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Integrating Radar and Radar Countermeasures

姜秋喜 著

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Network Radar Countermeasure Systems

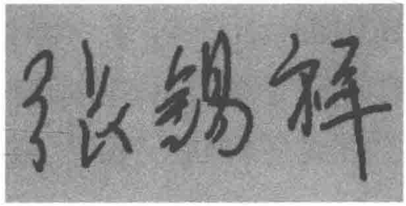
Foreword

In today's world, with the tide of change becoming more and more vigorous, the speed of innovation also accelerates. Particularly in the unknown and fierce military field, we need the spirit of innovation and call for innovative achievements. We are delighted to see the book *Network Radar Countermeasure Systems* introducing the concept of networking in the information age to radar countermeasures equipment systems, which is not only a scientific exploration of theoretical innovation, but also a successful work containing the spirit of innovation.

Radar and radar countermeasure, which form the important foundation of modern national defense and are significant symbols of the manifestation of defense capabilities and levels, are playing an increasingly important role in modern warfare. Since the use of radar from the 1930s, the battle of the radars has never stopped, and even intensified. This book is driven by these demands, following the concept of integrated development of the information age, to achieve the unions of passive and active, jamming and detection, reconnaissance and jamming, which is the major change in radar countermeasure systems in our country. Its approach, including concepts such as network, full-band coverage, transmitting and receiving remote deployment, distributed collaboration, network-based control, information sharing, and data fusion, not only contains a wide range of technological innovation, but also encompasses many new thoughts and ideas. What is more valuable is that the authors uses a lot of quantitative calculation and simulation data, to analyze and verify new ideas and new theories in depth, which not only increase the scientific network radar countermeasure system theory's credibility, but also allow access to a solid foundation of actual application.

Theory comes from practice and also guides practice, which can only be tested and improved in practice. This puts forward fresh ideas for new national comprehensive integrated air defense systems and provides guidance in China's national defense construction and military struggle preparation. I hope that this monograph can attract extensive attention and be put into engineering practice, into the reality of combat capability as soon as possible.

In view of this, I want to congratulate the publication of the book, hoping that it will inspire similar original books in the future.



Chinese Academy of Engineering
June 1, 2010

Zhang Xixiang

Preface

The development and application of military radar has been the focus of both sides in electromagnetic warfare. Since radar began to be used for military purposes, radar countermeasures that have been developed have never stopped and are still appearing in an endless stream. In the future of information warfare, the employment of single radar and a single radar countermeasure device or simple combined use of multiple devices can no longer fulfill the needs of joint operations. Therefore, both radar and radar countermeasures are facing new challenges.

To be specific, radar is confronted with the following threats: (1) the active radiation of radar may cause straight attacks of anti-radiation weapons and electronic jamming; (2) radar detects targets via the reflection of electromagnetic waves, bringing about the emergence of stealth technologies that can absorb and reduce the electromagnetic reflection; (3) radar acquires target information through antenna beam scanning, which results in a lower space of silence and leaves a door wide open for aircraft to execute low-altitude penetration. It is these threats that impel the rapid development of radar in its functions and anti-jamming capabilities. For instance, a series of new types of radar, such as frequency agile radar, frequency diversity radar, pulse compression radar, repetition frequency (RF) change radar, phased array radar, synthetic aperture radar, Doppler radar, mono-pulse radar, bi-/multi-static radar, passive radar, non-cooperative passive detection radar, sparse array radar, and netted radar, have been developed to meet radar's functional and survival needs.

Given the emergence of various modern advanced radar systems and anti-jamming measures, radar anti-jamming technologies are presenting a strong trend towards integration. Accordingly, the traditional radar countermeasure equipments, which are based on a single station or a single method of countermeasure, also face severe challenges. An integrated use of radar countermeasures is the only way to make it effective.

Radar and radar countermeasure are two sides of the same coin. They are opposite to each other, yet depend on each other and also promote each other. In the network era, however, the integration of radar and radar countermeasure is not only an inevitable demand of modern information warfare, but also an irresistible trend of the development of electronic warfare (EW) systems and radar systems. The network era makes the demand and trend possible.

From the perspective of information acquisition, radar detection is an important means to acquire target information from land, air, sea, and space. But the information detected by radar simply includes the coordinates, tracks, and speeds of the targets, and are unable to satisfy the needs of information operations that require adequate information on the actual attributes, weapons systems, and information systems of the targets. Electronic reconnaissance can fill this gap. For example, the relevant information about target radiation sources can be acquired by electronic reconnaissance, the information about target coordinates, tracks, and speeds can be obtained by passive locating, and the information about target platforms and weapons systems can be obtained by electronic "fingerprint" identification. Hence, a comprehensive access to battlefield situation information can be gained through the integration of radar detection and electronic reconnaissance, namely, the integration of active and passive information.

From the perspective of complementarities, a radar system is faced with four severe challenges: anti-radiation weapons, stealth targets, low-altitude penetration, and electronic jamming. Various types of radar, such as netted radar, bi-static/multi-static radar, and sparse array radar, have been developed to cope with these challenges. Theoretically speaking, however, any single mode of radar system still has several problems that are difficult to solve. The main problem with radar countermeasure lies in the passivity and non-cooperation of information acquisition. That is to say, information acquisition and selection of jamming objects depend on the operation of target radiation sources. Therefore, if active emission and passive reception is integrated, the "advantages" of radar would be enhanced while the "disadvantages" of electronic reconnaissance would be avoided.

From the perspective of target attack, radar detection is the primary means of missile guidance and weapons control. It is an important guarantee for executing a "hard" precision strike on targets. Radar countermeasure, by contrast, is the primary means of conducting a "soft" attack on targets, which is an important guarantee for achieving supremacy of the information, the air, and the sea. From this perspective, therefore, radar detection and radar countermeasure must be integrated. In other words, hard and soft attacks must be integrated.

From the perspective of the developing trend of weapons, system of systems (SoS) combat is an outstanding characteristic of the high-tech war. For example, intelligence acquisition and target attack tend to be integrated in information wars. By integrating radar detection and radar countermeasure, once physical targets or electronic targets are identified, the attack system embedded in the SoS can be employed to carry out electronic jamming suppression and guide firepower to strike them.

From the perspective of the developing rules of networks, the integration of radar and radar countermeasure is an inevitable trend of the times. Network-based battlefield systems depending on highly developed network information technology would become the basic form of future wars, and the direction of future revolution has shifted from "sensor-oriented war" to "network-oriented war". Network-based battlefield systems would provide the commander with real-time and transparent spatial awareness via multi-sensor fusion.

So, the integration of radar and radar countermeasure is an inevitable product of the Internet age. The network radar countermeasure system we propose is one that incorporates both reconnaissance and jamming. It combines active detection and passive detection in an organic way so that the precision of tracking location could be greatly improved and the interruption of target information could be effectively avoided when all the enemy's radios remain silent. The system makes it possible to extract target information from multiple aspects, which not only contributes to the analysis and identification of threats, but also helps to fundamentally remove false alarms. Besides, it also ensures an accurate and reliable estimation of the threatening targets' properties, parameters, numbers, and locations within the airspace of the warning area. This could shorten the response time and facilitate quick jamming guidance so as to meet specific tactical needs.

The network radar countermeasure system has three basic working modes. The first is the active mode, in which the transmitter of the system can be used as a jammer. Another advantage of this mode is that, through sending friend-or-foe identification signals to targets, receiving stations can discriminate the targets according to the corresponding responses to the signals. That is to say, it is able to conduct secondary radar friend-or-foe identification. In this mode, the transmitter of the system can also function as a radar transmitter to send detection signals. With the reflection (scatter) echoes of the targets, detection and tracking can be completed. The second is the typical passive mode, in which radar signal reconnaissance and passive tracking location are carried out with the use of the signals emitted from target radiation sources. So, the network radar countermeasure system has functions of both electronic intelligence (ELINT) and electronic support measures (ESM), which could use the receiver to complete parameter measurement, reconnaissance, identification, and jamming parameter guidance of radiation source signals. The third mode is a combination of the active and passive modes, in which some of the transmitters and receivers of the system work together in the first mode, while other receivers work in the second mode, so that the system could achieve the best performance. The network radar countermeasure system operates based on network mode, which means that it implements the connection, management, coordination, and control of the transmitting and receiving stations through network protocols. In addition to performing functions like connecting, managing, coordinating, controlling, and timing all the network nodes, the central station or a certain designated receiving station must complete data fusion and processing, conduct target detection, location, identification, tracking, and track plotting, as well as provide military intelligence and electronic intelligence, such as target numbers, target properties, locations, threat levels, and electronic series, so as to make the detection area transparent and provide clear intelligence for electronic attack.

The network radar countermeasure system effectively solves the vital problem with passive radar, whose detection effectiveness is completely dependent on the radiation characteristics of targets. When targets remain radio-silent, passive radar would fail to work properly.

The network radar countermeasure system also effectively overcomes the weakness of non-cooperative passive radar. Despite the non-cooperation of external transmitters, the system can successfully detect and track targets in concealment.

I would like to express my deepest gratitude to some renowned academicians in China, such as Wang Xiaomo, Bao Zheng, Li Deyi, Zhang Lvqian, Mao Erke, and Zhang Xixiang, for their inspiring guidance and unfailing help. Without their illuminating direction, this book could not have reached its present form. Sincere thanks also go to Prof. He You and Prof. Tang Ziyue for their invaluable suggestions. Also, I especially want to thank academician Ling Yongshun for his critical review of the book.

It is worth noting that the book is a result of collective wisdom and combined efforts. I feel particularly indebted to all my leaders for their full recognition and great encouragement during the formative period of the concept. Also, I am grateful to my doctoral students, including Li Mingliang, An Zhen, Ding Feng, Shen Aiguo, Wang Bo, and Wang Zheng. For their vigorous support throughout the publishing process, I really owe countless thanks. Finally, I shall thank Prof. Qi Jianqing for her contribution to the structure arrangement and theoretical analysis of the book.

Network radar countermeasure systems is a newly proposed concept. Therefore, many theories and engineering technologies need to be further studied and applied to engineering practice. This book provides a new research topic and intends to start further discussions in that direction. Due to the limit of my ability, inadequacy is unavoidable in the book. Your criticism and suggestions would be highly appreciated.

Hefei, China
August 28, 2010

Qiuxi Jiang

Contents

Chapter 1
Introduction to Network Radar Countermeasure Systems

1.1 Introduction

Since the application of radar in the 1930s, its function has extended from initial target detection to today's utilization in warning detection, tracking guidance, navigation control, arms control, remote control, topographic mapping, weather forecasting, and other functions. Expansion of the working characteristics and its functions accelerate the uses of radar. Collision avoidance radar, Doppler radar, navigation radar, weather radar, surveying, mapping radar, and other civilian aspects have brought great convenience to people's daily lives, which makes them closely related to radar. Remote warning radar, target indication radar, missile guidance radar, navigation radar, weapons control radar, and target imaging radar are widely used in the military field. Radar has become the important foundation of modern warfare and homeland defense. More importantly, it has become a significant part of joint operations in the information age.

However, the development and application of military radar has become the focus of the two sides locked in battle. We can say that confrontations using radar have not been stopped since the day it was put to military use, and is becoming more intense. Active radar electromagnetic radiation leads to a direct attack from anti-radiation weapons and from electronic jamming, and radar detects the targets depending on the reflection of electromagnetic waves, which has led to the emergence of electromagnetic stealth technology, enabling the absorption and reflection of waves. Radar depends on antenna beam scanning to obtain target information, which produces blind space and prevents low-altitude penetration aircraft from working normally. However, the rapid development of radar is also attributed to the expansion of its function and the four challenging threats mentioned above, such as the emergence of frequency agile radar, frequency diversity radar, pulse radar, pulse repetition frequency (PRF) change radar, phased array radar, synthetic aperture radar, Doppler radar, monopoles radar, bi-/multi-radar, passive radar, non-cooperative passive radar,

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sparse array radar, and networking radar, which resulted from its function and demands driven by everyday life.

The radar systems, such as frequency agile radar, frequency diversity radar, pulse compression radar, RF agile radar, phased array radar, synthetic aperture radar, Doppler radar, and monopoles radar, technically perform better in reconnaissance and anti-jamming tasks. But, as a single-station device, effective countermeasures and methods could always be found theoretically.

The transmitter and receiver are separated in bi-/multi-based radar systems, where the baseline range between the receiver and transmitter is of the same order of magnitude as the equivalent effective range. There are two kinds of bi-/multi-radars: the bi-static radar using accommodation transmitters and the composite bi-static radar using the joint work of single radars. The emitted radiation signal of a bi-static radar irradiates to the target, and the split receiver receives the scattered waves from the target and completes the detection and treatment. Each bi-static radar may appear to exhibit data redundancy; therefore, we can improve the positioning accuracy of bi-/multi- radar by combining and estimating this redundant data. So far, the typical bi-/multi- radars include the United States' Sanctuary air defense bi-static radar system, the tactical bi-static radar detection (TBIRD) system, bi-static alarm and control (BAC) system, multi-base measurement system (MMS), bi-static proximity warning system developed by the UK Plessey Company, bi-static radar experiment system studied at the University of London, Russia's Barrier radar, and so on. Especially, more and more bi-/multi-radar systems have been used in the homeland defense system in the United States, which are responsible for long-, middle-, and short-range strategic defense tasks. Multi-radar can be seen as a combination of a plurality of bi-static systems of transmitter stations. Each bi-static system firstly deals with the positioning processes independently, and then the results are transmitted to the central station for data integration, tracking, and other treatment. The key issue that should be solved by the bi-static system is the "three synchronization" problem of space, time, and phase, and solves the triangles problem formed by bi-static and objectives, which has a complex structure. The bi-static radar's resolution capability and accuracy are poorer than that of a single radar. What is more, the ability to distinguish between its sending and receiving baselines is almost lost. Due to the fact that the bi-/multi-radar's sending and receiving tasks are separated, antenna directivity only uses them in one direction separately, which leads to a great impact on side lobe clutter. The bi-static radar uses direction of arrival (DOA) direction angular positioning. Time difference of arrival (TDOA) positioning has some errors compared to the active and passive radar in positioning accuracy. What is more, a bi-/multi-mode base station arrangement has a greater impact on the detection area, and, therefore, there are many restrictions to its configurations and tactical uses.

Essentially, passive radar is the radar countermeasure reconnaissance system, which itself does not radiate electromagnetic waves, but obtains the target location and attributes by receiving electromagnetic waves radiated by the target. The development of passive radar began in the 1970s. The most famous products are the Tamara and VERA-E systems of the Czech company Tesla (now the ERA Company).

In addition, the Israeli-based EL/L-8300 and EL/L-8388 ground air defense electronic intelligence systems relied on a short time difference directional airborne system, which complete reconnaissance sorting and real-time tracking of multiple batches of air targets through the interception of airborne, shipboard, and ground-based radiation signals.

Russia and France also have similar equipment. China has equipped three Master baseline TDOA location system air passive detection equipment and four Master baseline TDOA location of a certain type of passive radar system. Passive radar itself does not radiate electromagnetic signals, receiving the radiated signal from target electronic equipment, compared with active radar, which has a long effect range, is concealed, and is not be easily found by others. In addition, in the working mechanisms of passive radar and positioning systems, the positioning methods are different from active radar, so the enemy's active electronic jamming equipment, which will become a passive radar's electronic jamming signal source, with be put to use to locate its position. Passive radar target detection is realized by receiving radiation from the target, regardless of its effective reflection cross-sectional area. So there is no essential difference in stealth aircraft and other aircraft. In addition, the passive radar can also discriminate the type of target and working conditions, etc., by intercepting radiation signal parameters. It can complete individual identification of targets through the identification of passive radar "fingerprint characteristics". However, the fatal problem of passive radar is that target detection depends totally on the presence of target electromagnetic radiation. If the target maintains radio silence status, passive radar would not work. In addition, other problems exist in passive radar, including: some disparities in detection and location precision compared with active radar; different forms of distribution corresponding to different location areas; the accuracy of low-altitude, long-range target location is poor, or even not possible at all. Passive radar only serves as a supplement and cooperative work for active radar.

Non-cooperative passive radar measures the TDOA and DOA of a television signal and FM broadcast signal's direct signal and uses the reflected signal from the target and Doppler shift to detect and locate the target. This positioning system has four advantages. First, it is similar to a bi-static radar or multi-stage radar system, and also works in the same wavelengths in its role of stealth target absorption as smaller FM radio and TV signals materials, it can deal with stealth targets effectively. Next, because the system itself does not emit electromagnetic energy, there is a good concealment, resisting radiation missiles effectively. Using the transmitted signal of commercial TV or FM radio stations, the system does not require expensive transmission equipment, which reduces costs. Finally, by working at low frequencies, it is not affected by small weather changes and is reliable, as well as yielding good system compatibility. But the downside is that the detection accuracy is not high enough, it cannot provide the data for precision attack weapons, and there will be a further study for chaff and other passive jamming on system