IF2 C-9

Production Costs Optimization of Microwave Circuits

P.C.K. Liu, K.K. So and K.C. Li
Department of Electronic Engineering
Hong Kong Polytechnic
Hunghom
Hong kong

Abstract

Formulations on production repair and throw-away costs in microwave circuit design is presented in this paper. The traditional methods of design centering and tolerancing are extended to incorporate the anticipated production costs. The approach provides direct physical meanings to the problem of yield optimization.

Introduction

When performing microwave circuit design in a production environment, it is faced with the problem of finding an optimal solution of cost and performance. Design centering and yield optimization have been introduced in the past and have been accepted as essential steps in the design of microwave circuits [1]. Most of the current yield optimization methods do not explicitly takes into account of repair costs and throw-away costs. These methods may be suitable for VLSI circuit fabrication and other production procedures where repair of a single circuit is either not feasible or too expensive to perform.

Production Yield

Let a circuit be represented by a point in the parameter space $x=(x_1, x_2, ..., x_n)$ with joint pdf $p(x)$. Yield can be defined as

$$Y = \int_{R_A} p(x)dx \qquad (1)$$

where R_A is the acceptable region of the design [2].

Alternatively, yield can also be expressed as

$$Y = \int_{-\infty}^{\infty} \delta(x)p(x)dx \qquad (2)$$

$$\text{where } \delta(x) \begin{cases} 1 & x \text{ in } R_A \\ 0 & x \text{ not in } R_A \end{cases} \qquad (3)$$

The above integration can be estimated numerically by the Monte Carlo method:

$$Y = \frac{\text{no. of samples in } R_A}{\text{total number of samples}} \qquad (4)$$

This traditional definition of yield will be specified as the Initial Yield Figure (IYF) which is the yield figure obtained before repair where as a Final Yield Figure (FYF) is defined as the yield figure obtained after repair is performed on those repairable circuits.

In our discussion throughout the paper, repair is used synonymously with tuning with the understanding that tuning is the major effort and catastrophic failure is not considered [3].

Production Costs and Objective Functions

An objective function can be defined as follows:

$$C = \sum_{i=1}^{n} \frac{\alpha_i}{tol_i} + \gamma\,(\text{repair costs} + \text{throw away costs}) \qquad (5)$$

where α_i and γ are suitable weighing functions.

The first part of the above function applies to the cost of tolerances and the second part of it relates to the cost of tuning and the cost of throw-away. It is obvious that the traditional worst-case design centering and yield optimization problems become sub-problems in this formulation. If some of the failed circuits can be repaired at reasonable prices, the IYF should be made less than 100%. After repair, the FYF obtained will be greater than the IYF and may attain a 100% in the case where throw-away are expensive. If throw-away is not expensive, or the circuit could be recycled, the FYF may be less than a 100% as well.

Tuning Costs

There are several possible approaches to model the cost of tuning. A convenient mathematical approximation based on the fact that the greater the violation of the specification, the higher is the cost of tuning is as follows:

$$C_{repair} = \mu \max\{f(s_j - g_j),\ j=1, \ldots, m\}(1 - \delta(x)) \qquad (6)$$

where s_j and g_j are the jth specification and the jth performance response at point x, respectively; m is the total number of design specifications; and μ is a suitable scaling factor.

The function f, is a continuous measure of the violation of the specification when s_j g_j. An example of f is as follows:

$$f = \exp(\ r(s_j - g_j)\ ) \qquad (7)$$

where r is a weighing constant

This approximation does not take into consideration of the choice of parameters and how the parameters are tuned to bring the responses back to specification. When the violation is beyond a pre-determined threshold, repair is assumed to be impossible. The throw-away cost is set to a constant equal to exp(rD).

Topological Interpretation of Tuning

Tuning is a process of bring a point x' which lies outside the acceptable region back into the region.

$$x' \text{ not in } R_A \xrightarrow{T} x \text{ in } R_A$$

or mathematically

$$x = x' + PT \qquad (8)$$

where P is a projection matrix and T is a vector containig the maximum tuning range of the tuning components. In the most ideal case, x' and x should be varied by one parameter. When T has only K non-zero elements, we say that the design is K Degree Tunable Design (KTD). A point x' lies outside R_A requires the tuning of k parameters is said to be a kth Order Tunable Outcome (kTO) provided $k \leq K$ and the parameters to be tuned belong to a subset of the KTD.

There is a unique minimum tuning strategy if k=1. However there are more than one tuning paths which can bring x' back into R_A if k>1. The identification of an optimal tuning strategy is outside the scope of this paper.

Examples

To illustrate the concepts and techniques of tuning, two examples are given below.

(1) Stripline Transformer [4]

Figure 1 shows a strip line transformer used to illustrate design centering and yield optimization in many past articles. The length l and width w are to be optimized in this example while all other parameters are kept constant.

$$C_{tol} = \frac{10}{tol_w} + \frac{10}{tol_l} \qquad (9)$$

$$C_{repair} = \frac{1}{n} \sum_{i=1}^{n} \exp[r(|\rho_i| - spec)](1 - \delta(x_i)) \qquad (10)$$

where n is the total number of samples, r is a weighing set at 50 and 100.

The results are as shown in Table 1 and illustrated in Figure 2. As shown, with moderate repair cost (r=50), the IYF is about 92% with corresponding cost of 1.7011. When repair cost is more heavily weighted (r=100), IYF=FYF=100% with corresponding higher cost of 1.9350. The results in this example produce a much larger tolerance value compared to that reported in [3] because we have for simplicity sake kept other parameters constant. By considering throw-away cost at a reasonable cost (exp(rD)=4.48) corresponding to a reflection coefficient at 0.28. The cost of production is further reduced to 1.6953 (see Table 2). It may be observed that the FYF now is at 99.58% and an IYF of 91.32%. The optimal tolerances in this case are larger than that obtained without throw-away.

(2) Ku Band Low Noise Amplifier

A schematic diagram of a Ku band low noise amplifier is as shown in Figure 3. The performance considered are noise Figure ≤ 0.8 dB and Gain ≥ 9 dB at a frequency range of 11.7 - 12.2 GHz. The four strip lines are equally toleranced. This case is a 1TD with the input stub tunable. The results are as shown in Table 3. With an tolerance of 0.2 mm of all the striplines, the IFY and FYF are 77.7% and 85.6%, respectively. To obtain the same yield figure (IYF) without tuning, the tolerance is reduced to 0.12 mm, a 40% reduction.

Conclusion

Design centering and tolerancing has been accepted as an essential step in microwave design to guarantee cost-effectiveness and high yield in the production stage. We have presented an extension of the concept by a mathematical formulation which estimates and hence optimizes the final yield figure if tuning is performed in the production. This method goes beyond the design stage and incorporate potential cost components of production in terms of tuning and repair. The examples show that if the cost of tuning and throw-away are reasonably low, a design with less than 100% IYF is cheaper and that via tuning a 100% FYF may be attained at a lower cost. Further work in this direction will lead to intelligent methods of automatic tuning and repair of microwave circuits.

References

[1] J.W.Bandler and S.H. Chen, "Circuit optimization: the state of art ", *IEEE Trans. Microwave Theory Tech. , vol.36 Feb. 1988*, pp. 424-443.

[2] A. MacFarland, J. Purviance, et.al., "Centering and tolerancing the components of microwave amplifiers," Proceedings of *IEEE 1987 MTT-S Int. Microwave Symposium*, 1987, pp. 633-636.

[3] E.C. Gominho, "An automated technique for post production tuning of Microwave Circuits," *Proceedings of IEEE 1989 MTT-S Int. Microwave Symposium*, 1989, pp. 765-767.

[4] J.W. Bandler, P.C. Liu and H. Tromp. " Integrated Approach to Microwave Design," *IEEE Trans. Microwave Theory Tech.* , vol.24, Sept 1976, pp. 584-590.

Table 1: Optimization results of example 1

Repair Cost Function (r)	Description	Optim. Nominal pt. (w,l) in mm	Optim. tol. (tol_w, tol_l) in %	Initial Yield (%)	Cost
50	Moderately weighed	8.8604, 8.9821	13.2238, 12.6189	92.053	1.7011
100	Heavily weighed	8.9951, 8.9808	10.8339, 10.0253	100	1.9350

Table 2: Optimization results with throw away consideration (r=50)

Throw away Constant (exp(rD))	Nominal pt. (w,l) in mm	Optim. tol. (tol_w, tol_l) in %	Initial Yield (%)	Final Yield (%)	Cost
4.48	8,8604, 8.9821	13.5045 12.8015	91.3223	99.5868	1.6953

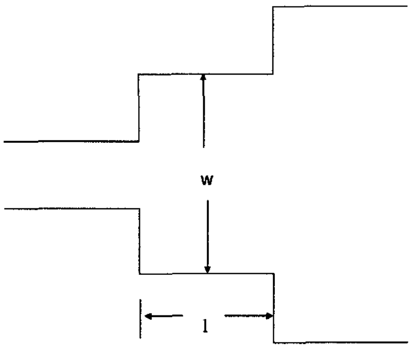

Figure 1: Stripline Transformer

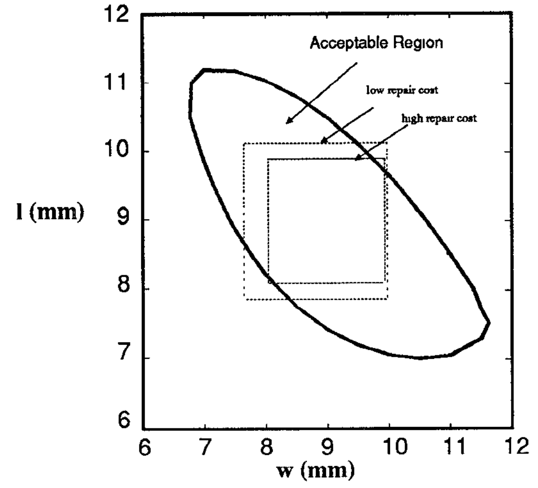

Figure 2: Graphical Representation of results of example 1.

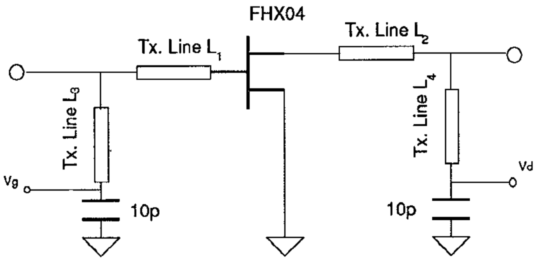

Figure 3: Ku Band low noise amplifier

Table 3: Optimization results of example 2

Tolerance of the striplines (mm)	Initial Yield (%)	Final Yield (%)
0.20	77.7	85.6
0.12	85	85