PREDICTING RELIABILITY OF MMICS USING MONTE CARLO ANALYTICAL TECHNIQUES (PART 3 OF 3)

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Part 1 of this article, published in the 1st Quarter 2008 issue of the RIAC Journal, addressed the methodology used to estimate monolithic microwave integrated circuit (MMIC) high temperature performance. Part 2 in the series, published in the 2nd Quarter 2008 issue of the Journal, covered MMIC model development. This last installment will discuss validation of the MMIC reliability model.

Validation of MMIC Reliability Model

The two circuit examples previously presented in Part 2 of this article have been simulated. For **Case 1**, the correlations between FETs of both the transimpedence amplifier (TIA) and the low noise amplifier (LNA) have been estimated by SPICE circuit analysis, and the Monte Carlo reliability simulations for both MMICs have also been performed. For **Case 2**, the LNA and power amplifier have been analyzed for validation.

LNA and TIA High Temperature Analysis

The assumptions for the reliability analysis are:

1) The relationship between channel temperature (T_j) and median life (t_m) is given by the Arrhenius equation as:

$$t_m = t_{mo} \exp\left[\frac{Ea}{k(T_j + 273)}\right]$$

where, $t_{mo} = 8.332\times10^{-15}$ for power type or 1.405×10^{-12} for the LNA, and
$k = 8.6\times10^{-5}$ eV/°K

2) The median life t_m at temperature T_m can be estimated by the given activation energy (Ea), test temperature (T_o) and median life (t_o):

$$t_m = t_{mo} \exp\left[\frac{Ea}{k\left(\frac{1}{T_o} + \frac{1}{T_m}\right)}\right]$$

The overall activation energy was calculated to be 1.6eV for each of the individual FETs.

3) Time to failure data of the MMIC components tested previously by the manufacturer most closely fits a lognormal distribution. Therefore, lognormal distributions are used for all FETs. The lognormal probability distribution function $f(t)$ is given as:

$$f(t) = \frac{1}{t\sigma\sqrt{2\pi}} \exp\left[\frac{1}{2}\left(\frac{\ln t - \ln t_m}{\sigma}\right)^2\right]$$

where σ (standard deviation) and t_m (median life) are two parameters that are given to determine operational lifetime t.

4) The interactions between FETs can be estimated by applying a weighting factor, $W_{ij} = 1/(1 - r_{ij})$ to modify the time to failure of the surviving components as previously discussed in Part 2 of this article.

5) The life performance of passive components can be neglected. The computational schematic for Monte Carlo technique applied to the TIA and the LNA MMIC reliability analysis is shown in Figure 1, and its algorithm is the following:

```
INPUT N (the desired sampling size)
While number of sampling n <= N
{For each sampling
        {Input number NC of components of the system and
        Group them into dependence or independence
        groups individually
        While i <= NC
                {Input sigma s and median life tm
                Select a random number x
                Transform random number x to random
                time to failure TTF based on its life distri-
                bution}
                Determine the component which is failed
                first and let its time to failure be T1.
                While j <= NC - 1
                {Modify the time to failure of all surviving
                components with a weighing factor w(ni,
                nj) based on their correlated relations.}
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Determine system time to failure Ti
Compute reliability, MTTF and error

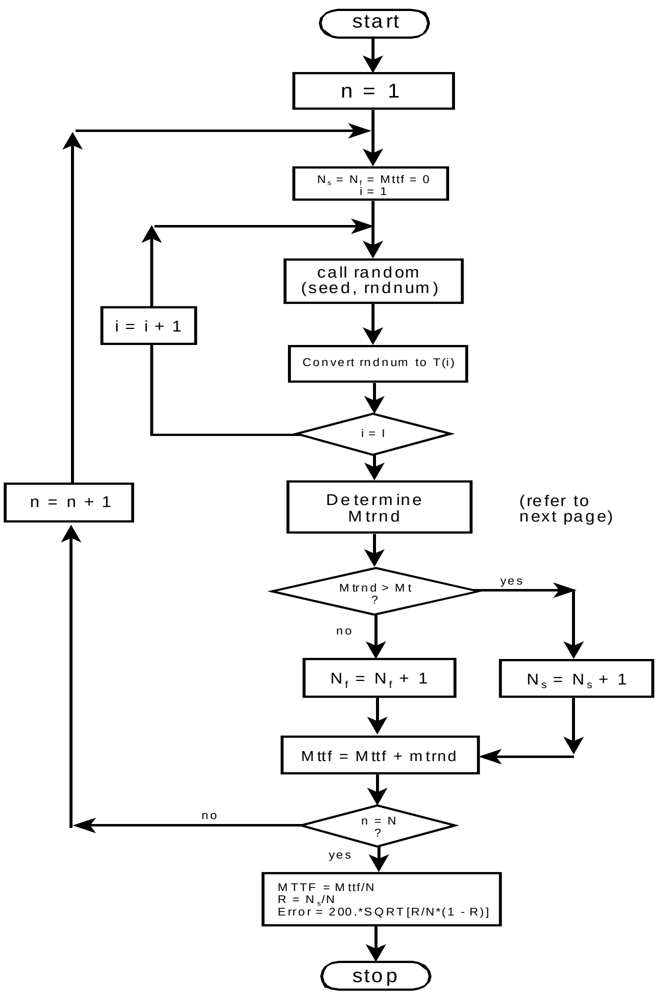

Figure 1: *Flow Chart for Calculation of MMIC MTTF*

LNA and Power Amplifier Reliability Analysis

The reliability analysis of both the amplifiers is similar as in the previous case, except that the s-dependent groups must be identified and weighting factors must be estimated by the equation under assumption 2. With some minor modifications, the algorithm and computer program for both TIA and LNA are still applicable for both the LNA and the power amplifier, (see Figure 2).

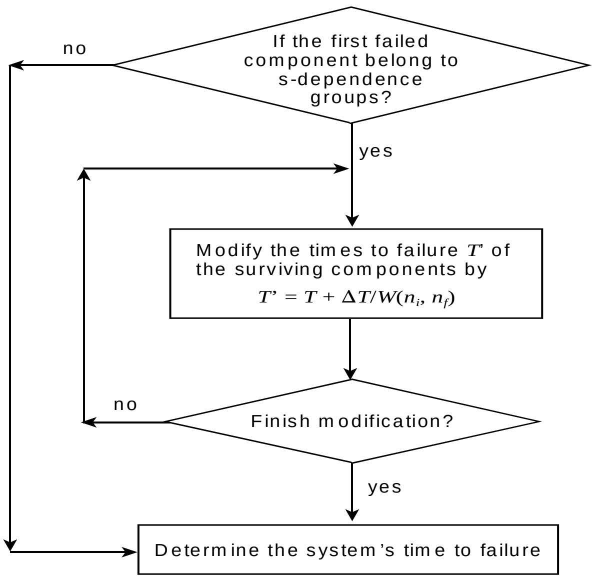

Figure 2: *The subroutine to estimate the modified MMIC time to failure*

Simulation Results

The results of the reliability simulation for TIA, and the LNA and power amplifier based on discrete component data are shown in Figures 3 to 51. The simulations by Monte Carlo techniques for both the dependent (modified by a weighting factor) and independent (based on the MIL-HDBK method) cases have been performed. The results show that the estimation of MMIC life, including interactions between FETs, is closer to experimental data than the estimation without taking into account the interactions. The results also indicate that interdependencies between devices is an important consideration and cannot be ignored.

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Figures 3 to 5 show that the simulations give a conservative estimation of the MTTF. The excellent agreement even holds for the temperature range of 225°C through 325°C, thus indicating that the simulation technique is applicable for high temperature simulations, where large non-linearities exist in the circuit's material properties. This investigation has therefore presented the simulation methodology for analog circuits operating in microwave systems such as MMICs. The approach outlined in this paper may be used for analog type circuits where the correlation coefficients have been identified.

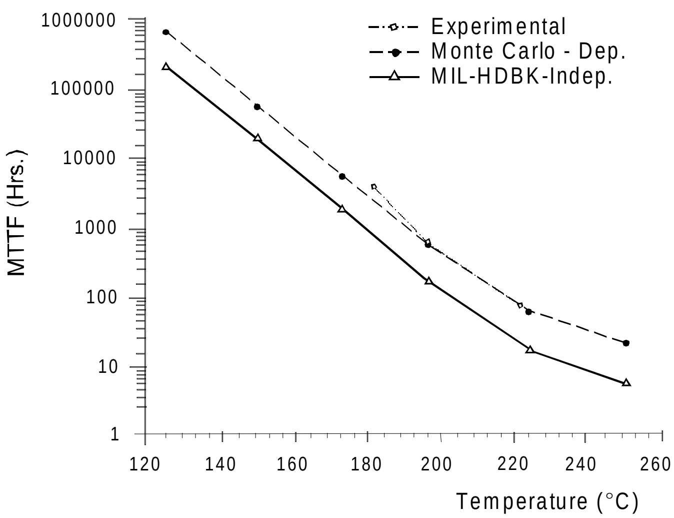

Figure 3: *MTTF versus Temperature for TIA*

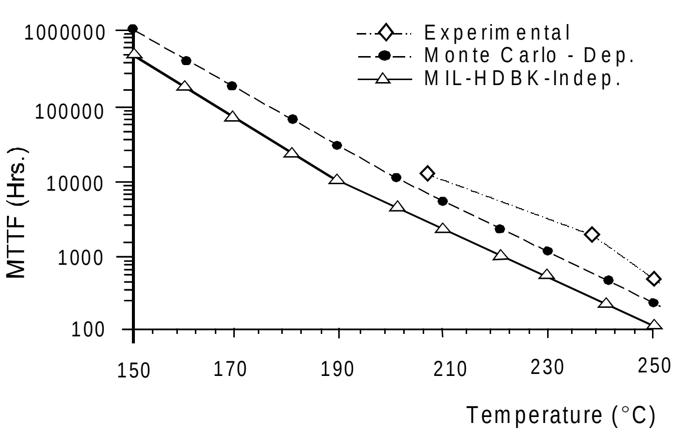

Figure 4: *MTTF versus Temperature for the LNA*

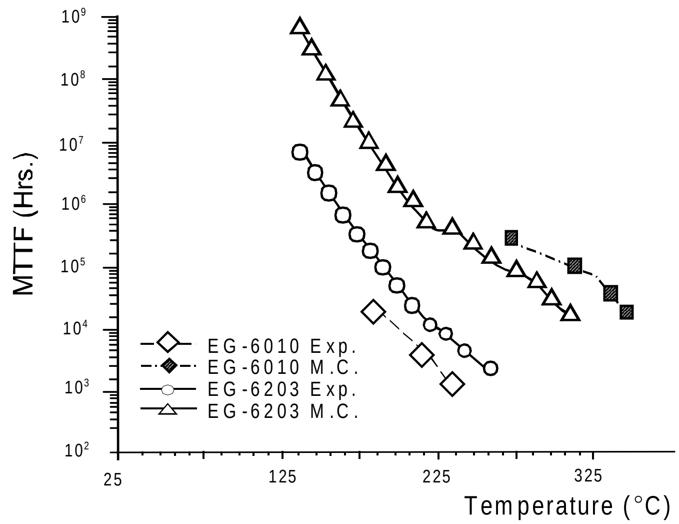

Figure 5: *MTTF versus Temperature for the LNA and Power Amplifier*

Conclusions

In the case of a complex MMIC circuit, it is not plausible to attain the analytical reliability by the Markov approach for constant failure rate, which perhaps is the best and most straightforward analytical approach to computations in systems with dependence. The equations become numerous and out of control for a large MMIC system, and the Markov method may break down when failure rates become non-constant. We have shown that the Monte Carlo technique is the appropriate methodology for predicting reliability of such complex circuits. We have successfully established a new reliability simulation model for MMICs and have shown that it has a wide applicability to analog circuits in general. The reliability model will be applicable over a wide temperature range and hence may be used for microwave systems.

References

1. MIL-HDBK-217F, "Reliability Prediction of Electronic Equipment", pp. 5-7, Sec. 5.4, 1990.
2. Yonglu Deng and Shibin Song, "Reliability Analysis of A Multicomponent System in A Multistate Markovian Environment," Microelectron. Reliab. Vol. 33, No. 9, pp. 1237-1239, 1993.