Wireless Networks and Mobile Communications Series

MILLIMETER WAVE TECHNOLOGY IN WIRELESS PAN, LAN, AND MAN

Edited by
Shao-Qiu Xiao
Ming-Tuo Zhou
Yan Zhang

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Chapter 1

Millimeter-Wave Monolithic Integrated Circuit for Wireless LAN

Jin-Koo Rhee, Dan An, Sung-Chan Kim, and Bok-Hyung Lee

Contents

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1.1 Introduction

The increase in high-performance personal computers (PCs) and multimedia equipment in offices and homes requires high-speed and broadband wireless data transmission. This requirement makes wireless indoor communication systems such as wireless local area networks (WLAN) and personal area networks (PAN) because of their portable convenience. For such short-range indoor broadband WLAN and PAN systems, the millimeter-wave band offers significant advantages in supplying enough bandwidth for the transmission of various multimedia content. In particular, there has been an increasing requirement for the development of the V-band WLAN for commercial applications. The frequency of 60 GHz is very useful for short-distance wireless communications due to the strong absorption characteristic by oxygen in the atmosphere. Therefore, frequency efficiency is improved compared to other frequency bands. In the last few decades, many research groups in the world have developed millimeter-wave LAN systems. For example, Communications Research Laboratory (CRL, now NiCT) took up the project of developing indoor WLAN systems using millimeter waves in 1992 [1]. The final goal of the millimeter-wave WLAN systems is to provide point-to-multipoint access with transmission rates higher than 100 Mbps for the connectivity of broadband integrated services digital networks (B-ISDNs) or conventional fast Ethernet. For these millimeter-wave WLAN applications, we have to solve some problems. First of all, we have to reduce the size and cost of the systems. The millimeter-wave systems are generally fabricated using HIC (hybrid integrated circuit) technology, causing a large system. MMIC (monolithic millimeter-wave integrated circuit) technology is regarded as an alternative to HIC technology due to its ability to integrate active with passive elements on a single semiconductor substrate [2–6]. The MMIC has advantages, such as small size, high reliability, high productivity, and low cost due to using semiconductor technologies compared to the conventional HIC. The main objective of this chapter is to discuss the MMIC technology and its applications for millimeter-wave wireless LAN. First, millimeter-wave WLAN will be introduced. Then, the modeling of active and passive devices will be described. The design and fabrication technologies of millimeter-wave circuits are presented. Finally, millimeter-wave monolithic circuits for WLAN applications are explained.

1.2 Millimeter-Wave Wireless Local Area Network

Recently, a broadband and high-speed indoor network for office and home environments has been required. Additionally, microwave frequency bands have been saturated and there is growing necessity to exploit new frequency bands that have not yet been utilized for commercial applications. For this reason, utilization of the millimeter-wave band has been recommended, and much research has been devoted to developing millimeter-wave wireless LAN. Advantages of millimeter-wave communication are very wide frequency band, high-speed transmission, and radiated power limitation for unlicensed use. Therefore, millimeter-wave WLAN can be utilized in short-range communication and indoor networks. In particular, a 60-GHz band is very useful for wireless short-distance communications due to strong absorption by oxygen. Thus, compared to other frequency bands, frequency efficiency is improved. Figure 1.1 shows the atmospheric absorption versus frequency [7]. Features to be noted are:

1. Good coexistence between millimeter-wave system and 802.11a/b/g & Bluetooth due to large frequency difference
2. Higher speed transmission, more than 1 Gbps
3. Exploitation of antenna directivity
4. Simple modulation/demodulation
5. Simple signal processing

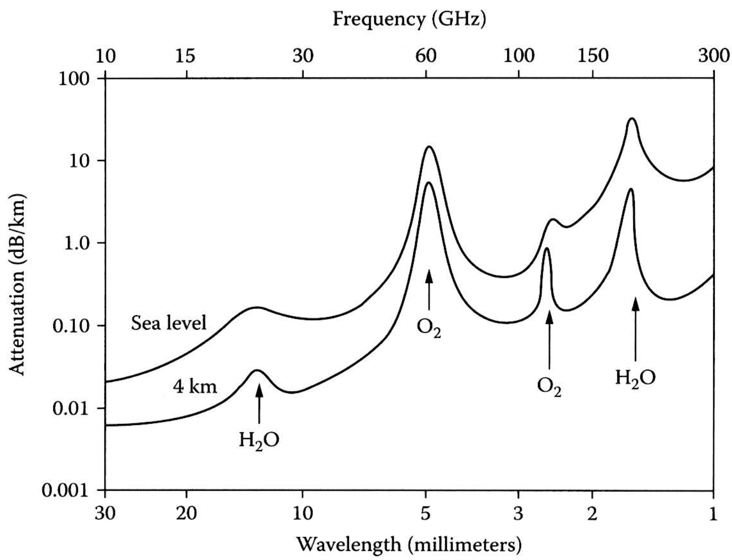
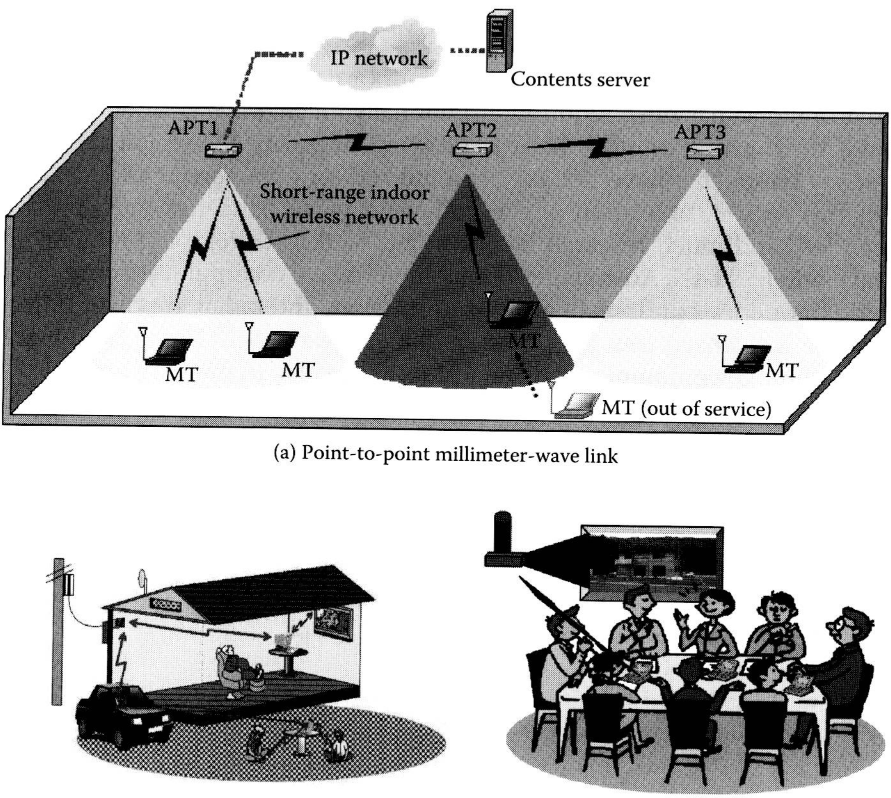


Figure 1.1 Average atmospheric absorption of frequency.



(a) Point-to-point millimeter-wave link

(b) Home utilization

(c) Office utilization

Figure 1.2 Utilizations of millimeter-wave wireless LAN.

Millimeter-wave WLAN is possible for wireless networks such as multimedia equipment, home appliances, videosignal transmissions, and personal computers. Utilization of millimeter-wave WLAN is explained in Figure 1.2. A millimeter-wave circuit and system have been developed using a waveguide module, hybrid integrated circuit method, resulting in large size, high cost, and low productivity. Use of these systems in wireless LAN has many problems due to small size and low cost in wireless LAN. To overcome these problems, high-speed devices such as high electron mobility transistors (HEMTs) and MMTCs need to be added to the millimeter-wave wireless LAN. Figure 1.3 shows normal millimeter-wave WLAN and millimeter-wave circuit components. Millimeter-wave components are usually composed of a low-noise amplifier (LNA), a power amplifier, an oscillator, and an up/down mixer. Also, passive components such as a filter, an antenna, a coupler, and a circulator are required. These components can be varied with system architecture. Millimeter-wave circuits must be

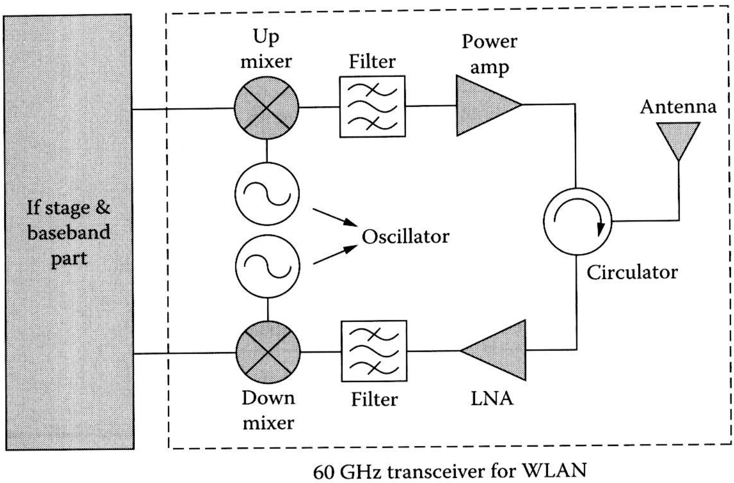


Figure 1.3 Millimeter-wave WLAN and millimeter-wave circuit components (IF, intermediate frequency).

realized high-speed operating characteristics, high linearity, small size, and low cost. For this reason, many technologies such as device modeling, circuit design, circuit fabrication, and measurement technology need to be developed for MMICs.

1.3 Millimeter-Wave Monolithic Integrated Circuit Technology

1.3.1 Millimeter-Wave Device and Modeling

1.3.1.1 Millimeter-Wave HEMT Technology

To fabricate the MMIC devices for the 60-GHz wireless LAN system, the development of active devices that have a high frequency, low noise, and high power performance is an essential theme. Since introduced in 1981 [8], the AlGaAs/GaAs HEMT has been widely used for the microwave region hybrid and monolithic circuits. However, the frequency performances of the conventional AlGaAs/GaAs HEMT devices cannot satisfy the millimeter-wave region (30–300 GHz) MMIC applications. In order to obtain the high-frequency performance, a Pseudomorphic HEMT (PHEMT), which has a relatively low energy band gap characteristic for higher conduction band offset, has been developed. The PHEMT epitaxial structure is shown in Figure 1.4. The epitaxial structure of the device consists of the following layers: an 500 nm GaAs buffer layer, an 18.5/1.5 nm AlGaAs/GaAs × 10 super-lattice buffer layer, a silicon planar doped layer ($1 \times 10^{12}/cm^2$), a 6-nm

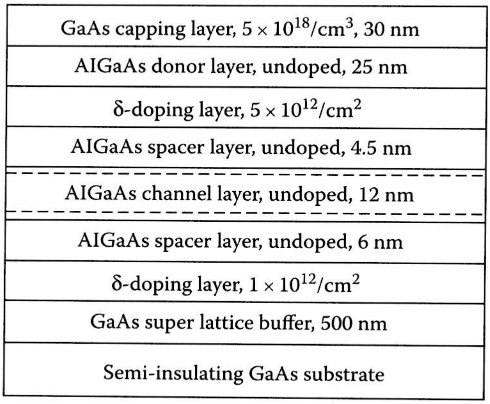
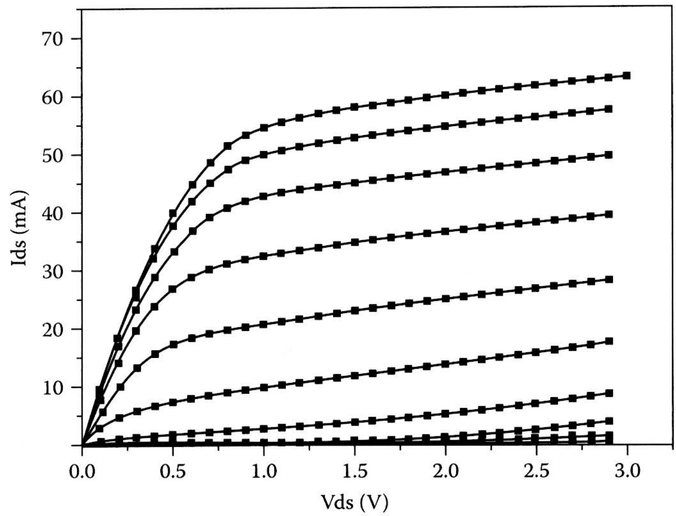
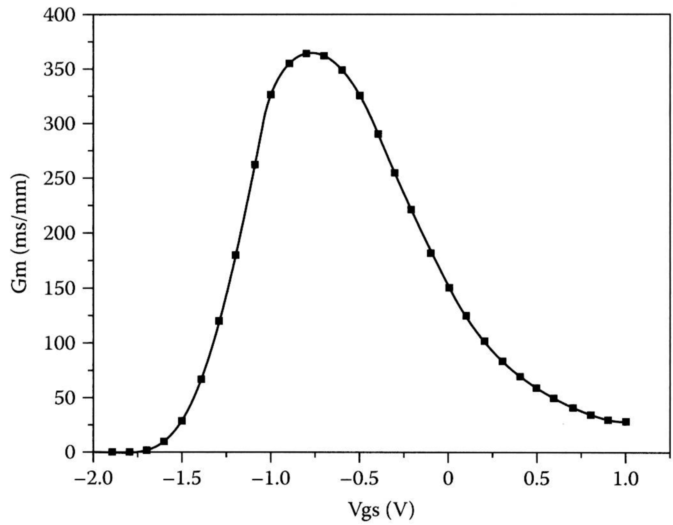


Figure 1.4 The epitaxial structure for PHEMT fabrication. (Copyright 2004. With permission from Elsevier.)

AlGaAs lower spacer layer, a 12-nm InGaAs channel layer, a 4-nm AlGaAs upper spacer layer, a silicon planar doped layer ($5 \times 10^{12}/cm^2$), a 25-nm AlGaAs donor layer, and a 30-nm GaAs cap layer [9–10]. In this chapter, the DC characteristics of the 70 μm × 2 PHEMTs were measured by an HP 4156A DC parameter analyzer. The obtained DC performances show a knee voltage (Vk) of 0.6 V, a pinch-off voltage (Vp) of –1.5 V, a drain-source saturation current (Idss) density of 384 mA/mm and a maximum extrinsic transconductance of 367.9 mS/mm, as shown in Figure 1.5. Radio frequency (RF) characteristics of the PHEMTs were examined by an HP 8510C vector network analyzer. The measurement of S-parameters was performed in a frequency range of 1–50 GHz. For this RF measurement, the drain and gate bias conditions of 2 V and –0.6 V were used. We obtained a current gain cut-off frequency (ft) of 113 GHz, a maximum frequency of oscillation (fmax) of 180 GHz, and a measured S21 gain of 3.9 dB at 50 GHz, as shown in Figure 1.6. HEMTs on InP substrates have demonstrated superior microwave and low-noise performances compared to PHEMTs on GaAs substrates. The excellent device performances of the InP-based HEMTs operating in the millimeter-wave region is mostly based on the InGaAs/InAlAs/InP material system. However, compared to GaAs-based wafers, InP-based wafers have some critical drawbacks, such as the mechanical fragility of the wafers and the higher material cost. Moreover, InP-based HEMTs are not quite proper for large-scale production because the backside etching rate for the InP material is much slower. In recent decades, active research has been done on GaAs-based metamorphic HEMTs (MHEMTs) to address the needs for both high microwave performance and low device cost [11–13]. The use of metamorphic buffers on GaAs substrates was introduced to accommodate the lattice mismatch between the substrate and the active layers, as



(a) I-V characteristics of PHEMT



(b) Transconductance characteristics of PHEMT

Figure 1.5 DC characteristics of GaAs pseudomorphic HEMT (gate length: 0.1 μm, total gate width: 140 μm). (Copyright 2004. With permission from Elsevier.)

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