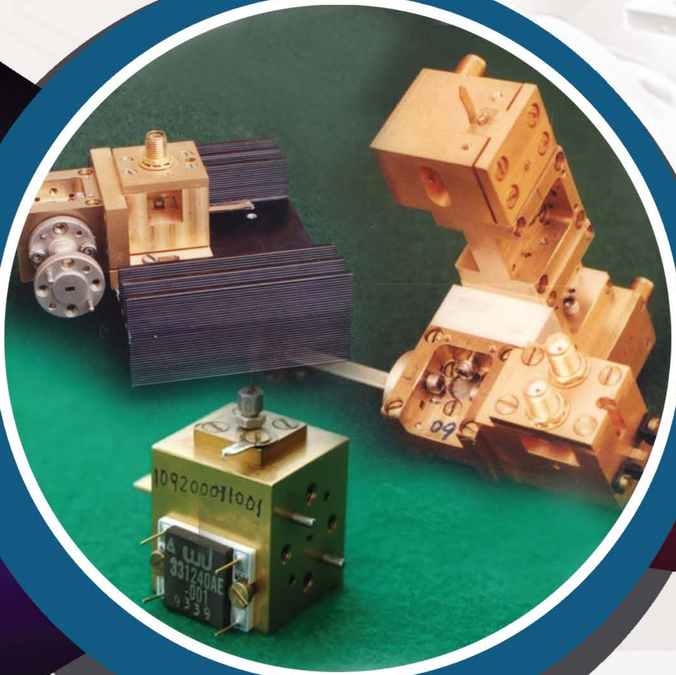
Advances in Millimeter Wave Technology

Awadhesh Kumar Shukla



Defence Research & Development Organisation
Ministry of Defence, New Delhi - 110 011, India

Advances in Millimeter Wave Technology

Advances in Millimeter Wave Technology

Awadhesh Kumar Shukla

Former Scientist 'G'
Defence Electronics Applications Laboratory (DEAL)
Dehradun, India

Defence Research and Development Organisation
Ministry of Defence, New Delhi – 110 011
2019

DRDO MONOGRAPHS/SPECIAL PUBLICATIONS SERIES

ADVANCES IN MILLIMETER WAVE TECHNOLOGY

Awadhesh Kumar Shukla

Cataloguing-in-Publication

Shukla, Awadhesh Kumar

Advances in Millimeter Wave Technology

DRDO Monographs/Special Publications Series

1. Millimeter Waves 2. Electromagnetic Radiation 3. Electromagnetic Spectrum

I. Title II. Series

621.3.029.65

ISBN 978-81-86514-63-4

Cover Design	*Printing*	*Marketing*
Rajesh Kumar	SK Gupta	Tapesh Sinha

Published by Director, DESIDOC, Metcalfe House, Delhi – 110 054.

Contents

Preface

It is well established that the millimeter wave spectrum has the performance advantage over infrared, laser, and visual band of frequencies. The millimeter wave technology is unique in many ways, the most striking aspect being its extraordinary broad bandwidth and having better penetration depth in adverse climatic conditions like smoke, dust, snow, and fog. Further, the wavelengths at millimeter wave bands being much smaller as compared to the conventional microwave frequencies, systems are smaller in size and weight, and thereby, have potential applications in airborne systems for various military programs. This feature of millimeter wave frequencies has been exploited in military as well as civilian applications. There is a growing need in wireless applications for ultra-high data rate transfer, at speeds of 10 Gbps and up, millimeter wave makes it possible. Worldwide R&D in millimeter wave area has demonstrated many successful tests to establish the technology with its promising potential for the future of defence and security.

This monograph addresses the development scenario of the entire millimeter wave spectrum (30 GHz - 300 GHz) comprising of devices, components and systems. The monograph is organised into seven chapters using top down approach. It begins with an introduction to frequency bands, unique millimeter wave applications in communication, key devices and circuit components for developments of systems. Chapter 2 discusses about millimeter wave devices and circuits. Devices include generating devices, e.g., IMPATT oscillators, concept of injection locking phenomenon in oscillators and power combining techniques, etc.

Chapter 3 starts with the millimeter wave control components like PIN and ferrite switches, phase shifters, circulators and isolators. The millimeter wave receiver components and circuits are discussed in chapter 4 which begins with the Gunn devices, various mixer circuits in different topologies, up and down converters and low noise amplifiers. Millimeter wave transceiver configurations for different applications are discussed in chapter 5, while chapter 6 is devoted to the development of millimeter wave systems useful for defence services. These are LOS systems to provide wireless communications, through point-to-point (Ship-to-Ship and Ground-to-Air or Air-to-Ground), millimeter wave imaging system to capture images in foggy and dusty environment and millimeter wave Identification of Friend & Foe (IFF) for application in battlefield and millimeter wave satellite terminals for secure communication in border areas through spot beams of satellite payload, etc.

Finally, chapter 7 presents future trends and technology challenges which discusses about Exploitation and challenges of millimeter wave frequency spectrum in futuristic military applications, broadband communication technology, optical technique of millimeter wave generation with low phase noise signal for applications in imaging and phased array radar systems; and millimeter wave options for mobile cell phones.

This monograph is based on the author's own notes that evolved over the past several years and his long experience in millimeter wave/microwave field. This monograph is not intended as a reference textbook but is oriented to add to the practical design and applications of millimeter wave technology in defence and civil sectors.

2019 Awadhesh Kumar Shukla

Acknowledgements

My sincere thanks to my colleague Dr UC Ray, former Scientist 'G' from SSPL, Delhi for encouragement to undertake this project to produce a monograph on 'Advances in Millimeter Wave Technology'. I am grateful to Director, Defence Electronics Applications Laboratory (DEAL) Dehradun for the permission to use library facility and also thankful to the library in-charge Mr DP Singh for help with reference search and library support.

I would like to thank my anonymous reviewers of this manuscript and giving valuable suggestions. I deeply appreciate the support I received from my wife Shashi Shukla during the course of this project.

Sincere thanks are due to Director, Defence Scientific Information and Documentation Centre (DESIDOC), Delhi for the ready cooperation and efficient support received in bringing out this monograph. I must in particular thank Ms Alka Bansal, Mr NK Chawla, and team, Monographs Division of DESIDOC for their excellent support in every possible manner.

I have written this monograph with many warm memories of all my colleagues and friends in Millimeter Wave Group of Defence Electronics Applications Laboratory (DEAL) Dehradun, without whom the success achieved would not have been possible.

2019 Awadhesh Kumar Shukla

List of Acronyms

AP	Active Protection
ATGM	Anti-tank Guided Missile
BPF	Band-Pass Filters
BUC	Block Up Converter
CCW	Counter-Clockwise
CIFF	Combat Identification of Friend or Foe
CPW	Coplanar Waveguide
DDR	Double-Drift Region
DEAL	Defence Electronics Applications Laboratory
FBG	Fibre Bragg Grating
FCC	Federal Communications Commission
HBNR	High Band Network Radio
HBT	Heterojunction Bipolar Transistor
HEMT	High Electron Mobility Transistor
ICW	Interrupted Continuous Wave
IF	Intermediate Frequency
IFF	Identification of Friend and Foe
IFL	Inter-Facility Link
ILA	Injection Locked Amplifier
IMPATT	Impact Avalanche Transit Time
LHC	Left-Handed Circularly
LMDS	Local Multipoint Distribution Services
LNA	Low-Noise Amplifier
LNBC	Low-Noise Block Converter
LNC	Low-Noise Converter
LO	Local Oscillator

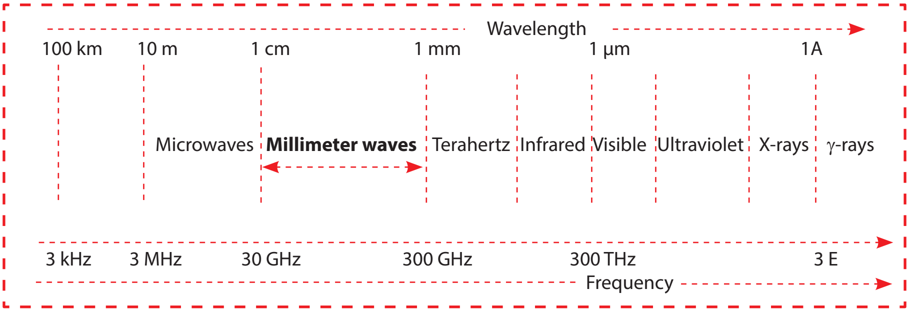
LOS	Line-of-Sight
LPI	Low Probability of Interception
MCM	Multi-chip MMIC Modular
MEMS	Micro-Electro-Mechanical Systems
MESFET	Metal-Semiconductor Field Effect Transistor
MITATT	Mixed Tunneling and Avalanche Transit Time
MMDS	Multichannel Multipoint Distribution Service
MMIC	Millimeter Wave Integrated Circuits
MVDS	Microwave Video Distribution Systems
MWS	Multimedia Wireless Systems
NDRR	Negative Diode Resistance Region
NRD	Non-Radiative Dielectric
NTC	Negative Temperature Coefficient
OBP	On-board Processing
OCXO	Oven Controlled Crystal Oscillator
OFHC	Oxygen Free High Conductivity
OMT	Ortho-Mode Transducer
OPLL	Optical Phase-Lock Loop
PBT	Permeable Base Transistor
PLO	Phase Locked Oscillator
PRF	Pulse Repetition Frequency
RFT	Radio Frequency Transciever
RHC	Right-Handed Circularly
RPG	Rocket-Propelled Grenade
RWH	Ridely Watkins-Hilsum
SATCOM	Satellite Communication
SDR	Single-Drift Region
SPDT	Single-Pole Double-Throw
SSPA	Solid State Power Amplifier
TCTD	Two-Channel Time Duplexer
TED	Transfer Electron Device
TLT	Test Loop Translator
TUNNETT	Tunnel Injection Transit Time
USFCC	US Federal Communications Commission
VCA	Voltage Controlled Attenuator

CHAPTER 1

Introduction to Millimeter Waves

The progress of science and technology has been closely linked to mankind's continuous pursuit of utililising Electromagnetic (EM) spectrum towards higher frequencies as this has opened up new application potentials and enabled new capabilities for defence and security including commercial applications. The EM radiation range from lower Radio Frequencies (RF) to gamma rays corresponding to wavelengths from kilometers to angstrom.

The EM radiation is classified by the wavelength (in order of decreasing wavelength and increasing frequency) from RF to γ-rays, including microwaves and millimeter waves, as shown in Fig. 1.1.



Note: m = meter, cm = centimeter, mm = millimeter, µm = micrometer = 10^{-6} and A = angstrom = 10^{-10}

Figure 1.1. Electromagnetic Spectrum

The RF include any electromagnetic wave spanning the frequency range between 3 kHz to 300 GHz. Practically, RF is defined between 100 kHz to 1 GHz, microwaves between 3 GHz to 30 GHz, and the millimeter wave region is placed between microwave and infrared regions in electromagnetic spectrum, and it ranges from 30 GHz to 300 GHz.

Because microwaves and millimeter waves penetrate the ionosphere, hence these waves are fully utilised for Satellite Communication (SATCOM) applications. This characteristic also provides suitability of millimeter waves for terrestrial communications. The applications may be as Local Multipoint Distribution Service (LMDS) and Multichannel–Multipoint Distribution Service (MMDS).

In the beginning, communication systems used multiplexing scheme for speech signals over a microwave carrier, but in the present scenario, microwaves and millimeter waves are used to build communication systems for any kind of information, i.e., voice, data, facsimile, and video.

1.1 MILLIMETER WAVES AND THEIR CHARACTERISTICS AS PART OF ELECTROMAGNETIC SPECTRUM

In 1865, James Clerk Maxwell proved that the EM wave propagates at the velocity of light[1], and in 1888, generation of electromagnetic waves was established by Hertz who found that their characteristics were similar to the light. The history of millimeter wave technology goes back to the 1890's when Sir Jagadish Chander (JC) Bose was experimenting with millimeter wave signals at just about the time when his contemporaries like Marconi[2] were trying to make radio communications.

Sir JC Bose, in 1895, first demonstrated at the Presidency College, Kolkata, India, transmission and reception of electromagnetic waves at 60 GHz, over a distance of 23 meters, through two intervening walls by remotely ringing a bell and detonating some gunpowder[3]. First practical use of millimeter wave was established by Sir JC Bose. For millimeter-systems system, Sir Bose pioneered development of millimeter wave components, such as a spark-gap generator, coherer detector, and other antennae subsystems.

Quasi-optical technique was selected by Sir JC Bose, corresponding to millimeter ranging wavelengths from 2.5 cm to 5 mm. Millimeter wave system developed by Sir JC Bose was the milestone achievement in the Asian continent.

Following Bose's research, millimeter wave technology was confined within the boundaries of the Calcutta University and government laboratories for almost half a century. The technology started so, saw its early applications in Radio Astronomy in the 1960s, followed by its applications in the military in the 1970s. In the 1980s, the development of Millimeter Wave Integrated Circuits (MMIC) created opportunities for mass manufacturing of millimeter wave products for commercial applications. In the 1990s, the beginning of automotive collision-avoidance radar at 77 GHz marked the first consumer-oriented use of millimeter wave frequencies above 40 GHz[4].

In 1995, the US Federal Communications Commission (USFCC) opened the spectrum ranged between 59 GHz and 64 GHz for unlicensed wireless communication, resulting in the development of a plethora of broadband

DRDO MONOGRAPHS/SPECIAL PUBLICATIONS SERIES

About the Book

For the growing need in wireless spectrum by wide bandwidth applications such as ultra-high data rate transfer, at speeds of 10 Gbps and up, millimeter wave plays important role in providing reliable spectrum solutions. Worldwide R&D in millimeter wave area has demonstrated many successful tests to establish the technology with its promising potential for the future of defence and security.

This monograph explores the design and implementation of millimeter wave active/passive circuits and systems using waveguide/MMIC (Monolithic Microwave Integrated Circuit) and planar waveguide technology. Extensive use is made of photographs of systems, line diagrams showing various techniques, and important system characteristics.

It begins with an introduction to frequency bands, unique millimeter wave applications in communication. It presents detailed discussions about millimeter wave devices and circuits, generating devices, e.g., IMPATT oscillators and Gunn oscillators, where concept of injection locking phenomenon in oscillators and power combining techniques, etc., have been highlighted. Receiver components, millimeter wave transceiver configurations and development of millimeter wave systems technology useful for defence services are presented. It also discusses future trends and technology challenges which enlighten about exploitation and challenges of millimeter wave frequency spectrum in futuristic military applications such as broadband communication technology, optical technique of millimeter wave generation with low phase noise signal for applications in imaging and phased array radar systems and millimeter wave options for mobile cell phones.

The book is written to support and supplement millimeter wave and subsystems/system courses of scientific institutions/university as well as a reference for researchers, professionals, and high RF frequency design engineers working in this exciting field of millimeter wave technology.

About the Author

Shri Awadhesh Kumar Shukla is Former Scientist 'G', Defence Electronics and Applications Laboratory (DEAL), DRDO Ministry of Defence. His education include BSc (PCM) in 1974 and BTech (Electronics & Telecommunication) from J.K. Institute, University of Allahabad, in 1978; and Fellow, Institution of Electronics and Telecommunication Engineers (IETE), New Delhi.

He joined DRDO in 1979, and contributed significantly in nurturing the millimeter wave technology, through Indigenisation of Millimeter Wave Components. He developed 140 GHz components and demonstrated passive millimeter wave imaging using indigenised components first time in the country. He designed and developed successfully Ka-band ground segment communication technology for defence forces and also developed high power solid state/magnetron-based transmitter front-end receiver at millimeter frequency for radar applications as a part of missile guidance unit. As DRDO Program Manager for indigenisation of devices and circuit components from industry, he indigenised these passive/active components and developed no. of indigenous vendors in the country for development of millimeter wave components.

He published 35 research papers in international and national journals. He received IGMDP Award for significant contribution in NAG Seeker Head; Technology Group Award for Development of Millimeter Wave Subsystems/System; and Laboratory Award for Development of Low Noise Amplifier.

Price: INR ₹ 1340
US $ 32
UK £ 29

978-81-86514-63-4

9 788186 514634

Defence Scientific Information & Documentation Centre
Defence Research & Development Organisation
Ministry of Defence, Metcalfe House, Delhi - 110054, India