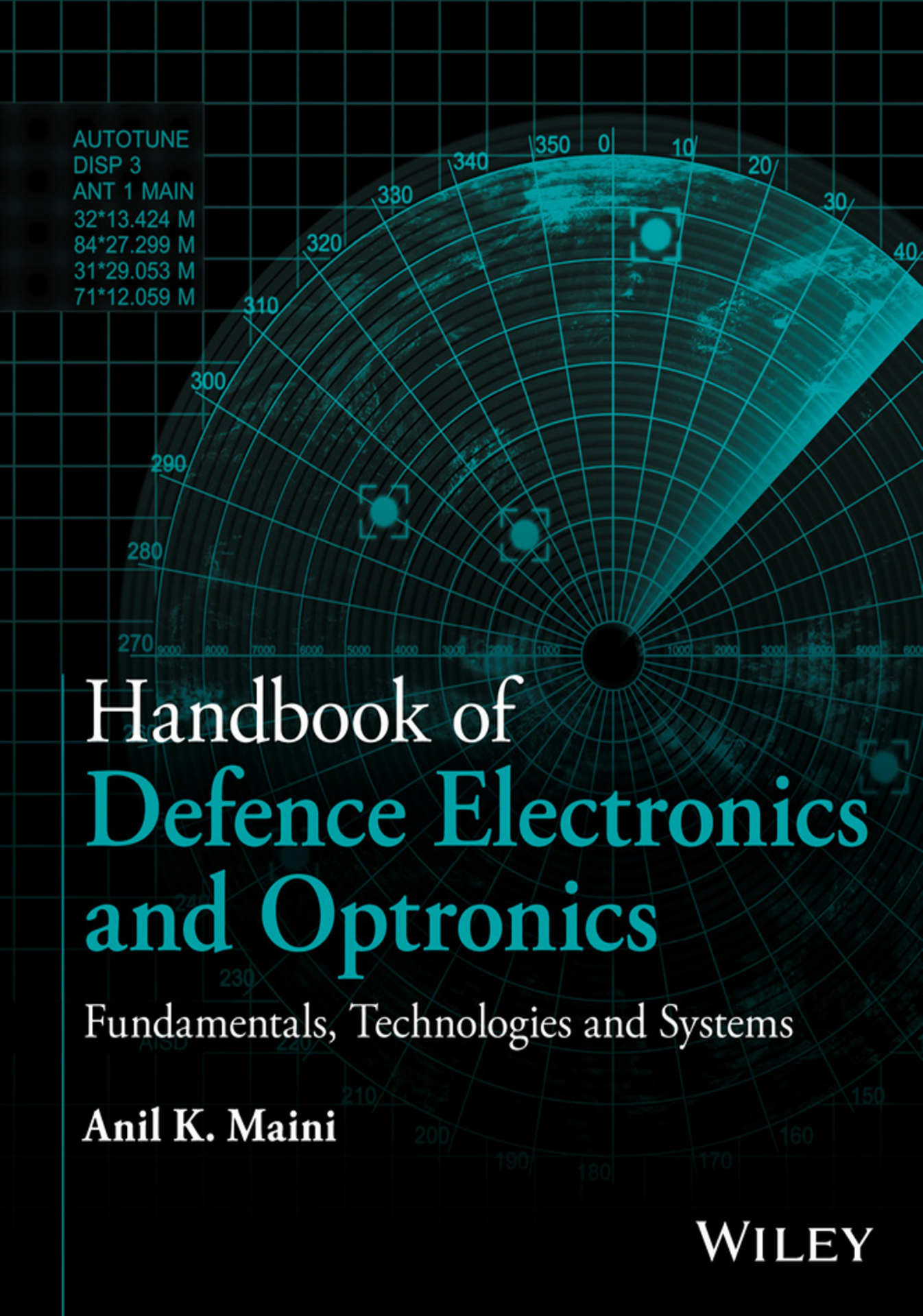

Handbook of Defence Electronics and Optronics

Fundamentals, Technologies and Systems

Anil K. Maini

WILEY

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and Systems

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"A wee bit of heaven drifted down from above.... a handful of happiness,
a heart full of love for sure
Precious, priceless and lovable...the gift of life,
So sacred and pure"
Dedicated with love and blessings
To my new born bundle of joy, my grandson Kiaan

Anil K. Maini

Contents

Preface

Defence Electronics and Optronics, today, is a complete subject in itself. It includes, in its vast domain a wide range of subjects, radar systems, communication satellites, electronic warfare, directed-energy weapons, precision guided munitions, laser systems, optronic sensors, nuclear weapons, space warfare, and so on. Since the early 1940s, during the era of World War II, electronics and optronics have penetrated almost every conceivable area of application of both the tactical battlefield and the strategic domain. The applications have grown at a very fast rate, not only in already existing domains; newer application areas for defence electronics and optronics are finding favour with the Armed Forces. The enormity of the subject of *Defence Electronics and Optronics* and the interest it currently holds internationally in terms of ever increasing usage for a variety of scenarios, and also the kind of interest shown by the Armed Forces and investments being made towards their research and development, underlines the importance of a book that addresses all these topics.

This book comprehensively covers the subject of *Defence Electronics*; covering all topics related to *Defence Electronics* and *Defence Optronics*. The book begins with *Military Communications* in Chapter 1. The opening chapter focuses on communication techniques and systems; antennas and propagation modes; optical communications, including both free space communication, fibreoptic communication; emerging concepts such as software defined radio, net-centric warfare and C^4ISR, and some representative military communications equipment for the whole range of applications. *Radar Fundamentals* in the second chapter and *Military Radars* in the third follow that. Chapter 2 presents a detailed description of fundamentals such as radar's operational parameters, radar range equation, radar transmitters and receivers, radar antennas and different types of radar based on principle of operation such as continuous wave (CW) radar, FM-CW radar, pulse Doppler radar, moving target indicator (MTI) radar, tracking radar, pulse compression radar, synthetic aperture radar, over-the-horizon radar (OTHR), monostatic and bistatic radar, surveillance radar and laser radar. Chapter 3 comprehensively covers common military radar systems including target detection, surveillance and tracking radars, fire control radars, ground penetration radars and weapon locating radars. The emphasis in this chapter is on the salient features and applications of major international radar systems in these categories with an overview of involved technologies.

The fourth and fifth chapters cover *Satellite Technology* and *Military Satellites*, respectively. Chapter 4 covers satellite orbits and trajectories, in-orbit operations, satellite hardware and components of a satellite network. Chapter 5 presents an overview of military communication satellites, reconnaissance satellites, SIGINT satellites, early warning satellites, weather forecasting satellites, navigation satellites, and related topics.

Electronic Warfare, covered in the sixth chapter, is the next major topic covered in the book. The chapter extensively covers both electronic warfare and electro-optic warfare systems. Electronic warfare systems' classification, involved technologies and systems are

comprehensively described first in this chapter. Major topics covered under electronic warfare systems include different categories of electronic warfare systems, electronic support measures (ESM) such as signal intelligence, radiation intelligence and telemetry intelligence; passive and active electronic countermeasures (ECM) such as chaff, decoys and various types of jammers and electronic counter countermeasures (ECCM). Stealth technologies are also discussed in the chapter. Salient features of major international electronic warfare systems and their deployment scenarios is another highlight of this chapter. The next major topic discussed in this chapter relates to electro-optic countermeasures (EOCM). EOCM systems play an important role in the present-day warfare due to widespread use of lasers and other electro-optic systems. Both passive as well as active electro-optic countermeasures are discussed in this chapter with particular emphasis on laser warning and countermeasures and missile approach warning sensor and infrared countermeasures. Active protection systems are briefly discussed towards the end of the chapter.

Laser technology, optoelectronics and their military applications are discussed next in Chapters 7–10. This section begins with Chapter 7 on *Laser Fundamentals* covering operational basics of lasers and related concepts, laser parameters and their measurement techniques and different types of lasers, mainly including solid state, gas and semiconductor lasers. This is followed up by a comprehensive description of electronics that goes along with a laser optics module to make it a laser source or laser system in *Laser Electronics*. Chapter 8 begins with a brief overview of basic building blocks of laser electronics before it moves on to comprehensive treatment of electronics for solid state, gas and semiconductor laser sources.

Optronic sensors are used in a wide range of military applications both as a part of an overall system and also as individual devices. Chapter 9 on *Photo Sensors and Related Devices* begins with an overview of photo sensors covering important types, major performance specifications and application circuits. These photo sensors are generally used in laser range finders and related devices, laser seekers, laser warning sensors, LIDAR receivers, LADAR sensors, and so on. This is followed by discussion on sensor systems such as night vision devices (NVD), thermal imaging (TI) sensors, CCD and CMOS sensors, FLIR (forward looking infrared) sensors and navigation sensors, including ring laser and fibreoptic gyroscopes.

Having discussed lasers in terms of their operational basics, different types and the electronics that goes with them to make usable laser systems, Chapter 10 discusses tactical military applications of lasers and related devices in *Military Laser Systems*. Major laser systems discussed in this chapter include laser aiming devices, laser range finders and target designators; laser based sensor systems, including laser proximity sensors, laser bathymetry sensors, laser based explosive detection sensors, LADAR sensors and LIDAR sensors.

Precision guided munitions including both radar guided munitions and electro-optically guided munitions are discussed in Chapter 11, titled *Precision Guided Munitions*. The chapter begins with an introduction to different guidance techniques followed by detailed discussion of radar guided munitions, laser guided munitions, infrared guided missiles and GPS/INS guided weapons. Advantages and limitations of different categories of precision guided munitions along with salient features of some common international weapon systems in these categories are in focus in this chapter.

A category of weapon systems that has rapidly evolved in the last decade, transforming itself from laboratory prototypes to field deployable systems, is the class of directed-energy weapon (DEW) systems. DEW systems have been projected to replace kinetic energy weapons for tactical applications in not-too-distant future and strategic applications by 2030. In the concluding chapter of the book on *Directed-Energy Weapons*, after a brief introduction to history of origin of the DEW concept, different categories of DEW systems are discussed. These include particle

beam weapons, high-power microwaves, laser-based DEWs and laser-induced plasma channel weapons. The focus is, however, on the two major categories of DEW systems, namely, high-power microwaves (HPM) and laser DEW systems. Merits and demerits of these systems, the involved hardware, major international systems and their application potential are covered in the chapter.

This book is the only one of its kind on the subject of defence electronics and defence optronics that amalgamates the whole gamut of topics in this area. Major topics exhaustively covered in the book include the operational fundamentals of radar, military radar systems, operational fundamentals of satellites, military satellites, electronic countermeasures and counter countermeasures, electro-optic countermeasures, laser fundamentals, laser electronics, tactical military laser systems, radar and electro-optically guided and GPS/INS guided precision strike weapons, fibreoptic and free space laser communication, optronic sensors including photo sensors, LIDAR and LADAR sensors, spectroscopic and interferometric sensors, proximity sensors, bathymetry sensors, particle beam weapons, laser induced plasma channel (LIPC) weapons, less-lethal laser systems including laser dazzlers, laser ordnance disposal systems and lethal directed-energy laser weapons, including chemical, solid state and fibre-based DEW systems, high-power microwaves and E-bombs. The book covers each of the topics in their entirety, from fundamentals to advanced concepts, military systems and related technologies, thereby, leading the reader logically from the operational basics of military systems to involved technologies and battlefield deployment and applications. Each of the topics is discussed keeping in view the military applications. The book also gives an overview of important military systems in different categories along with their application potential. Current status of various military technologies and systems and future trends are also discussed. An Illustrated Glossary at the end of each chapter summarizes important terms, definitions and concepts. A comprehensive bibliography at the end of each chapter will particularly interest researchers.

It is intended to be a reference book for engineers and scientists working in R&D centres, the defence industry and academic institutes engaged in research, development and use of defence electronics and optronics systems. The book also fulfils the requirements of a text book for graduate level students and a reference book for researchers and for industry and military professionals. It is also intended for a wide cross-section of professionals working in the Armed Forces. The book is also intended to be a useful reference for defence experts and strategic planners. I hope that the book will be well received by the readers. Suggestions from readers to make the book more useful in future editions would be highly appreciated.

Anil K. Maini

1

Military Communications

There is a host of technologies that are in use in the state-of-the-art communications equipment used by the Armed Forces world over. Be it the land-based systems or systems in use at sea, in air or space, military communications equipment embraces many technologies. No one technology dominates military communications systems; instead, a number of technologies are used to provide secure and reliable communications. Different generations of communications equipment have been in use by the Armed Forces for various applications over the last 100 years or so. Improvements seen in each new generation of communications equipment have been largely driven by the development of better hardware, including improved components, more sophisticated circuits and more precise manufacturing. The opening chapter begins with discussion on the fundamental topics of communication such as communication techniques and systems; antennas and propagation modes; optical communications including both free-space communication, fibreoptic communication and laser communication, particularly for underwater applications. This is followed by detailed description of emerging concepts employed in the current generation of communications equipment such as software-defined radio, net-centric warfare and C^4ISR. Some representative military communications equipment for the whole range of applications are briefly discussed towards the end.

1.1 Introduction to Military Communications

Military communications technologies are complex and wide ranging. Development of new technologies and advances in existing technologies has led to different generations of communications equipment. Each generation of equipment has leveraged enhanced life and performance of components and emergence of a range of new components due to technological advances. Extended operating time of portable radios used by the Armed Forces in the battlefield due to availability of new battery technologies is one such example. Some of the major concerns faced by military planners relate to improving security and reliability of communications. Another concern relates to integration, which means achieving interoperability among a wide range of communications systems and technologies.

Features and capabilities of communications equipment both for commercial and military usage are undergoing revolutionary changes leading to availability of new generation of sophisticated communications devices and equipment enabling faster, more secure, less costly and more flexible communications. As outlined in the previous paragraph, security and interoperability are the two major concerns. While security-related issues have been resolved a large extent,

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Figure 1.1 LG's V10 smart phone. (*Source:* LG Electronics, https://creativecommons.org/licenses/by/2.0/deed.en.CC BY 2.0.)

integration of contrasting communications technologies (or in other words interoperability of different technologies and equipment) is one of the most important challenges facing military technology developers.

Modern radio and networking technologies such as smart phones, tablets, high-speed networks and other sophisticated technologies offer many new opportunities, though they too pose challenges vis-à-vis security and interoperability issues. Very few communication devices have seen such rapid growth and usage and consequential benefits as the smart phones and tablets. Smart phones with touch screen interfaces, internet access and an operating system capable of executing downloaded apps perform many of the functions of a computer. A tablet too is a portable PC with a form factor slightly larger than that of a smart phone. Both can fit into the cargo pocket of a soldier's uniform. Smart phone and tablet apps have given troops the ability to perform a range of tasks anytime anywhere and allowed commanders to instantly distribute essential documents directly to the troops. Network and device security concerns had earlier hindered widespread deployment of smart phones in the Armed Forces and with the availability of new generation smart phones, such as those using Google's Android 6.0 Marshmallow OS, these concerns have been addressed. This has even brought smart phones onto classified networks enabling soldiers access secret level mission command computer systems. Reportedly, the US Government has certified some smart phones, such as the LG G5 using Android OS version 6.0.1 and the V10 using Android OS version 5.1.1 (Figure 1.1), for use in environments where security is the top concern.

Keeping pace with smart phone and other commercial radio innovations, the next major military communications relevant technology evolving quite rapidly is that of *Ground Mobile Radio* (GMR). GMR of the future will focus on two main approaches, namely *Soldier Radio Waveform* (SRW) and *Wideband Networking Waveform*. SRW is an open-standard voice and data waveform used to extend wideband battlefield networks to the tactical edge. It is designed as a mobile ad-hoc waveform and it functions as a router within a wireless network. It is used to transmit vital information over long distances and elevated terrains including mountains and other natural or

Figure 1.2 AN/PRC-154 JTRS Rifleman Radio.

manmade obstructions, and allows communication without a fixed infrastructure such as cellular tower or satellite. The WNW is the next-generation high throughput military waveform, developed under the Joint Tactical Radio System (JTRS) Ground Mobile Radio (GMR) program. It uses the Orthogonal Frequency Division Multiplexing (OFDM) Physical Layer. With its mobile ad-hoc networking (MANET) capabilities, the waveform is designed to work well in both urban landscape as well as a terrain-constrained environment, since it can locate specific network nodes and determine the best path for transmitting information. Combination of these two technologies allows secure networked communications among platoon, squad and team level soldiers. It will also facilitate communication with combat commanders via satellite. The *JTRS-HMS* (Joint Tactical Radio System Handheld Manpack Small form fit) *Rifleman RadioType AN/PRC-154* (Figure 1.2) developed by Thales and General Dynamics, designed to deliver networking connectivity to front line troops and capable of transmitting voice and data simultaneously via SRW (Soldier Radio Waveform), is one example of a GMR accepted for military use. JTRS also interfaces with smart phones. A vehicle-mounted software-defined radio system for ground mobile communications is the one being developed under the Mid-Tier Networking Vehicular Radio (MNVR) programme of the U.S. Army based on the Falcon family of wide band tactical radios. The Harris Corporation has developed the AN/VRC-118 (V)1 under this programme (Figure 1.3).

Another significant technological development has been in the field of wireless networking such as the *Mesh Networks* including *Mobile Ad-hoc Networks* (MANETs). These networking technologies are potentially capable of supporting both JTRS as well as smart phones. Also, these networking technologies provide high-bandwidth networking capabilities for handheld radios, ground and airborne vehicle communications, and security and tactical wireless sensors such as those used to monitor wireless security cameras positioned around critical infrastructure. MANETs can be networked to interconnect multiple mobile phones within a specified coverage area offering greater bandwidth and better connectivity. One application of the MANET is its use by convoys and other team-oriented missions to remain in constant communication with their movement spread over a large terrain. Another application of mesh networks is their use for control and coordination of unmanned ground vehicles. These remotely controlled unmanned vehicles following predefined paths may be used as targets by fighter aircraft pilots during training exercises in the same manner as Pilotless Target Aircraft (PTA) used by Air-Defence ground forces for training purposes.

Figure 1.3 AN/VRC-118 (V)1 MNVR. (*Source:* Courtesy of Harris Corporation.)

Satellite communication too plays an important role in military communications. Though smart phones and other cutting edge communications technologies have impacted on the utility of satellites for military communications, satellite communication continues to remain relevant with its potential of providing ubiquitous satellite coverage to terrestrial communications systems including smart phones. It would be worthwhile mentioning here that, other than the communications services, military satellites are extensively used for intelligence gathering, weather forecasting, early warning and providing navigation and timing data. Software Reprogrammable Payload (SRP), a satellite-rooted technology with its down-to-earth communication potential, is an adaptation of a small radio receiver designed for space applications into a full-fledged radio frequency system initially targeted for UAS (Unmanned Airborne System) communications. SRP is nothing but an airborne SDR (Software-Defined Radio) that facilitates beyond line-of-sight communications. The SRP development program is a joint effort between the Office of Naval Research (ONR), Naval Research Lab (NRL) and Marine Corps Aviation. SRP is a flexible, reconfigurable while-in-operation software-defined radio designed to meet current and future requirements of Unmanned Aircraft System (UAS) communications by Marine Corps. It is currently targeted at the American unmanned aerial vehicle AAI Shadow. The ability to reconfigure SRP's function in operation ensures that marines are able to share data, access capabilities and effectively command while they engage the adversary. SRP, configured around a software-defined radio platform, is designed to perform multiple functions, which include UHF communications relay with interference mitigation, UHF IP router capability, an automated identification system, single channel ground and airborne radio systems and so on. SRP has an open architecture very similar to that of JTRS and is interoperable with it.

Another communication technology that can become a potential game changer in military communications is that of *Cognitive Radio* for reasons of being inherently interoperable, having higher compatibility, reduced interference and enhanced security. The concept of cognitive radio addresses the problem of spectrum congestion that causes acute scarcity of spectrum space. It uses computer intelligence to automatically adapt to band conditions and user requirements.