RF and Microwave Wireless Systems

KAI CHANG
WILEY SERIES IN MICROWAVE AND OPTICAL ENGINEERING

KAI CHANG, Editor
Texas A&M University

FIBER-OPTIC COMMUNICATION SYSTEMS, Second Edition • Govind P. Agrawal
COHERENT OPTICAL COMMUNICATIONS SYSTEMS • Silvello Betti, Giancarlo De Marchis and Eugenio Iannone
HIGH-FREQUENCY ELECTROMAGNETIC TECHNIQUES: RECENT ADVANCES AND APPLICATIONS • Asoke K. Bhattacharya
COMPUTATIONAL METHODS FOR ELECTROMAGNETICS AND MICROWAVES • Richard C. Booton, Jr.
MICROWAVE RING CIRCUITS AND ANTENNAS • Kai Chang
MICROWAVE SOLID-STATE CIRCUITS AND APPLICATIONS • Kai Chang
RF AND MICROWAVE WIRELESS SYSTEMS • Kai Chang
DIODE LASERS AND PHOTONIC INTEGRATED CIRCUITS • Larry Coldren and Scott Corzine
MULTICONDUCTOR TRANSMISSION-LINE STRUCTURES: MODAL ANALYSIS TECHNIQUES • J. A. Brandão Faria
PHASED ARRAY-BASED SYSTEMS AND APPLICATIONS • Nick Fourakis
FUNDAMENTALS OF MICROWAVE TRANSMISSION LINES • Jon C. Freeman
OPTICAL SEMICONDUCTOR DEVICES • Mitsuo Fukuda
MICROSTRIP CIRCUITS • Fred Cardioli
HIGH-SPEED VLSI INTERCONNECTIONS: MODELING, ANALYSIS, AND SIMULATION • A. K. Goel
FUNDAMENTALS OF WAVELETS: THEORY, ALGORITHMS, AND APPLICATIONS • Jaideva C. Goswami and Andrew K. Chan
ANALYSIS AND DESIGN OF INTEGRATED CIRCUIT ANTENNA MODULES • K. C. Gupta and Peter S. Hall
PHASED ARRAY ANTENNAS • R. C. Hansen
HIGH-FREQUENCY ANALOG INTEGRATED CIRCUIT DESIGN • Ravender Goyal (ed.)
MICROWAVE APPROACH TO HIGHLY IRREGULAR FIBER OPTICS • Huang Hung-Chia
NONLINEAR OPTICAL COMMUNICATION NETWORKS • Eugenio Iannone, Francesco Matera, Antonio Mecozzi, and Marina Settembre
FINITE ELEMENT SOFTWARE FOR MICROWAVE ENGINEERING • Tatsuo Itoh, Giuseppe Pelosi and Peter P. Silvester (eds.)
SUPERCONDUCTOR TECHNOLOGY: APPLICATIONS TO MICROWAVE, ELECTRO-OPTICS, ELECTRICAL MACHINES, AND PROPULSION SYSTEMS • A. R. Jha
OPTICAL COMPUTING: AN INTRODUCTION • M. A. Karim and A. S. S. Awwal
INTRODUCTION TO ELECTROMAGNETIC AND MICROWAVE ENGINEERING • Paul R. Karmel, Gabriel D. Colef, and Raymond L. Camisa
MILLIMETER WAVE OPTICAL DIELECTRIC INTEGRATED GUIDES AND CIRCUITS • Shiban K. Koul
MICROWAVE DEVICES, CIRCUITS AND THEIR INTERACTION • Charles A. Lee and G. Conrad Dalman
ADVANCES IN MICROSTRIP AND PRINTED ANTENNAS • Kai-Fong Lee and Wei Chen (eds.)
This page intentionally left blank
RF and Microwave Wireless Systems
This page intentionally left blank
To my parents and my family
This page intentionally left blank
Preface xi
Acronyms xiii

1 Introduction 1
1.1 Brief History of RF and Microwave Wireless Systems 1
1.2 Frequency Spectrums 3
1.3 Wireless Applications 6
1.4 A Simple System Example 7
1.5 Organization of This Book 8

2 Review of Waves and Transmission Lines 10
2.1 Introduction 10
2.2 Wave Propagation 12
2.3 Transmission Line Equation 17
2.4 Reflection, Transmission, and Impedance for a Terminated Transmission Line 20
2.5 Voltage Standing-Wave Ratio 22
2.6 Decibels, Insertion Loss, and Return Loss 27
2.7 Smith Charts 33
2.8 S-Parameters 39
2.9 Coaxial Lines 41
2.10 Microscript Lines 43
2.11 Waveguides 50
2.12 Lumped Elements 54
2.13 Impedance Matching Networks Problems 55
References 63

vii
CONTENTS

3 Antenna Systems 67

3.1 Introduction 67
3.2 Isotropic Radiator and Plane Waves 69
3.3 Far-Field Region 71
3.4 Antenna Analysis 73
3.5 Antenna Characteristics and Parameters 74
3.6 Monopole and Dipole Antennas 80
3.7 Horn Antennas 86
3.8 Parabolic Dish Antennas 88
3.9 Microstrip Patch Antennas 90
3.10 Antenna Arrays and Phased Arrays 98
3.11 Antenna Measurements 104
Problems 104
References 109

4 Various Components and Their System Parameters 111

4.1 Introduction and History 111
4.2 Couplers, Hybrids, and Power Dividers/Combiners 114
4.3 Resonators, Filters, and Multiplexers 118
4.4 Isolators and Circulators 128
4.5 Detectors and Mixers 130
4.6 Switches, Phase Shifters, and Attenuators 134
4.7 Oscillators and Amplifiers 139
4.8 Frequency Multipliers and Dividers 143
Problems 145
References 148

5 Receiver System Parameters 149

5.1 Typical Receivers 149
5.2 System Considerations 150
5.3 Natural Sources of Receiver Noise 152
5.4 Receiver Noise Figure and Equivalent Noise Temperature 154
5.5 Compression Points, Minimum Detectable Signal, and Dynamic Range 158
5.6 Third-Order Intercept Point and Intermodulation 161
5.7 Spurious Responses 166
5.8 Spurious-Free Dynamic Range 166
Problems 168
References 171

6 Transmitter and Oscillator Systems 172

6.1 Transmitter Parameters 172
6.2 Transmitter Noise 173
10 Multiple-Access Techniques 294

10.1 Introduction 294
10.2 Frequency Division Multiple Access and Frequency Division Multiplexing 294
10.3 Time Division Multiple Access and Time Division Multiplexing 295
10.4 Spread Spectrum and Code Division Multiple Access 298
References 303

11 Other Wireless Systems 304

11.1 Radio Navigation and Global Positioning Systems 304
11.2 Motor Vehicle and Highway Applications 309
11.3 Direct Broadcast Satellite Systems 313
11.4 RF Identification Systems 313
11.5 Remote Sensing Systems and Radiometers 317
11.6 Surveillance and Electronic Warfare Systems 320
Problems 328
References 330

Index 333
Preface

Wireless personal mobile and cellular communications are expected to be one of the hottest growth areas of the 2000s and beyond. They have enjoyed the fastest growth rate in the telecommunications industry—adding customers at a rate of 20–30% a year. Presently, at least six satellite systems are being developed so that wireless personal voice and data communications can be transmitted from any part of the earth to another using a simple, hand-held device. These future systems will provide data and voice communications to anywhere in the world, using a combination of wireless telephones, wireless modems, terrestrial cellular telephones and satellites. The use of wireless remote sensing, remote identification, direct broadcast, global navigation, and compact sensors has also gained popularity in the past decade. Wireless communications and sensors have become a part of a consumer’s daily life. All of these wireless systems consist of a radio frequency (RF) or microwave front end.

Although many new wireless courses have been offered at universities and in industry, there is yet to be a textbook written on RF and microwave wireless systems. The purpose of this book is to introduce students and beginners to the general hardware components, system parameters, and architectures of RF and microwave wireless systems. Practical examples of components and system configurations are emphasized. Both communication and radar/sensor systems are covered. Many other systems, such as, the global positioning system (GPS), RF identification (RFID), direct broadcast system (DBS), surveillance, smart highways, and smart automobiles are introduced. It is hoped that this book will bridge the gap between RF/microwave engineers and communication system engineers.

The materials covered in this book have been taught successfully at Texas A&M University to a senior class for the past few years. Half of the students are from RF and microwave areas, and half are from communications, signal processing, solid-state, optics, or other areas. The book is intended to be taught for one semester to an undergraduate senior class or first-year graduate class with some sections assigned to
students for self-study. The end-of-chapter problems will strengthen the reader's knowledge of the subject. The reference sections list the principal references for further reading.

Although this book was written as a textbook, it can also be used as a reference book for practical engineers and technicians. Throughout the book, the emphasis is on the basic operating principles. Many practical examples and design information have been included.

I would like to thank all of my former students who used my notes in class for their useful comments and suggestions. I would also like to thank Mingyi Li, Paola Zepeda, Chris Rodenbeck, Matt Coutant and James McSpadden for critical review of the manuscript. Michelle Rubin has done an excellent job in editing and preparing the manuscript. Taehan Bae has helped to prepared some of the art work. Finally, I wish to express my deep appreciation to my wife, Suh-jan, and my children, Peter and Nancy, for their patience and support.

Kai Chang

February 2000
### Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF</td>
<td>array factor</td>
</tr>
<tr>
<td>AGC</td>
<td>automatic gain control</td>
</tr>
<tr>
<td>AM</td>
<td>amplitude modulated</td>
</tr>
<tr>
<td>AMPS</td>
<td>advanced mobile phone service</td>
</tr>
<tr>
<td>APTS</td>
<td>advanced public transit systems</td>
</tr>
<tr>
<td>ASK</td>
<td>amplitude shift keying</td>
</tr>
<tr>
<td>ATIS</td>
<td>advanced traveler information system</td>
</tr>
<tr>
<td>ATMS</td>
<td>advanced traffic management system</td>
</tr>
<tr>
<td>AUT</td>
<td>antenna under test</td>
</tr>
<tr>
<td>AVCS</td>
<td>advanced vehicle control system</td>
</tr>
<tr>
<td>AVI</td>
<td>automatic vehicle identification</td>
</tr>
<tr>
<td>BER</td>
<td>bit error rate</td>
</tr>
<tr>
<td>BPF</td>
<td>bandpass filter</td>
</tr>
<tr>
<td>BPSK</td>
<td>biphase shift keying</td>
</tr>
<tr>
<td>BSF</td>
<td>bandstop filter</td>
</tr>
<tr>
<td>BW</td>
<td>bandwidth</td>
</tr>
<tr>
<td>CAD</td>
<td>computer-aided design</td>
</tr>
<tr>
<td>CDMA</td>
<td>code division multiple access</td>
</tr>
<tr>
<td>CEP</td>
<td>circular probable error</td>
</tr>
<tr>
<td>CMOS</td>
<td>complementary MOS</td>
</tr>
<tr>
<td>CP</td>
<td>circularly polarized</td>
</tr>
<tr>
<td>CPL</td>
<td>cross-polarization level</td>
</tr>
<tr>
<td>CRTs</td>
<td>cathode ray tubes</td>
</tr>
<tr>
<td>CT1/2</td>
<td>cordless telephone 1/2</td>
</tr>
<tr>
<td>CTO</td>
<td>cordless telephone O</td>
</tr>
<tr>
<td>CVO</td>
<td>commercial vehicle operations</td>
</tr>
<tr>
<td>CVR</td>
<td>crystal video receiver</td>
</tr>
<tr>
<td>CW</td>
<td>continuous wave</td>
</tr>
</tbody>
</table>
DBS  direct broadcast satellite
DC  direct current
DECT  digital European cordless telephone
DR  dynamic range
DRO  dielectric resonator oscillator
DSB  double side band
DSSS  direct-sequence spread spectrum
ECCMs  electronic counter-countermeasures
ECMs  electronic countermeasures
EIRP  effective isotropic radiated power
EM  electromagnetic
ESM  electronic support measure
EW  electronic warfare
FCC  Federal Communications Commission
FDD  frequency division duplex
FDM  frequency division multiplexing
FDMA  frequency division multiple access
FETs  field-effect transistors
FFHSS  fast frequency-hopping spread spectrum
FHSS  frequency-hopping spread spectrum
FLAR  forward-looking automotive radar
FMCW  frequency-modulated continuous wave
FM  frequency modulated
FNBW  first-null beamwidth
FSK  frequency shift keying
GEO  geosynchronous orbit
GMSK  Gaussian minimum shift keying
GPS  global positioning system
GSM  global system for mobile communication
G/T  receiver antenna gain to system noise temperature ratio
HBTs  heterojunction bipolar transistors
HEMTs  high-electron-mobility transistors
HPA  high-power amplifier
HPBW  half-power beamwidth
HPF  high-pass filter
IF  intermediate frequency
IFM  instantaneous frequency measurement
IL  insertion loss
IMD  intermodulation distortion
IM  intermodulation
IMPATT  impact ionization avalanche transit time device
IM3  third-order intermodulation
IP3  third-order intercept point
I/Q  in-phase/quadrature-phase
IVHS  intelligent vehicle and highway system
JCT Japanese cordless telephone
J/S jammer-to-signal
LAN local area network
LMDS local multipoint distribution service
LEO low earth orbit
LNA low-noise amplifier
LO local oscillator
LOS line-of-sight
LPF low-pass filter
LP linearly polarized
MDS minimum detectable signal
MEO medium-altitude orbit
MESFETs metal–semiconductor field-effect transistors
MIC microwave integrated circuit
MLS microwave landing system
MMIC monolithic microwave integrated circuits
MSK minimum shift keying
MTI moving target indicator
NMT Nordic mobile telephone
OQPSK offset-keyed quadrifase shift keying
PAMELA pricing and monitoring electronically of automobiles
PA power amplifier
PAE power added efficiency
PCM pulse code modulation
PCN personal communication networks
PCS personal communication systems
PDC personal digital cellular
PHS personal handy phone system
PLL phase-locked loops
PLO phase-locked oscillators
PM phase modulation
PN pseudonoise
PRF pulse repetition frequency
PSK phase shift keying
8-PSK 8-phase shift keying
16-PSK 16-phase shift keying
QAM quadrature amplitude modulation
QPSK quadrifase shift keying
RCS radar cross section
RF radio frequency
RFID radio frequency identification
RL return loss
SAR synthetic aperture radar
SAW surface acoustic wave
SEP spherical probable error
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFDR</td>
<td>spurious-free dynamic range</td>
</tr>
<tr>
<td>SFHSS</td>
<td>slow frequency-hopping spread spectrum</td>
</tr>
<tr>
<td>SLL</td>
<td>sidelobe levels</td>
</tr>
<tr>
<td>SMILER</td>
<td>short range microwave links for European roads</td>
</tr>
<tr>
<td>SNR</td>
<td>signal-noise ratio</td>
</tr>
<tr>
<td>SOJ</td>
<td>stand-off jammer</td>
</tr>
<tr>
<td>SPDT</td>
<td>single pole, double throw</td>
</tr>
<tr>
<td>SPST</td>
<td>single pole, single throw</td>
</tr>
<tr>
<td>SP3T</td>
<td>single pole, triple throw</td>
</tr>
<tr>
<td>SQPSK</td>
<td>staggered quadriphase shift keying</td>
</tr>
<tr>
<td>SS</td>
<td>spread spectrum</td>
</tr>
<tr>
<td>SS-CDMA</td>
<td>spread spectrum code division multiple access</td>
</tr>
<tr>
<td>SSJ</td>
<td>self-screening jammer</td>
</tr>
<tr>
<td>SSMI</td>
<td>special sensor microwave imager</td>
</tr>
<tr>
<td>STC</td>
<td>sensitivity time control</td>
</tr>
<tr>
<td>TACS</td>
<td>total access communication system</td>
</tr>
<tr>
<td>TDM</td>
<td>time division multiplexing</td>
</tr>
<tr>
<td>TDMA</td>
<td>time division multiple access</td>
</tr>
<tr>
<td>TE</td>
<td>transverse electric</td>
</tr>
<tr>
<td>TEM</td>
<td>transverse electromagnetic</td>
</tr>
<tr>
<td>TM</td>
<td>transverse magnetic</td>
</tr>
<tr>
<td>TOI</td>
<td>third-order intercept point</td>
</tr>
<tr>
<td>T/R</td>
<td>transmit/receive</td>
</tr>
<tr>
<td>TWTs</td>
<td>traveling-wave tubes</td>
</tr>
<tr>
<td>UHF</td>
<td>ultrahigh frequencies</td>
</tr>
<tr>
<td>VCO</td>
<td>voltage-controlled oscillator</td>
</tr>
<tr>
<td>VHF</td>
<td>very high frequency</td>
</tr>
<tr>
<td>VLF</td>
<td>very low frequency</td>
</tr>
<tr>
<td>VSWR</td>
<td>voltage standing-wave ratio</td>
</tr>
<tr>
<td>WLANs</td>
<td>wireless local-area networks</td>
</tr>
</tbody>
</table>
RF and Microwave Wireless Systems
CHAPTER ONE

Introduction

1.1 BRIEF HISTORY OF RF AND MICROWAVE WIRELESS SYSTEMS

The wireless era was started by two European scientists, James Clerk Maxwell and Heinrich Rudolf Hertz. In 1864, Maxwell presented Maxwell’s equations by unifying the works of Lorentz, Faraday, Ampere, and Gauss. He predicted the propagation of electromagnetic waves in free space at the speed of light. He postulated that light was an electromagnetic phenomenon of a particular wavelength and predicted that radiation would occur at other wavelengths as well. His theory was not well accepted until 20 years later, after Hertz validated the electromagnetic wave (wireless) propagation. Hertz demonstrated radio frequency (RF) generation, propagation, and reception in the laboratory. His radio system experiment consisted of an end-loaded dipole transmitter and a resonant square-loop antenna receiver operating at a wavelength of 4 m. For this work, Hertz is known as the father of radio, and frequency is described in units of hertz (Hz).

Hertz’s work remained a laboratory curiosity for almost two decades, until a young Italian, Guglielmo Marconi, envisioned a method for transmitting and receiving information. Marconi commercialized the use of electromagnetic wave propagation for wireless communications and allowed the transfer of information from one continent to another without a physical connection. The telegraph became the means of fast communications. Distress signals from the S.S. Titanic made a great impression on the public regarding the usefulness of wireless communications. Marconi’s wireless communications using the telegraph meant that a ship was no longer isolated in the open seas and could have continuous contact to report its positions. Marconi’s efforts earned him the Nobel Prize in 1909.

In the early 1900s, most wireless transmission occurred at very long wavelengths. Transmitters consisted of Alexanderson alternators, Poulsen arcs, and spark gaps. Receivers used coherers, Fleming valves, and DeForest audions. With the advent of DeForest’s triode vacuum tube in 1907, continuous waves (CW) replaced spark gaps,
and more reliable frequency and power output were obtained for radio broadcasting at frequencies below 1.5 MHz. In the 1920s, the one-way broadcast was made to police cars in Detroit. Then the use of radio waves for wireless broadcasting, communications between mobile and land stations, public safety systems, maritime mobile services, and land transportation systems was drastically increased. During World War II, radio communications became indispensable for military use in battlefields and troop maneuvering.

World War II also created an urgent need for radar (standing for radio detection and ranging). The acronym radar has since become a common term describing the use of reflections from objects to detect and determine the distance to and relative speed of a target. A radar’s resolution (i.e., the minimum object size that can be detected) is proportional to wavelength. Therefore, shorter wavelengths or higher frequencies (i.e., microwave frequencies and above) are required to detect smaller objects such as fighter aircraft.

Wireless communications using telegraphs, broadcasting, telephones, and point-to-point radio links were available before World War II. The widespread use of these communication methods was accelerated during and after the war. For long-distance wireless communications, relay systems or tropospheric scattering were used. In 1959, J. R. Pierce and R. Kompfner envisioned transoceanic communications by satellites. This opened an era of global communications using satellites. The satellite uses a broadband high-frequency system that can simultaneously support thousands of telephone users, tens or hundreds of TV channels, and many data links. The operating frequencies are in the gigahertz range. After 1980, cordless phones and

![Summary of the history of wireless systems.](FIGURE 1.1)
cellular phones became popular and have enjoyed very rapid growth in the past two decades. Today, personal communication systems (PCSs) operating at higher frequencies with wider bandwidths are emerging with a combination of various services such as voice mail, email, video, messaging, data, and computer on-line services. The direct link between satellites and personal communication systems can provide voice, video, or data communications anywhere in the world, even in the most remote regions of the globe.

In addition to communication and radar applications, wireless technologies have many other applications. In the 1990s, the use of wireless RF and microwave technologies for motor vehicle and highway applications has increased, especially in Europe and Japan. The direct broadcast satellite (DBS) systems have offered an alternative to cable television, and the end of the Cold War has made many military technologies available to civilian applications. The global positioning systems (GPSs), RF identification (RFID) systems, and remote sensing and surveillance systems have also found many commercial applications.

Figure 1.1 summarizes the history of these wireless systems.

1.2 FREQUENCY SPECTRUMS

Radio frequencies, microwaves, and millimeter waves occupy the region of the electromagnetic spectrum below 300 GHz. The microwave frequency spectrum is from 300 MHz to 30 GHz with a corresponding wavelength from 100 cm to 1 cm. Below the microwave spectrum is the RF spectrum and above is the millimeter-wave spectrum. Above the millimeter-wave spectrum are submillimeter-wave, infrared, and optical spectrums. Millimeter waves (30–300 GHz), which derive their name from the dimensions of the wavelengths (from 10 to 1 mm), can be classified as microwaves since millimeter-wave technology is quite similar to that of microwaves. Figure 1.2 shows the electromagnetic spectrum. For convenience, microwave and millimeter-wave spectrums are further divided into many frequency bands. Figure 1.2 shows some microwave bands, and Table 1.1 shows some millimeter-wave bands. The RF spectrum is not well defined. One can consider the frequency spectrum below 300 MHz as the RF spectrum. But frequently, literatures use the RF term up to 2 GHz or even higher.

The Federal Communications Commission (FCC) allocates frequency ranges and specifications for different applications in the United States, including telecommunications, radios, satellite communications, cellular phones, police radar, burglar alarms, and navigation beacons. The performance of each application is strongly affected by the atmospheric absorption. The absorption curves are shown in Fig. 1.3. For example, a secure local area network would be ideal at 60 GHz due to the high attenuation caused by the O₂ resonance.

As more applications spring up, overcrowding and interference at lower frequency bands pushes applications toward higher operating frequencies. Higher frequency operation has several advantages, including:
FIGURE 1.2  Electromagnetic spectrum.
1. Larger instantaneous bandwidth for greater transfer of information
2. Higher resolution for radar, bigger doppler shift for CW radar, and more detailed imaging and sensing
3. Reduced dimensions for antennas and other components
4. Less interference from nearby applications
5. Fast speed for digital system signal processing and data transmission
6. Less crowded spectrum
7. Difficulty in jamming (military applications)

<table>
<thead>
<tr>
<th>Designation</th>
<th>Frequency Range (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q-band</td>
<td>33–50</td>
</tr>
<tr>
<td>U-band</td>
<td>40–60</td>
</tr>
<tr>
<td>V-band</td>
<td>50–75</td>
</tr>
<tr>
<td>E-band</td>
<td>60–90</td>
</tr>
<tr>
<td>W-band</td>
<td>75–110</td>
</tr>
<tr>
<td>D-band</td>
<td>110–170</td>
</tr>
<tr>
<td>G-band</td>
<td>140–220</td>
</tr>
<tr>
<td>Y-band</td>
<td>220–325</td>
</tr>
</tbody>
</table>

FIGURE 1.3 Absorption by the atmosphere in clear weather.
The use of higher frequency also has some disadvantages:

1. More expensive components
2. Higher atmospheric losses
3. Reliance on GaAs instead of Si technology
4. Higher component losses and lower output power from active devices
5. Less accurate design tools and less mature technologies

The electron mobility in GaAs is higher than that in silicon. Therefore, GaAs devices can operate at higher frequencies and speeds. Current silicon-based devices are commonly used up to 2 GHz. Above 4 GHz, GaAs devices are preferred for better performance. However, GaAs processing is more expensive, and the yield is lower than that of silicon.

1.3 WIRELESS APPLICATIONS

Two of the most historically important RF/microwave applications are communication systems and radar; but there are many others. Currently, the market is driven by the phenomenal growth of PCSs, although there is also an increased demand for satellite-based video, telephone, and data communication systems.

Radio waves and microwaves play an important role in modern life. Television signals are transmitted around the globe by satellites using microwaves. Airliners are guided from takeoff to landing by microwave radar and navigation systems. Telephone and data signals are transmitted using microwave relays. The military uses microwaves for surveillance, navigation, guidance and control, communications, and identification in their tanks, ships, and planes. Cellular telephones are everywhere.

The RF and microwave wireless technologies have many commercial and military applications. The major application areas include communications, radar, navigation, remote sensing, RF identification, broadcasting, automobiles and highways, sensors, surveillance, medical, and astronomy and space exploration. The details of these applications are listed below:

1. *Wireless Communications*. Space, long-distance, cordless phones, cellular telephones, mobile, PCSs, local-area networks (LANs), aircraft, marine, citizen’s band (CB) radio, vehicle, satellite, global, etc.
2. *Radar*. Airborne, marine, vehicle, collision avoidance, weather, imaging, air defense, traffic control, police, intrusion detection, weapon guidance, surveillance, etc.
3. *Navigation*. Microwave landing system (MLS), GPS, beacon, terrain avoidance, imaging radar, collision avoidance, auto-pilot, aircraft, marine, vehicle, etc.
4. Remote Sensing. Earth monitoring, meteorology, pollution monitoring, forest, soil moisture, vegetation, agriculture, fisheries, mining, water, desert, ocean, land surface, clouds, precipitation, wind, flood, snow, iceberg, urban growth, aviation and marine traffic, surveillance, etc.

5. RF Identification. Security, antitheft, access control, product tracking, inventory control, keyless entry, animal tracking, toll collection, automatic checkout, asset management, etc.

6. Broadcasting. Amplitude- and frequency-modulated (AM, FM) radio, TV, DBS, universal radio system, etc.

7. Automobiles and Highways. Collision warning and avoidance, GPS, blind-spot radar, adaptive cruise control, autonavigation, road-to-vehicle communications, automobile communications, near-obstacle detection, radar speed sensors, vehicle RF identification, intelligent vehicle and highway system (IVHS), automated highway, automatic toll collection, traffic control, ground penetration radar, structure inspection, road guidance, range and speed detection, vehicle detection, etc.

8. Sensors. Moisture sensors, temperature sensors, robotics, buried-object detection, traffic monitoring, antitheft, intruder detection, industrial sensors, etc.

9. Surveillance and Electronic Warfare. Spy satellites, signal or radiation monitoring, troop movement, jamming, antijamming, police radar detectors, intruder detection, etc.

10. Medical. Magnetic resonance imaging, microwave imaging, patient monitoring, etc.

11. Radio Astronomy and Space Exploration. Radio telescopes, deep-space probes, space monitoring, etc.

12. Wireless Power Transmission. Space to space, space to ground, ground to space, ground to ground power transmission.

1.4 A SIMPLE SYSTEM EXAMPLE

A wireless system is composed of active and passive devices interconnected to perform a useful function. A simple example of a wireless radio system is shown in Fig. 1.4.

The transmitter operates as follows. The input baseband signal, which could be voice, video, or data, is assumed to be bandlimited to a frequency $f_m$. This signal is filtered to remove any components that may be beyond the channel's passband. The message signal is then mixed with a local oscillator (LO) signal to produce a modulated carrier in a process called up-conversion since it produces signals at frequencies $f_{LO} + f_m$ or $f_{LO} - f_m$ which are normally much higher than $f_m$. The modulated carrier can then be amplified and transmitted by the antenna.

When the signal arrives at the receiver, it is normally amplified by a low-noise amplifier (LNA). The LNA may be omitted from some systems when the received signal has enough power to be mixed directly, as may occur in short-distance
communication links. The mixer then produces a signal at a frequency $f_{IF} + f_m$ or $f_{IF} - f_m$ in a process called down-conversion since $f_{IF}$ is chosen to be much lower than $f_{LO}$. The signal is filtered to remove any undesired harmonic and spurious products resulting from the mixing process and is amplified by an intermediate-frequency (IF) amplifier. The output of the amplifier goes to a detector stage where the baseband signal $f_m$, which contains the original message, is recovered.

To perform all of these functions, the microwave system relies on separate components that contribute specific functions to the overall system performance. Broadly speaking, microwave components can be classified as transmission lines, couplers, filters, resonators, signal control components, amplifiers, oscillators, mixers, detectors, and antennas.

1.5 ORGANIZATION OF THIS BOOK

This book is organized into 11 chapters. Chapter 2 reviews some fundamental principles of transmission lines and electromagnetic waves. Chapter 3 gives a brief overview of how antennas and antenna arrays work. Chapter 4 provides a discussion