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Impact and Improvement of Resistor Process Variation on RF Passive Circuit Design in Integrated Passive Devices (IPD) Technology

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Abstract

The influence of process variation on resistor in RF passive design is investigated. By expanding the layout size of resistor, the accuracy of resistance can be improved to overcome the process variation in integrated passive devices (IPD) technology. In order to address this critical effect in RF passive design, three common components, including a 50 Ω termination, a 100 Ω resistive load in the Wilkinson power divider and a 1 Ω resistor for current sensing, are demonstrated. The effectiveness of layout expansion skill for precise RF resistors show the process variation could be minimized to 0.16%. By using these accurate resistors, the characteristics of RF passive designs are also improved.

1. Introduction

Several layout skills are applied to help devices in the integrated circuits to resist the process variation [1], such as size expansion, close placement, interdigitation, common centroid, and dummies at the end of device. Depends on the device, foundry and application, some would present the most efficient improvement. In the RF designs, some of the rules are not useful because of the extra parasitic effect. For the RF resistor in the IPD technology, the simplest and most effective solution is to expand the layout size. Because the resistance used in the RF design are mostly in the middle or small value, so the layout dimension would not be a problem comparing with the performance-driven demand. For the reason of compact layout, and the less use, the RF designers often ignore the impact of the resistor with minimum layout rule in the design phase. In this work, the main variation source of resistor is discussed. And the size expansion skill for accurate resistance is examined. Furthermore, the influence of the resistors in RF applications is depicted in the following sections.

2. Process and Variation of Resistor

The technology used in this work is IPD which is a passive only process for wireless communication systems or RF applications. Passive components like filter, balun, phase shifter or power divider can be implemented using

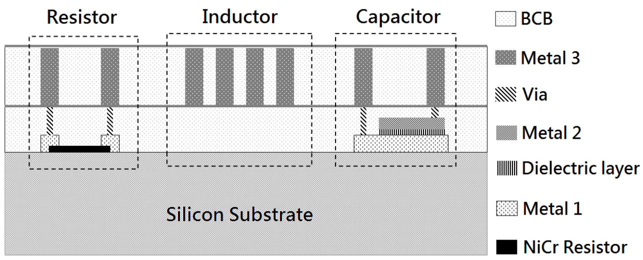

Fig. 1 The cross-section and RF passive devices of the IPD technology.

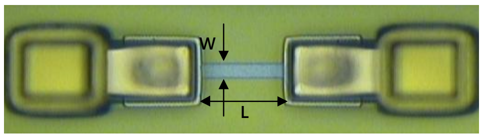

Fig. 2 A layout example of a 120Ω IPD resistor.

this IPD process with high resistivity silicon substrate for low cost and high volume production. It enables customers to integrate passive only circuits with other active devices for multi-chip module (MCM) applications [2]-[3]. It has three metal layers with low dielectric constant material as shown in the Fig.1. The thick Cu Metal is designated for inductor, an interlayer SiN dielectric could form MIM capacitor, and NiCr layer is used for implementation of RF resistance.

The resistor has nominal sheet resistance of 20 Ω/square with a minimum layout rule of 5 μm. The number of squares determines the total resistance. For example, Fig. 2 shows a photo graph of a 120 Ω resistor with the width (W) of 5 μm and length (L) of 30 μm. The fabricated resistance could have a common ±10% process variation as claimed in the technology document which could be a drawback in the RF design. The main source of the resistor variation is that, the deposited 500Å NiCr layer is lifted-off after the patterning process which induces a variation of ΔW, while the L is well controlled and limited by the interconnect (via) formation. As a result, the resistance (R) varies with the ΔW as shown in eq. (1). To obtain a more accurate R, minimize the ΔW is desired.

$$R = \frac{L}{(W + \Delta W)} \times \ \Omega / square \qquad (1)$$

Table I The Resistance Precision in Different Expansion Sizes

Size Expansion	Resistance (Ω) @ 300k Hz		
	Target: 50	Target: 100	Target: 1
1X	55.17	112.28	1.27
2X	51.42	105.85	1.12
4X	50.09	101.79	1.10
6X	49.92	100.44	1.08

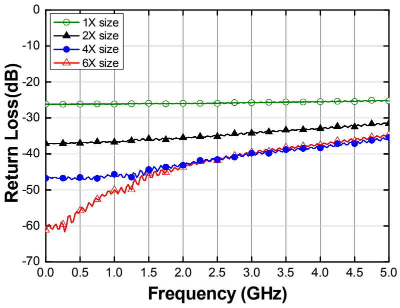

Fig. 3 The larger size of 50 Ω shows the better termination property with less reflection.

3. Improvement of Resistor and Its RF Applications

By increasing the W and L to be equivalent to the origin resistance, the sensitivity to process can be reduced. Because the lift-off process would cause certain ΔW. When the layout size is expanded, the effect of the fixed ΔW to the overall variation becomes relatively small. In this work, three resistance values with different sizes are implemented. As shown in Table 1, it can be observed the resistor in larger size could achieve the more accurate resistance as expected. The following paragraphs demonstrate the influence of inaccurate resistance in the common RF passive components.

Matching of 50 Ω Termination

The impedance matching to minimize reflections is achieved by making the load impedance equal to the source impedance. In the RF world, the 50 Ω reflections-less matching is desired in every system for maximum power transfer. In some RF circuits, the 50 Ω resistor is embedded in the design such as the termination of a directional coupler. Because the performance of the 50 Ω would affect significantly the whole system, it is deserved to pay more attention on its accuracy. According to the theory, an ideal 50 Ω load could achieve an infinitely small return loss over the whole frequency range, but this situation does not exist in the real world. The practical way is try to minimize the return loss. Fig. 3 shows the measured return loss of the four sizes 50 Ω resistors, and it can be recognized obviously that the better matching is achieved by a larger resistor layout size.

Isolation of Wilkinson Power Divider

The purpose of the Wilkinson Power Divider is to split the power of the input equally between two output ports. A lumped Wilkinson power divider as shown in Fig. 4 consists of two equivalent π type LC networks to replace two quarter-wavelength (λ/4) transmission line sections in the traditional Wilkinson power divider and an isolation resistor with a value of 100 Ω (2Zo). Except for low insertion loss, good match and small imbalance in phase and amplitude, an important property of a high performance power divider is the isolation between output ports. And this parameter is dominated by the isolation resistor. Fig. 4 shows the designed 2.5 GHz power dividers which have all identical components except for the 100 Ω isolation resistor with two different sizes of 1X and 6X as mentioned in the previous section. And Fig. 5 shows the measured three ports S-parameters, and the power divider with 100 Ω in 6X size exhibits 5 dB better isolation than another with 100 Ω in 1X size because of the accurate impedance control.

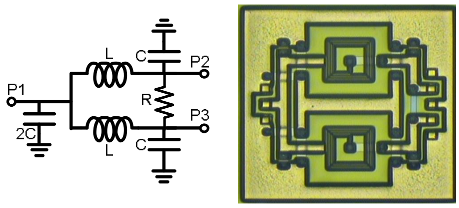

Fig. 4 The schematic and the photograph of the lumped Wilkinson power divider.

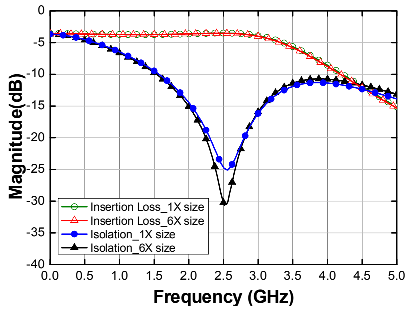

Fig. 5 The isolation of Wilkinson power divider could be improved by more than 5 dB with a more accurate resistor.

4. Conclusions

The reason of process variation of resistor in the IPD technology is investigated. By adopting the layout skill of size expansion, the sensitivity to process can be minimized. Three frequently used resisters of 50 Ω, 100Ω and 1 Ω with different size are examined. And the improved accuracy also present better characteristics in their RF passive design applications. The effectiveness of layout expansion skill for precise RF resistors is proved in this work.

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