RF Circuit Design

Fundamentals

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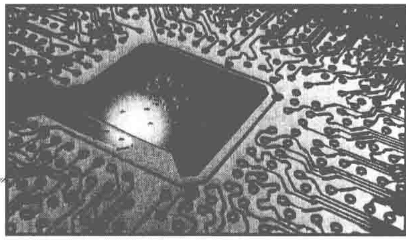


Preface

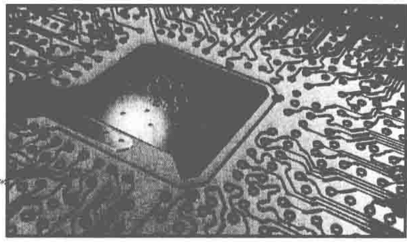
RF integrated circuit chip, with high performance and low cost, meets the demands of mobile phone communication, mobile Internet communication and satellite navigation wireless communication technology. It has been experienced remarkable growth. Therefore, it is extremely important to train a large number of RF integrated circuit chip designers and foster innovative capacities to improve the development of China's Information Technology Industry. However, most of the domestic teaching materials, in this area, are inspired from abroad which leads to several ambiguities. The book is based on 20 years of experience in designing RF chip and providing interrelated theoretical concepts about the microwave signal. Therefore, it will be comprehensible for readers to adopt and upgrade the theory.

This book is divided into 11 chapters. Chapter 1 introduces basic concepts and lumped circuit models about RF. It mainly includes the basic concepts of microwave, resistance, inductance and the equivalent model of capacitance. Chapter 2 introduces correlative knowledge of resonant circuit and filter; it basically including the concepts of quality factor as well as high pass, low pass and band pass filters design methods is also incorporated. Chapter 3 focus on the transmission line theory and its types; along with areas of RF and relative concepts S parameter. Chapter 4 introduces correlative matching theories about impedance and three matching internet: L-type matching, π-type, and T-type matching. Chapter 5 introduces the important tool usage in RF circuit design-Smith Chart. This chapter introduces the main parts of Smith Impedance Chart-impedance circle, impedance operation, impedance conversion and the application of Smith Impedance Chart in the transmission line. Chapter 6 highlight the signal-flow graph, including the basic concepts of the signal-flow graph, Mason's formula and some theories about conversion power gain. Chapter 7 introduces the design of small signal amplifier and several important concepts: the plus, stability and noise factor. Chapter 8 introduces related theories of power divider, power synthesis and power coupler. Chapter 9 focus on some basic theories about PIN diode and power switch. Chapter 10 briefly introduces some applications of power amplifier in the system, including DPD, CFR and ET, etc. Chapter 11 introduces some theories and applications of EMC and EMI.

This book introduces its own system of integrating theories and practices. It also incorporates interrelated theories in the process of RF circuit design. It can be used as a reference book and as a guideline for RF circuit design engineers at the advanced level. The book provides many classic examples of my first-hand experiences while designing RF circuit, which will surely help the readers have better a understanding (or application) from the learning material. The context is easy to read, especially for self-reading. It has been acknowledged as an ideal teaching material for students of senior level in undergraduate programs and for students in the graduate schools majored in Microelectronics, Radio-technology as well as Communication and Electronics. Further more, the book can be used as a good reference for engineers who design RF circuit.

The book is written by Professor LIU Yi, and YAN Wei. Dr. CHEN Lei and Kevin Song have provided valuable insights the book translation work. I also sincerely thank my colleagues who had supported me throughout the writing and compilation of this book.

LIU Yi in Shanghai



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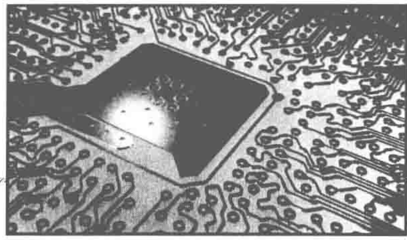
CHAPTER 1



RF Concepts Lumped Component Models

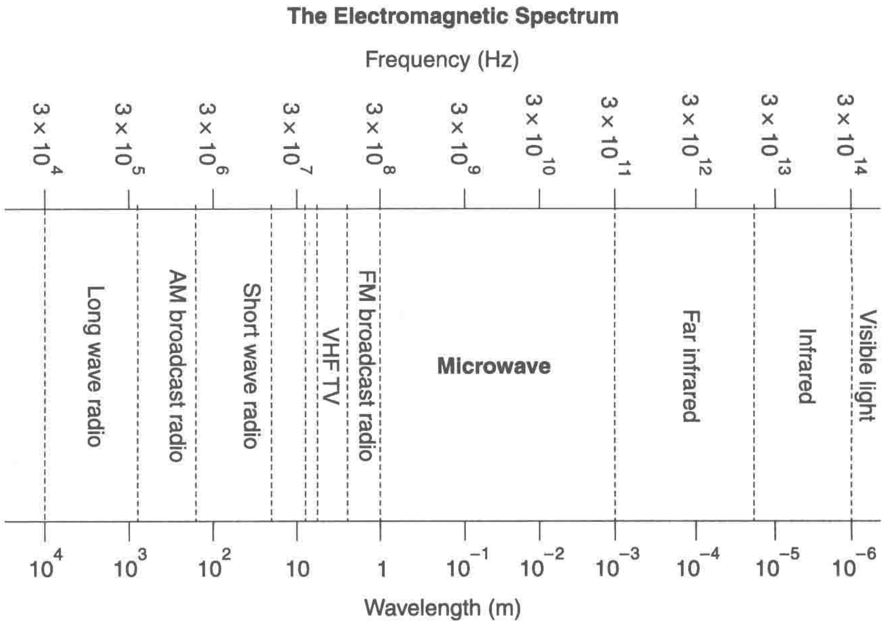
With the consistent growth of our society, science and technology have played a vital role in communications industry leading to a revolution. In China, mobile communications, network communications, and "Compass II" navigation system in the field of radio frequency chip tremendous market potential. In the mobile phone market, intelligent machines have been provided and catered to thousands families. To enable power, signal and better tuner (tuner), this technology has played a commendable role making the phone more efficient.

This chapter is mainly deals with concepts from various aspects of electromagnetic waves, straight wire inductance, core inductors, resistors, inductors, capacitors and other RF equivalent circuit of one unfolding narrative.

1.1 BASIC CONCEPTS REVIEW

1.1.1 The Electromagnetic Spectrum

The term microwave refers to alternating current signals with frequencies between 300 MHz (3×10^8 Hz), the period, $T = 1/f$, of a microwave signal which ranges from 3 ns (3×10^{-9} sec) to 3 ps (3×10^{-12} sec), respectively, and the corresponding electrical wavelength ranges from $\lambda = c/f = 1$ m to $\lambda = 1$ mm, respectively, where $c = 3 \times 10^8$ m/sec, the speed of light in a vacuum. Signals with wavelengths according to the order of millimeters are called millimeter waves. Because of the high frequencies (and short wavelengths), standard circuit theory cannot be used directly to solve the microwave network problems. In a sense, standard circuit theory is an approximation of the broader theory of electromagnetics as described by Maxwell's equations. This is due to the fact that, in general, the lumped circuit element approximation of circuit theory is not valid at microwave frequencies. Microwave components usually are distributed elements, where the phase of a voltage or current changes significantly over the physical length of the device because the device dimensions are on the order of the microwave wavelength. At much lower frequencies, the wavelength is so large that there is little variation in phase across the dimensions of a component. The electromagnetic spectrum see Fig. 1.1.



Typical Frequencies	
AM broadcast band	535-1605 kHz
Shortwave radio	3-30 MHz
FM broadcast band	88-108 MHz
VHF TV (2-4)	54-72 MHz
VHF TV (5-6)	76-88 MHz
UHF TV (7-13)	174-216 MHz
UHF TV (14-83)	470-890 MHz
Microwave ovens	2.45 GHz

Approximate Band Designations	
L-band	1-2 GHz
S-band	2-4 GHz
C-band	4-8 GHz
X-band	8-12 GHz
Ku-band	12-18 GHz
K-band	18-26 GHz
Ka-band	26-40 GHz
U-band	40-60 GHz

Fig. 1.1 The electromagnetic spectrum

1.1.2 Vector Coordinates in Rectangular and Polar Form

$$\text{Impedance} = \text{Resistance} \pm \text{Reactance}$$

$$Z = R \pm jX \text{ (Ind: +, Cap:-)}$$

where, $X_L = 2\pi fL$ and $X_c = 1/(2\pi fC)$.

$$\text{Admittance} = \text{Conductance} \pm \text{Susceptance}$$

$$Y = G \pm jB \text{(Ind:-, Cap: +)} = 1/Z = 1/(R \pm jX)$$

where, $B_L = 1/(2\pi fL)$ and $B_C = 2\pi fC$. Vector coordinates in rectangular and polar form see Fig. 1.2. Impedance/admitt ance planes see Fig. 1.3.

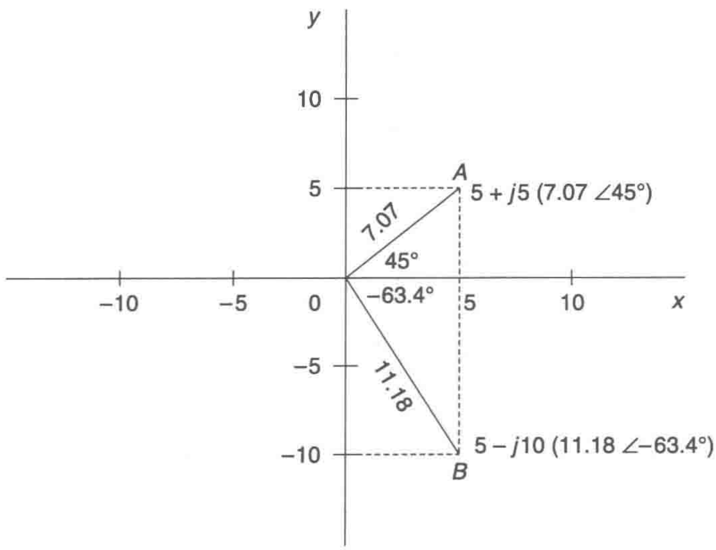


Fig. 1.2 Vector coordinates in rectangular and polar form

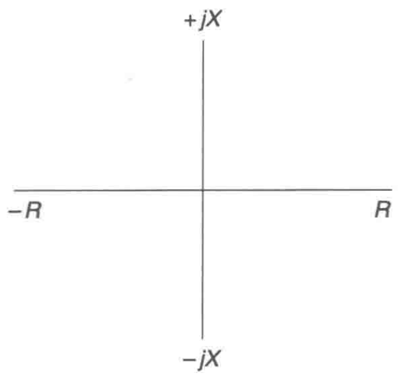


Fig. 1.3 Impedance / admittance planes

1.1.3 Combining Components

Series connections see Fig. 1.4.

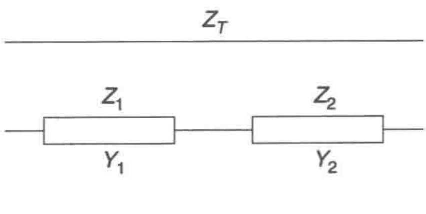


Fig. 1.4 Series connection

$$Z_T = Z_1 + Z_2$$
$$= (R_1 + jX_1) + (R_2 + jX_2)$$

Parallel connections see in Fig. 1.5.

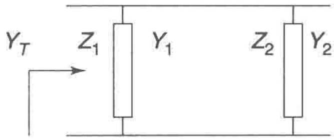


Fig. 1.5 Parallel connection

$$Y_T = Y_1 + Y_2$$
$$= (G_1 + jB_1) + (G_2 + jB_2)$$

Wavelength and phase change see in Fig. 1.6.

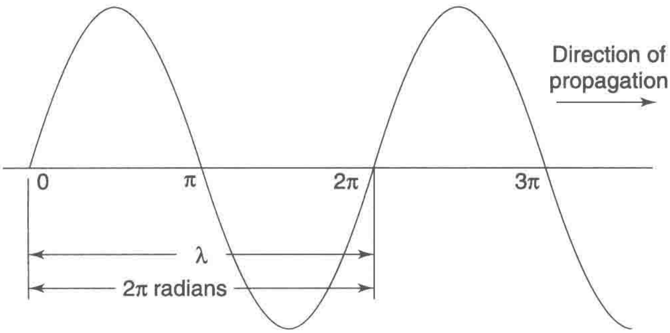


Fig. 1.6 Wavelength and phase change

$$\lambda = \frac{1}{\sqrt{\varepsilon_\gamma}} . \frac{v}{f}$$

Where, v = velocity of propagation in free space.

f = frequency of Oscillation.

ε_γ = Relative dielectric constant of the medium.

1.1.4 Skin Effect

- As frequency is increased, it increases the current density around surface.
- Skin depth $\delta_s = \frac{1}{\sqrt{\pi f U_r U_0 \sigma}}$, in which $J_x = \frac{J_0}{e}$ or 37% J_0 Skin effect sees in Fig. 1.7. Current of the skin effect sees in Fig. 1.8.