A Robust Design of MMIC using Taguchi Method

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Abstract

In this paper, we demonstrate a robust design of Monolithic Microwave Integrated Circuits (MMIC) using Taguchi Method. In accordance with Taguchi Method, noise factors, which are uncontrollable sources of variation, and control factors, which are available to control both the deviations and the mean-values by circuit designers were assigned to an orthogonal array. We simulated radio frequency (RF) characteristics by the orthogonal array. For an optimization procedure, we evaluated a criterion for stability (Taguchi Method's signal-to-noise ratio) and a criterion for average values (Taguchi Method's sensitivity). In order to realize this design approach, we have developed a modified Angelov Model to take those factors into the non-linear equivalent circuit parameters of a transistor (Tr). To demonstrate the effectiveness of the technique, first of all, we designed a MMIC using the center value of the factors as a conventional method. Next, we designed another MMIC by this new method focusing on the improvement of the variation and the average value of linear gain characteristics. We fabricated the both MMICs and evaluated the distribution of the linear gain characteristics. As a result, we have successfully improved the signal-to-noise ratio (SN) of +3.7 dB, the standard deviation of -33%, and the average value of +0.7 dB. Furthermore, we also optimized the saturated output power (Psat), which is nonlinear characteristic. Simulation results indicated the improvement of the distribution and the average of the Psat.

Introduction

It is a key issue to reduce development time and to stabilize production yield in the product development process. The more shrinkage of MMIC die size has progressed in recent years, the larger variation of RF characteristics occurs in the production even by a small disturbance. Therefore, ensuring quality stability of the products becomes more difficult and the yield of the RF characteristics may result unstable in the mass-production.

For a conventional design methodology, we were necessary to repeat the circuit design and the trial production, because we designed with the only center values of RF characteristics and evaluated distribution at the actual trial production stage to ensure the yield stability. In contrast, Taguchi method enables the estimation of the variation of each noise factors at the simulation phase. Additionally, control factors satisfying desired RF characteristics and yield stability are visually obtained by using the Graphs of Factorial Effects. To realize this technique, we used the orthogonal array, which can obtain simulation results with good accuracy and efficiency though the limited number of combinations. For iterative calculation, we have developed calculation modules reading it from the outside of the simulator. In this paper, we report on the method and the effect of improvement of the characteristic variation of the MMIC using this technique.

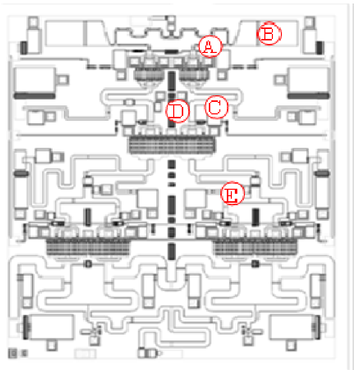
Design approach & Improvement effects

The conventionally designed MMIC using the center value of factors is shown in Fig. 1. We have modified this circuit with improvement of the variation and the average of a linear gain using Taguchi Method. First, we chose 10 factors as the noise factors including transistor parameters like tranceconductance (Gm), Gate-Source capacitance (Cgs), gate resistance (Rg), and so on, as shown in Fig. 2, and physical parameters like substrate thickness, and the capacitance of the MIM capacitors. These parameters are sensitive to the RF characteristics. We assigned manufacturing variations to the L36 orthogonal array with each variation of 3 levels (minimum, average, maximum). Next, we chose 17 factors as the control factors including the line width, length, and area of the MIM capacitors. Then we assigned them to L54 orthogonal array with 3 levels. In total, we carried out 1994 combination of calculations, reading 27 factors (10 noise factors + 17 control factors) using L54xL36 into a simulator. Fig. 3 shows the graphs of Factorial Effects of the result. Using this figure, we optimized by two design steps. First, we chose the level and the factors to increase the SN ratio as shown in Fig .3(A). Next, we increased the average value in the factors in the small variation of the SN ratio as shown in Fig .3 (B).

To verify the effectiveness of this new design approach, we actually manufactured the both MMICs designed with the conventional method and this new method. In this manufacturing process, we had intentionally included the variation in the noise factors. Fig. 4 and 5 show the results of the Gain characteristics. In this way, we succeeded in the improvement of SN of +3.7 dB, the standard deviation of -33%, and the average value of +0.7 dB. Furthermore, we also optimized the Psat, which is nonlinear characteristic. Simulation results indicated the improvement of the distribution and the average of the Psat.

Conclusion

We report on the method and the effect of improvement of the characteristic variation of the MMIC using Taguchi Method. If this technique is used in the microwave circuit, anyone will be able to easily and visually attain optimization in a design phase without depending on experience and intuition. We succeeded in proving the improvement effect by the actual MMIC production.



A: Line #1 Length
B: Line #2 Width
C: Area of the MIM capacitor #1
D: Area of the MIM capacitor #2
E: Line #3 Length
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Fig.1 The circuit layout of the power amplifier
Chip size: 2.6 x 3.0 mm, GaAs substrate thickness: 28 um, Frequency: 13.7 – 14.5 GHz

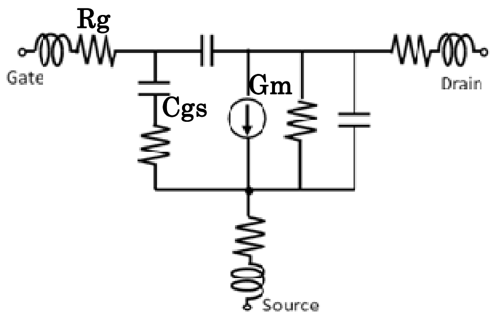

Fig. 2 The nonlinear equivalent circuit model of a transistor (Angelov Model)

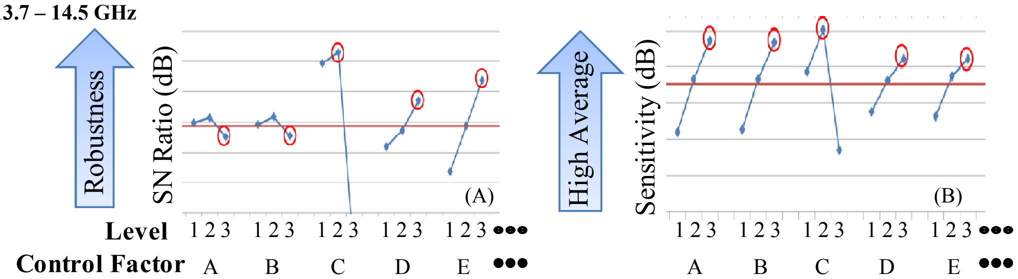

Fig. 3 Graphs of Factorial Effects. Control Factors are same as Fig. 1

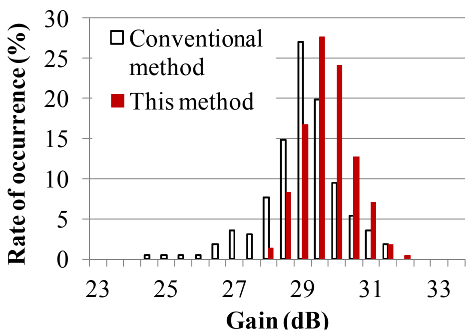

Fig. 4 Comparison of the linear gain distribution (Actual measurement)

Type	Conventional method	This method	Δ
SN (dB)	28.4	32.1	3.7
Ave. (dB)	28.8	29.5	0.7
σ (dB)	1.10	0.73	-0.36 (-33%)

Fig. 5 Comparison of the variation of the linear gain in the actual measurement (The signal to noise ratio, average and sigma)