# DESIGN AND ANALYSIS OF ELECTRONIC CIRCUITS FOR WORST CASE ENVIRONMENTS AND PART VARIATIONS

**Practice:**

Design all circuits to perform within defined tolerance limits over a given mission lifetime while experiencing the worst possible variations of electronic piece parts and environments.

**Benefit:**

The probability of mission success is maximized by assuring that all assemblies meet their mission electrical performance requirements at all times.

**Programs That Certified Usage:**

Viking, Voyager, Galileo, Magellan

**Center to Contact for Information:**

Jet Propulsion Laboratory (JPL)

**Implementation Method:**

Derive part parameter variations for the environments and life of a specific mission and combine them with the initial tolerances of the parts as procured to produce a worst case part variation database for each mission or project. Apply classical circuit analysis techniques, and determine if each circuit and each assembly meets its specified performance attributes over the most extreme but realizable combinations of part variation sources.

**Technical Rationale:**

Classical reliability practice is generally associated with minimizing catastrophic failures of parts. Of equal importance, however, is assuring that the desired essential mission controls and scientific measurements are made with the intended accuracy, fidelity, and stability. To this end, a uniform, disciplined, systematic approach to performance design verification is essential. Uniformity is achieved by use of a common part variation data base by all analysts on a specific project. Discipline is achieved by a common analysis containing qualitative and quantitative circuit performance attributes which are traceable to the assembly, subsystem and system requirements. Also required is a stated or implied level of statistical confidence which results from the use of either an EVA (Extreme Value Analysis) or an RSS (Root Sum Squared) approach to the circuit performance variation at some statistical level, usually $2\sigma$ or $3\sigma$. Another statistical approach is the Monte Carlo (MC) method of repeated trials with randomly selected combinations of part variations. Table 1 compares the

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relative merits of these three approaches and is followed by the differences of input and output formats and information content.

**Table 1. Comparison of Advantages/ Disadvantages**

| Statistical Approach | Advantages | Disadvantages |
|---|---|---|
| EVA | • Permits most readily obtainable estimate of circuit worst-case performance.<br>• Does not require statistical input for circuit parameters. | • Most pessimistic estimate of circuit worst case performance |
| RSS | • Results in more realistic estimate of worst case performance than EVA.<br>• Knowledge of parameter PDF not required. | • Standard deviation of part parameter's probability distribution is needed.<br>• Uses approximation: circuit performance variability is normally distributed.<br>• Assumes circuit sensitivities remain constant over range of parameter variation. |
| Monte Carlo | • Most realistic estimate of true worst case. | • Requires use of computer. Also, computer must be capable of generating uniform random variables.<br>• Knowledge of parameter PDF is required. |

**Comparison of Differences In Input Format**

**Inputs**

- **Piece-Part Parameter Variations**
  (Inputs-Format of Data).

  - **Extreme Value Analysis**

    Defined by the *limits of the variability* and the *circuit directional sensitivities* to part variations.

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- **Root-Sum-Square**

  Defined by the *biases* and *standard deviations of the parts variability* and magnitude of *circuit sensitivities.*

- **Monte Carlo**

  Defined by the *probability distnbution* of the variability (no sensitivity analysis required).

**Comparison of Differences In Output Format**

**Outputs**

- **Circuit WC Performance Limits**
  (Outputs-Format of Results)

  - **Extreme Value Analysis**
    Result is two discrete numbers., *W.C. Max. and W.C. Min.*
    Comparison yields pass/fail results only (non-statistical).

  - **Root-Sum-Square**
    Result is a mean & standard deviation of the circuit attribute probability distribution.
    Comparison predicts probability of circuit attribute falling within specified limits.

  - **Monte Carlo**
    Result is a histogram of the circuit attributes' probability distribution.
    Comparison predicts probability of circuit attribute falling within specified limits.

It is generally recommended that the EVA be applied as the required method for non-serviceable hardware because of its extreme conservatism. The RSS and MC methods are considered approximately equal to each other if utilized at the same statistical level. These can be safely employed for serviceable or recalibrateable equipment, but are considered the lowest level of confidence allowable for non-serviceable (i.e. satellites, spacecraft, etc.) hardware, and then should be accepted only as a formal waiver to the EVA process. Any circuit which does not meet its attributes at 3σ extremes cannot be considered high reliability in the functional sense.

To achieve the project benefits from performing a Worst Case Analysis, the commitment must be mission wide to prevent any "weak links" in the performance chain. For critical circuitry, preliminary analyses may be required to validate a conceptual design approach at PDR. The typical period of maximum benefit is to apply WCA concurrently with the detailed design phase and have it completed in advance of, and in support of, the CDR.

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**Impact of Nonpractice:**

Early designs of electronic circuits were either empirical or considered initial part tolerances only. This proved to be inadequate in that numerous equipments failed to remain within specifications at extreme temperatures or over prolonged life. More disciplined approaches followed, but analysts functioning independently were inconsistent in their part variation assumptions. The number of test and field failures fell, but still remained intolerably high, and large systems suffered from inconsistent risk levels. Since about 1965, WCA has been practiced to varying degrees. Based on experience by those trained in the review of designs, the probability of the output design from a competent circuit designer passing all WCA criteria was about 50% in 1991. Thus, the necessity for acknowledgement of the need, a well-founded database, and a systematic, well documented approach.

The absence of a structured WCA activity jeopardizes the long term integrity of the initial design. The probability of failing a hardware qualification test and subsequent design modifications is greatly increased, and the risk of incorporating the changes is not quantifiable. Using inherited hardware designs in environments which are different from the original adds an additional degree of jeopardy if there is no documented WCA from which to extrapolate.

**Reference:**

1. JPL Publication D-5703, "Reliability Analysis Handbook", July 1990.