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Christopher Saint, Judy Saint

# 集成电路版图基础

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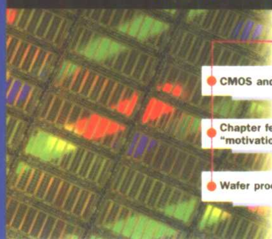

- CMOS and bipolar design and layout
- Chapter features: self-study examples, "motivation" boxes & executive summaries
- Wafer processes

# IC Layout Basics

## A PRACTICAL GUIDE

Christopher Saint / Judy Saint

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# 出 版 前 言

微电子技术是信息科学技术的核心技术之一，微电子产业是当代高新技术产业群的核心和维护国家主权、保障国家安全的战略性产业。我国在《信息产业“十五”计划纲要》中明确提出：坚持自主发展，增强创新能力和核心竞争力，掌握以集成电路和软件技术为重点的信息产业的核心技术，提高具有自主知识产权产品的比重。发展集成电路技术的关键之一是培养具有国际竞争力的专业人才。

微电子技术发展迅速，内容更新快，而我国微电子专业图书数量少，且内容和体系不能反映科技发展的水平，不能满足培养人才的需求，为此，我们系统挑选了一批国外经典教材和前沿著作，组织分批出版。图书选择的几个基本原则是：在本领域内广泛采用，有很大影响力；内容反映科技的最新发展，所述内容是本领域的研究热点；编写和体系与国内现有图书差别较大，能对我国微电子教育改革有所启示。本套丛书还侧重于微电子技术的实用性，选取了一批集成电路设计方面的工程技术用书，使读者能方便地应用于实践。本套丛书不仅能作为相关课程的教科书和教学参考书，也可作为工程技术人员的自学读物。

我们真诚地希望，这套丛书能对国内高校师生、工程技术人员以及科研人员的学习和工作有所帮助，对推动我国集成电路的发展有所促进。也衷心期望着广大读者对我们一如既往的关怀和支持，鼓励我们出版更多、更好的图书。

清华大学出版社
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2003.9

I dedicate this work to the insight of Dr. Alan Hughes.

Alan spotted the fact that I was not very capable in the clean room, and encouraged me to pursue activities that genuinely interested me. Since that time, I have been fortunate enough to not do a single day's work.

I play with some of the planet's biggest, most expensive toys, and people actually pay me for it. Thanks, Alan.

—Chris

Not only that, but Sue cooks up a mean barbecue.

—Judy

# Introduction

IC layout is a very new field. Mask design has been with us for 30-odd years, but has only recently been considered a profession. People wanting to move into that profession—new college graduates and people wanting a career change—are required to know some extremely complicated principles. Likewise, experienced layout engineers find the complexity of modern IC processing requires an ever-increasing understanding of these fundamentals.

Finding a reference that covers everything a layout engineer needs to know has up until now been difficult. Isolated sections of various other works briefly touch on some of the fundamentals that a layout designer should know, but complete coverage, all in one place, has not been available.

*IC Layout Basics: A Practical Guide* seeks to change that. We want to give new layout designers all the theory and basic understanding they need to become productive and provide a resource they can refer to during their careers. We also want to give experienced layout professionals an increased depth of understanding of the components and techniques they use daily.

This book begins with basic semiconductor theory and continues through the development and construction of the common devices used in modern semiconductor processes. It gives the reader in-depth access to useful design equations, techniques and methods of performing IC layout that should prove invaluable throughout his or her career.

Information is presented in humorous, illustrated and well-paced segments.[1] Anecdotes and asides provide perspective and break the text at key points to increase motivation, without compromising the quality of the highly technical data.

Complete and readable. Welcome to *IC Layout Basics: A Practical Guide.*

*Christopher Saint*
*Judy Saint*

[1] This may be the first Bedtime Engineering Book.

# Contents

CHAPTER 1

# Basic Circuit Theory

## Chapter Preview

Here's what you're going to see in this chapter:

- Review of basic circuit theory
- Materials that conduct, don't conduct, and partially conduct electricity
- How to make semiconducting material
- Two types of semiconducting materials—negative and positive
- The importance of the junction between these two materials
- Making switches using electric fields
- Putting two Complementary types of switches in series
- Using these Complementary switches as a decision-making circuit
- How to make logic circuits

And more . . .

## Opening Thoughts for the Reader

You should already be familiar with most of the circuitry concepts in the first few pages of this chapter, as well as the idea of integrated circuits (IC). We will present a short review as a brief, common reference.

Most of an integrated circuit's functions are achieved by using electrical current in some way—steering current, switching current, or using current to develop a voltage. Much of this steering, switching and voltage creation use what are known as **semiconductor** materials.

Unlike a regular light switch that can only be on or off, a semiconductor switch can be on, off, or somewhere in between. This semiconductor switch is called a **transistor.**

In this chapter, we will build a transistor switch from semiconductor material, then use transistors to develop logic circuits.

*Chip design begins with the process development team, continues through your circuit designers, and ends with you, the layout engineer.*

*You are integral to the successful manufacture of new chips. If you can design your layout with more knowledge, creativity and efficiency, you can save your company millions of dollars. Your chips will tend to work better than expected right off the wafer the first time. They will often be smaller than the design the next layout engineer might have drawn. You will catch and correct disastrous mistakes before production.*

*You can be immensely valuable to your company as a good layout engineer, particularly as the last person in the pipeline before actual production.*

### *Conventions Used in This Book*

- Diagrams will be drawn showing the width of a material as the vertical dimension and length as the horizontal.
- Current will be assumed to be flowing from the left edge to the right edge unless stated otherwise.
- The word "he," and all masculine references, shall include the word "she," or the appropriate feminine reference.[1]
- Illustrations are instructional only and do not portray all real elements or proportions actually involved in a process. We're keeping it simple.
- The reader is to retain a sense of humor, enjoy reading our book, and keep work as fun as possible. Always look for the undiscovered. There is a lot of it out there.

## Basic Circuit Review

Following is some basic circuit theory for your quick reference. We only present an overview at this point. Readers are expected to already be familiar with

[1]At my insistence. I get so distracted by all the his or her, he/she, s/he, he or she or she or he attempts. There must be a better way.—*Judy*

basic circuit equations and concepts. If you need more help with these ideas, see the bibliography for suggested further readings.

## Opposites Attract—Likes Repel

Remember the phrase "Opposites Attract." Materials of opposite sign value (polarity) will attract each other, while like signs will repel. For example, atoms with positive charges will attract other atoms with negative charges, even at a distance. These same positive atoms will repel atoms with like positive charges, also at a distance.

**Opposites attract.**

Without this weird law of nature, the awesome circuits you will see in this book would not work.

*I want to know why electrons attract and repel at a distance. I mean really why. How can one little electron have the faintest idea about the next door neighbor electrons? In fact, positive and negative charges aren't even different, there is only a different number of electrons. They shouldn't know anything about that. They can't count.*

*And why can't we see gravity? And magnets shouldn't work, either! And what really is past the infinity of space? And what is that creamy white stuff inside a Hostess cupcake? It's a frustrating world.—Judy*

## Units of a Basic Schematic

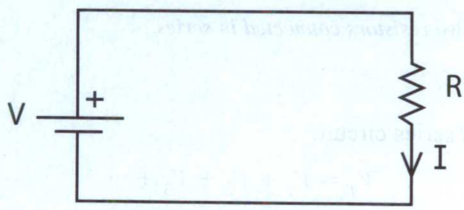


***Figure 1–1.*** *Voltage, resistance, and current all exist together in a circuit.*

Voltage, $V$, is measured in **volts.**

Resistance, $R$, is measured in **ohms.**

Current, $I$, is measured in **amperes**, or **amps.**

| | | | |
|---|---|---|---|
| Kilometer | $\frac{1000}{1}$ | 1000 | $1e^3$ |
| Meter | $\frac{1}{1}$ | 1 | 1 |
| Centimeter | $\frac{1}{100}$ | 0.01 | $1e^{-2}$ |
| Millimeter | $\frac{1}{1000}$ | 0.001 | $1e^{-3}$ |
| Micrometer (micron) | $\frac{1}{1,000,000}$ | 0.000001 | $1e^{-6}$ |
| Nanometer | $\frac{1}{1,000,000,000}$ | 0.000000001 | $1e^{-9}$ |
| Picometer | $\frac{1}{1,000,000,000,000}$ | 0.000000000001 | $1e^{-12}$ |
| Femtometer | $\frac{1}{1,000,000,000,000,000}$ | 0.000000000000001 | $1e^{-15}$ |

## Series Formulas

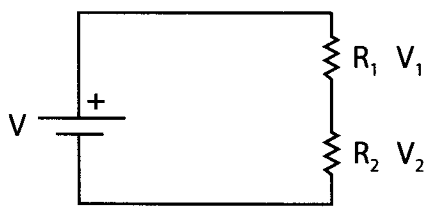


***Figure 1–2.*** *Two resistors connected in series.*

Total voltage in a series circuit:

$$V_T = V_1 + V_2 + V_3 + \cdots \qquad \textit{volts}$$

Total resistance in a series circuit:

$$R_T = R_1 + R_2 + R_3 + \cdots \qquad \textit{ohms}$$

## Parallel Formulas

Total current in a parallel circuit:

$$I_T = I_1 + I_2 + I_3 + \cdots \qquad \textit{amps}$$

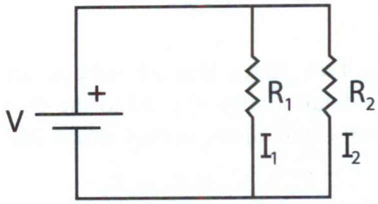


*Figure 1–3. Two resistors connected in parallel.*

Total resistance in a parallel circuit:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots \qquad \textit{ohms}$$

## Ohm's Law

Simply put, **Ohm's Law** states that voltage is equal to the current multiplied by the resistance.

$$V = IR \qquad \textit{volts}$$

Variations of this relationship are

$$I = V/R \text{ and } R = V/I \qquad \textit{amps, ohms}$$

Below is a convenient triangle to help you keep your VIR formulas the right way around.

- In the top of the triangle, you always see voltage.
- The bottom two corners are always current and resistance.
- You look at the triangle to remind yourself of the formulas.
- Use your finger to cover the item to be determined.
- The remaining two letters automatically form the appropriate calculation.

Don't you wish all formulas were this easy?

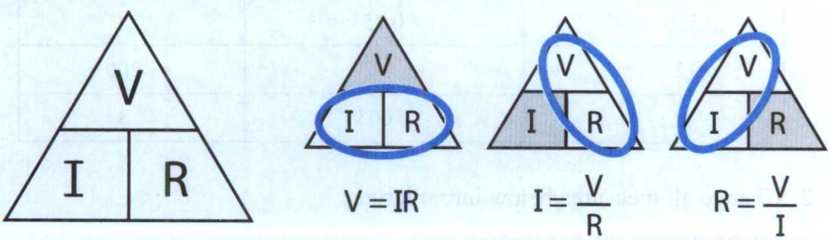


*Figure 1–4. Clever triangle method to remember the Ohm's Law formula variations.*

## Kirchhoff's Laws

**Kirchhoff's Voltage Law** states that all voltage drops in a closed circuit should add up to the total voltage applied to the circuit. In other words, the amount you put in will equal all the voltage drops that occur in the circuit.

$$V_T = V_1 + V_2 + V_3 + \cdots \qquad \textit{volts}$$

**Kirchhoff's Current Law** states that all the various currents leaving a junction should add up to the total current entering the junction.

$$I_T = I_1 + I_2 + I_3 + \cdots \qquad \textit{amps}$$

This means that in any point having some current flowing in and some flowing out, these amounts must be the same. We cannot have more coming in than is being allowed to exit, for example.

*Just reading about Laws is rather boring, but these relationships can be translated into algebraic equations. With equations, we can then solve for missing parts.*

*That's the importance of having these rules. You get to solve for otherwise unknown values. That, and being able to quote fancy names at dinner parties.*

You can effectively consider capacitors and inductors as resistors, although their resistance value is sensitive to the frequency of the voltage across them.

## Try It

1. Use Ohm's Law to complete the chart below.

| Voltage *(volts)* | Current *(amps)* | Resistance *(ohms)* |
|---|---|---|
| 5.2 | 0.25 | |
| 12 | | 200 |
| | 0.003 | 3 |

2. Change all measures below into microns.

   (a) 25 thousandths of an inch

   (b) 2500 nanometers