Specifications • Schematics and Block Diagrams • Interconnection Lists and Wiring Diagrams • Full Parts Lists • Theory of Operation • Product Operational Environments • Product Operational Configurations • Thermal Design Analysis	• Analyst must be knowledgeable of the circuit and parameters being examined, including timing diagrams where appropriate

Worst Case Circuit Analysis (WCCA) (Cont'd)

Table 3. Worst Case Circuit Analysis Process (Cont'd)

Action	Rationale
Plan the Analysis • Develop a Functional Breakdown and Theory of Operation • Establish the Analysis Scope • Develop a Part Parameter Database (See Table 2, 4, and 5)	• Functional breakdown should include block diagrams that outline major sub functions • Block diagrams should detail all functional interactions (inputs and outputs) • Primary considerations include analysis of worst case circuit performance, and analysis of proper part application (i.e., derating) • Secondary considerations may include circuit shielding, noise, EMI, ground loops and temperature control • Critical part parameters include environmental (ambient and self-heating temperature, vibration, humidity, radiation) and component aging characteristics
• Identify Method of Analysis (See Table 1)	• Extreme Value Analysis (EVA) is easiest to apply. Analysis of a given circuit/product under simultaneous worst case parts limits. Results are conservative. • Root-Sum-Squared (RSS) is a statistical approach. Results are more realistic than EVA, but methodology is more labor intensive. • Monte Carlo Analysis (MCA) randomly selects part parameters and analyzes resulting system performance. Many simulations (typically 1,000 to 50,000 runs) must be made. Piece-part parameter statistical distributions must be known (or assumed normal).
Perform the Analysis • Worst Case Stress Analysis • Worst Case Performance Analysis	• Identifies components that are overstressed under worst case conditions (or exceed product derating guidelines) • Analyze circuit to determine if performance under worst case conditions is achieved (simultaneous change of environmental conditions and part parameters to their worst realizable extremes) • For circuit partitioning, minimize the active components to as few logical blocks as possible • Include circuit and timing diagrams, as appropriate, in the analysis • Compare WCCA results with the specifications, documenting all inconsistencies
Document the Results	• Analysis results should be verifiable (document or reference all information used to develop the analysis - circuit equations, part data sources, and circuit simulation tools used) • If problems are found during the analysis, develop and propose potential fixes and alternative solutions

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Table 4. Effected Parameters vs. Source of Variation

Component Type	Environmental Source of Variation	Parameter Effected
Bipolar/Field Effect Transistors	Temperature	H_{FE} (Bias) , V_{BE} (Bias) I_{CBO} (Bias) RDS_{ON} (Bias) , V_{TH} (Bias)
	Radiation	H_{FE} (Bias) , I_{CBO} (Bias) V_{CE} (Saturation) (Random & Bias) V_{TH} (Bias)
Rectifiers/Switching Diodes	Temperature	V_F (Bias) , T_S (Bias) , I_R (Bias)
	Radiation	I_R (Bias) , V_F (Bias)
Zener Diodes	Temperature	V_Z (Bias) , (Sometimes Random) Z_Z (Bias)
Resistors	Temperature	Resistance (Bias & Random, Random)
	Humidity	Resistance (Bias) Carbon Composition
	Aging (Powered)	Resistance (Bias & Random)
	Life (Unpowered)	Resistance (Bias & Random)
	Vacuum	Resistance (Bias)
	Mechanical	Resistance (Bias & Random)
Capacitors	Temperature	Capacitance (Bias and/or Random) ESR (Bias), DF (Bias, Non Linear)
	Aging	ESR (Bias), Capacitance (Bias and/or Random)
	Mechanical	Capacitance
	Electrical	Voltage Coefficient
	Vacuum	Capacitance (Bias, Non Hermetic)
	Humidity	Capacitance (Bias)
Linear ICs	Radiation	Voltage, current offset (Random), A_{OL} (Bias)
	Temperature	Voltage, current offset (Bias & Random), Random A_{OL} (Bias)
Digital ICs	Temperature • Rise/Fall Time • Propagation Delay Radiation	Propagation Delay (Bias)
Magnetics (strongly dependent on materials)	Temperature	Saturation flux density (Bias) Permeability (Bias) Core Loss (Bias, Nonlinear, Nonmonotonic)
	Aging	Saturation flux density (Bias, very small)
	Mechanical	Permeability (Bias) Saturation flux density (Bias)
Relays	Temperature	Pull in/Drop out current/volts (Bias) Contact resistance (Bias, Secondary effect) Mechanical Contact Resistance (Bias)

H_{FE}	gain	V_F	forward voltage	ESR	equivalent series resistance
I_{CBO}	collector-base output current	T_s	storage time	DF	dissipation factor
RDS_{ON}	on-drain source resistance	I_R	reverse current	A_{OL}	open loop gain
V_{TH}	threshold voltage	V_z	zener voltage		
V_{CE}	collector-emitter voltage	Z_z	zener impedance		

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Table 5. Circuit Parameters for WCCA

Digital Circuit Parameters	
• Circuit Logic • Circuit Timing • Pulse Widths • Current Draw • Compatibility	
Analog Circuit Parameters	
• Comparator - Threshold Precision - Switching Speed/Time Constant - Offset Stability - Hysteresis	• Oscillator - Frequency, Accuracy, Stability - Output Power Level Stability - Output Impedance - Phase Stability - Noise & Spurious Output - Load Impedance
• Filter - Insertion Loss - Frequency Response - Input/Output Impedance - Spurious or Out-of-Band Feedthrough - Phase Response - Linearity - VSWR	• Detector - Bias Voltage - Frequency Range - VSWR - Input Impedance - Output Impedance - Input
• Modulator - Frequency Response - Input/Output Impedance - Insertion Loss - Deviation - Phase Response - Linearity - Output Level - VSWR	• RF Switch (Solid State/Mechanical) - Drive Requirements - Power Dissipation - Power Handling - Switching Speed - Input/Output Impedance - Insertion Loss - Frequency Response - Video Feedthrough - Switch Duty Cycles - VSWR
• Multiplier - Output Power - Frequency Response - Input/Output Impedance - Input Drive	• Coupler, Circulator - Insertion Loss - Frequency Response - Power Handling - Input/Output Impedance - Magnetic Leakage - VSWR - Directivity
• Mixer (Converter) - Noise Figure - Frequency - Output Spectrum - Intercept Points - Compression Points - Terminating Impedance - Group Delay - Power Dissipation - Conversion Loss - Driver Requirements	• Stripline, Waveguide, Cavity - Mode Suppression - Adjustment Range, Resolution - Dimensional Stability - Input/Output Impedance - Material Stability - Insertion Loss - VSWR

Source:

- RAC Publication, CPE, *Reliability Toolkit: Commercial Practices Edition*.

For More Information:

- RAC Publication, CRTAWCCA, *Worst Case Circuit Analysis Application Guidelines*.