Yield Analysis of a Stripline Wilkinson Power Divider using Monte Carlo Samples of Interpolated Full Wave Simulation Data Using Sonnet

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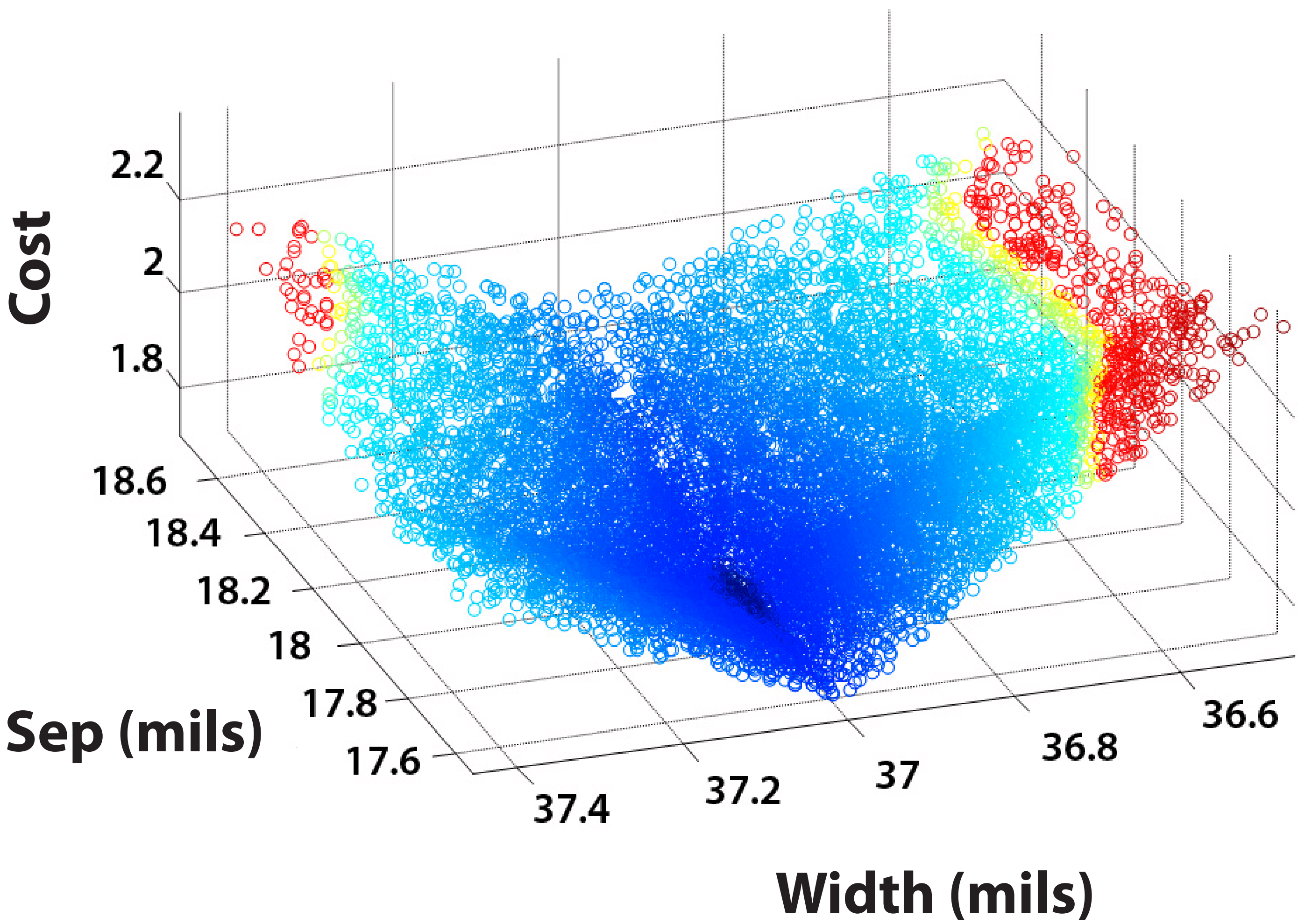

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Abstract

The use of Monte Carlo samples of interpolated data from a linearly spaced grid of electromagnetic simulation data for yield analysis is investigated. The motivation for this approach stems from a desire to have accurate yield metrics without the need to fabricate a large number of circuits or run a large number of full wave simulations. A means to estimate circuit yield values with relatively little computational effort is presented.
A Wilkinson power divider designed with Sonnet's electromagnetic simulation engine, ***em*™**, is provided as a simple example.

Introduction

The development of conventional yield models requires a large number of sample fabricated boards and a large amount of CPU time. As such, much work has been performed on the topic of manufacturing yield estimation [1, 2]. To overcome the drawbacks of conventional yield analysis methods the authors propose that full wave electromagnetic simulations only be performed at fixed increments within carefully determined error regions. The electromagnetic simulation engine used in this work is Sonnet's em. The error regions mimic the extent of fabrication errors relating to the design layout or stackup. Two example error regions might be etching errors producing trace width deviations of +/- 2 mils, or perhaps substrate anisotropy with vertical permittivity +/- 10% off from horizontal permittivity [3].

The grid of electromagnetic simulation data can be interpolated to produce a surface that maps error values to expected performance. A large number of Monte Carlo samples of the resulting surface can be performed with very little computational effort. Monte Carlo samples can be selected according to a probability distribution function (PDF) that mimics the real world fabrication error tendencies. Since the Monte Carlo samples represent potential fabrication errors with likelihoods similar to real world fabrication, the ratio of acceptable circuit samples to the total number of samples represents a fairly accurate estimate for the fabrication yield.

Method

The method proposed in this work consists of six steps:

1. Fabricate sample circuits.
    a. In quantities sufficient to generate a statistically viable distribution.
2. Measure physical geometric dimensions of sample circuits.
3. Construct PDF of the geometric variables.
4. Perform full wave electromagnetic (em) simulations on a linearly spaced grid.
    a. The grid may be relatively course.
    b. The grid must cover the extents of the sampled geometries.
5. Interpolate a cost surface from the em simulations.
    a. Spline interpolation is recommended.
6. Perform Monte Carlo analysis by sampling the cost surface of (5) with the PDF of (3).

Circuit Fabrication

This work is obviously geared toward high volume commercial circuit manufacturers. The measured physical dimension data used in this work was obtained from a high output manufacturer.

Physical Measurement of Circuit Dimensions

The measurement of physical circuit dimensions for large numbers of circuits is generally automated. A common method involves computer controlled cameras used with measurement software. For stripline circuits where the circuitry is in an internal layer, x-ray imaging can be used. The measurements for the stripline circuits in this work were likely performed before lamination.

Construction of PDF

The data used in this work was assumed to have a normal distribution. In many cases the multivariate PDF generated can actually be decomposed into separate independent PDF's assuming the underlying random variables are independent. This is not necessary for this method.

Grid of ***em***™ Data

The fourth step of the proposed method is to obtain full-wave simulation data for variations of the project with linearly spaced error variable values. Each variable should be swept so as to produce an N-dimensional surface that maps values of the variables to a cost value as determined by a cost function. For the Wilkinson power divider example, presented in this paper, computed cost is comprised of the phases and magnitudes of the scattering parameters.

Monte Carlo Method Based Samples

The cost values for any off-grid points can be estimated so long as they fall within the range of the grid. These interpolated samples are extremely inexpensive to calculate while maintaining accuracy proportional to the density of the em data grid. The low computational cost of the sampling allows for the computation of several million samples in mere seconds.

The interpolated cost value at a sampled point can be compared to a threshold value in order to "decide" whether a circuit corresponding to the sample point would perform adequately. The ratio of samples that perform better than the threshold compared to the total number of samples is the manufacturing yield.

Software Implementation

The electromagnetic simulations of this work were performed using Sonnet ***em***. The method proposed in this work, as well as the verification and comparison, was all implemented in Matlab. The free toolbox, SonnetLab was used to interface Matlab with Sonnet.

Wilkinson Power Divider

Wilkinson power divider designs can vary from simple [4] to complex [5]. To demonstrate the yield analysis approach, the authors have designed a stripline Wilkinson power divider circuit in Sonnet which will experience two forms of fabrication error. A 3D view of the circuit is shown in Fig. 1. The first type of error is in the width of traces and the second is the gap between the traces at the position of the resistor. Figure 2 shows a top down view of the circuit. The variable "W" represents the trace width and is nominally 37 mils. The variable "S" represents the gap width which has a nominal value of 18 mils.

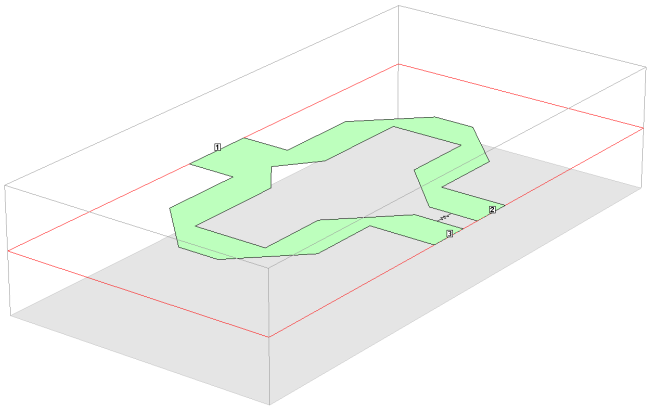

Figure 1: Wilkinson Power Divider Circuit

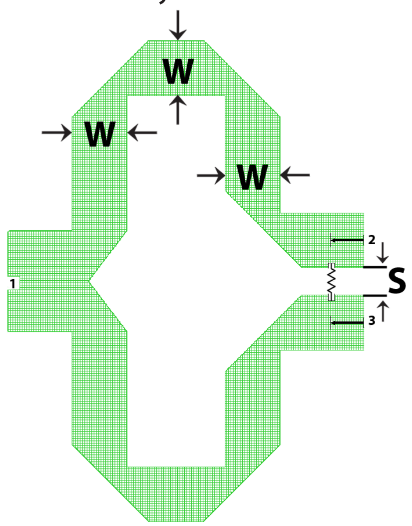

Figure 2: Parameterized Circuit

All variations of the project will have width and gap values within a range of +/- 2 mils from nominal. For the purposes of this example, seven linearly spaced values for each variable were used to generate a forty-nine point grid of width and gap values. The circuit variations were simulated with Sonnet's electromagnetic simulation engine (***em***) at a frequency value of 5 GHz. The scattering parameter data was sent to a cost function. A circuit with |S21| = |S31| = -3dB and ang(S21) = ang(S31) = 90° would generate a cost of zero. This is impossible due to electrical losses and geometry discretization. Any deviation from the ideal results in a real number that is the cost. Greater deviations from the ideal generate greater cost values. The grid of em calculated costs are shown in Fig. 3.

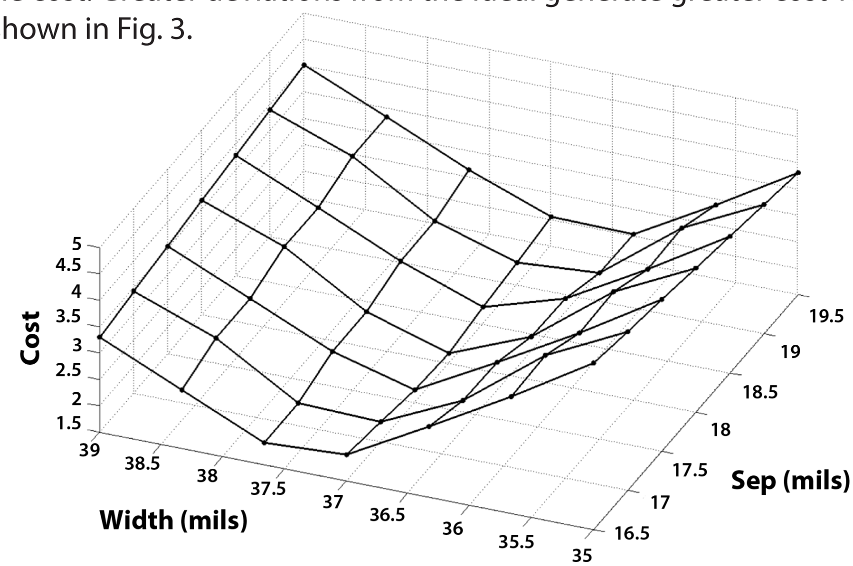

Figure 3: Grid of em Based Cost Data

The ***em*** data can be interpolated and sampled according to a PDF. Statistics quantifying the distribution of the fabrication error were obtained through collaboration with an industry leading RF component manufacturer. The cost at each sampled value can be seen in Fig. 4. The blue colored region in the center corresponds to samples that perform acceptably. The red region near the fringes represents samples that performed inadequately.

The yield value is the ratio of samples that have an acceptable cost value versus the total number of samples. The cost threshold used for this example was approximately 2.1. The yield value for the proposed design is approximately 95%.

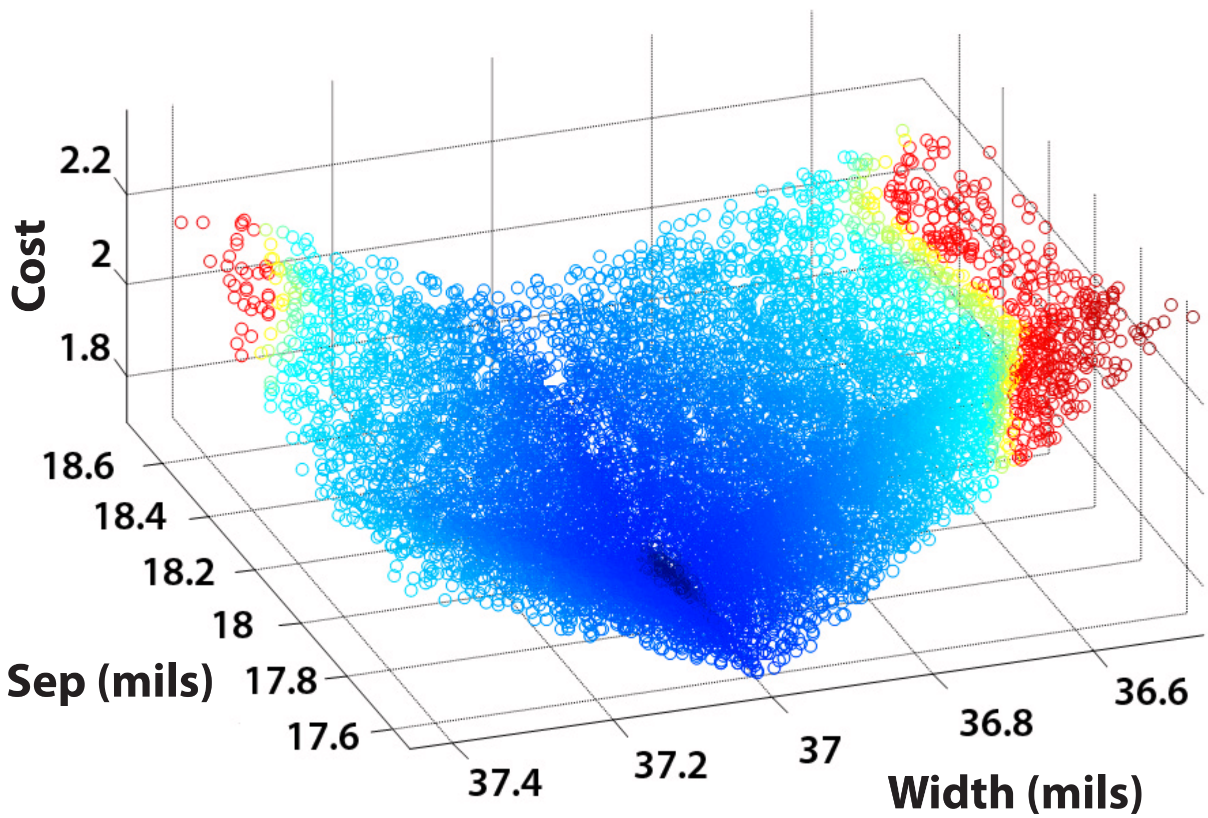

Figure 4: A Scatter Plot of Monte Carlo Samples

Conclusion

Traditional yield metrics are capable of achieving a high level of accuracy. However, traditional yield analysis approaches typically require the fabrication of a large sample of test boards or a large number of expensive simulations. The main idea presented in this work is that with a relatively modest number of manufactured circuits, and relatively few electromagnetic simulations, accurate yield predictions can be made.

References

1. Jones, I.W.; Spence, R.; , "Cost reduction of Monte Carlo yield estimates," Electronic Circuits and Systems, IEEE Proceedings G , vol.134, no.6, pp.249-258, December 1987

2. Johnson, M.W.; Herr, Q.P.; Sparge, J.W.; , "Monte-Carlo yield analysis [of Josephson circuits]," Applied Superconductivity, IEEE Transactions on , vol.9, no.2, pp.3322-3325, Jun 1999

3. James C. Rautio, Richard L. Carlson, Brian J. Rautio and Serhend Arvas, "Shielded Dual Mode Microstrip Resonator Measurement of Uniaxial Anisotropy," IEEE Transactions on Microwave Theory and Techniques, Vol 59, No. 3, 2011

4. Pozar, David M. Microwave Engineering. Hoboken: John Wiley & Sons, 2005.

5. Sandi Ibrahimpašic, Moamer Hasanovic, "Multi-Section Wilkinson Power Splitter with Tuned Quarter-Wave Transformers to Compensate for Different Velocities in Even and Odd Mode", Annual Review of Progress in Applied Computational Electromagnetics, vol. 26, April. 2010.