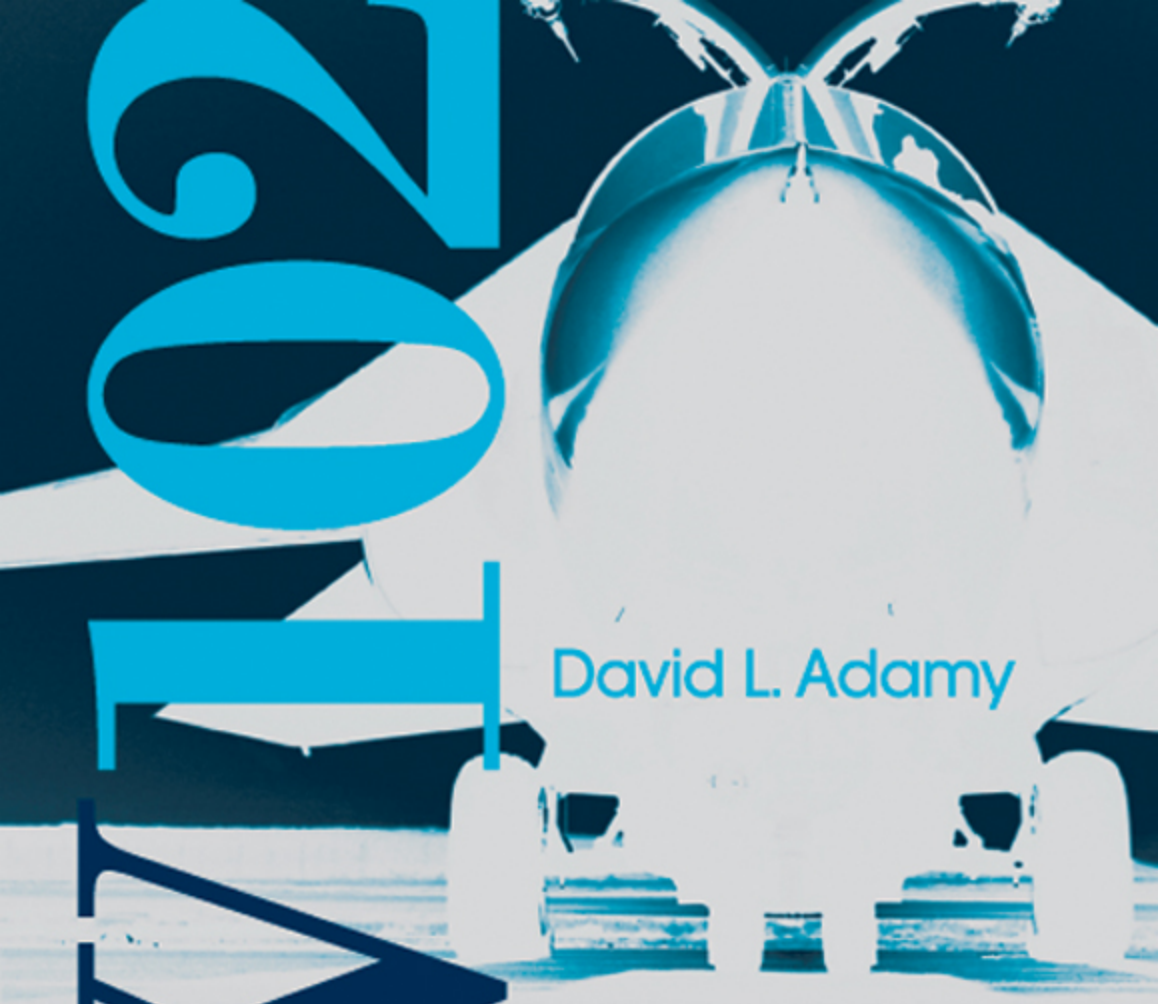
EW 102



David L. Adamy

A Second Course in Electronic Warfare

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Like EW 101 which came before it, this book is dedicated to my colleagues in the EW profession—in and out of uniform. Some of you have gone repeatedly into harm's way, and most of you have often worked long into the night to do things that are beyond the comprehension of the average person. Ours is a strange and challenging profession, but most of us can't imagine following any other.

Contents

Preface

EW 101 has been a popular column in the *Journal of Electronic Defense* (*JED*) for 10 years now—covering various aspects of electronic warfare (EW) in two-page bites on a month-to-month basis. The first 60 of those columns were reorganized into chapters with added material for continuity to become the book *EW 101*. The book, like the columns, has been very popular, but, since then, there have been almost 60 more *EW 101* columns. Some have provided deeper information on subjects covered in the first book and some are on entirely new EW areas. It was clearly time for another book—thus *EW 102*.

The target audiences for this book are the same as that for *EW 101*: new EW professionals, specialists in some part of EW, and specialists in technical areas peripheral to EW. Another target group is managers who used to be engineers—who now must make decisions based on input from others (who may or may not be trying to break the laws of physics). In general, the book is intended for those to whom a general overview, a grasp of the fundamentals, and the ability to make general-level calculations is valuable.

I sincerely hope that this book helps you be a better EW professional. The free world needs the best you have to offer in this important field of endeavor.

1

Introduction

This is the second book in the series, and like other books in that position it is intended to have stand-alone value——but not be redundant with the first book (in this case, *EW 101*). Like the first book, this one collects the material presented in many months of *EW 101* columns, organizes the material into chapters, and adds introductory and supplementary material for completeness——so it reads like a book rather than a collection of columns. It also has a feature requested by many readers of both the book and the columns: Solved problems.

This book comprises almost entirely new material that was not in the *EW 101* book. The exceptions are the sections which provide additional scope to material covered in *EW 101*. In those cases, there is a brief overview of the relevant *EW 101* material. The subjects covered in the rest of the book are:

- Chapter 2: Threats, from a functional and signal point of view. *EW 101* talked about threats in context, but never really focused in on them.
- Chapter 3: Radar Characteristics, is a functional discussion of the different kinds of radars——with emphasis on their significance to electronic warfare.
- Chapter 4: Infrared and Electro-Optical Considerations in Electronic Warfare, including heat seeking missiles, IR imagery systems, night vision devices, laser designators, and countermeasures.
- Chapter 5: EW Against Communications Signals, including radio propagation, digital communication, jamming, and various issues

regarding emitter location. Discussions are also extended to the EW impact of spectrum spreading.

- Chapter 6: Accuracy of Emitter Location Systems, including emitter location techniques (a brief review), error statistics, and circular error probable for all common emitter location techniques.
- Chapter 7: Communication Satellite Links, including the way satellite link performance is predicted, and link jamming.
- Appendix A: A large appendix of problems with solutions. These problems cover the subjects in both *EW 101* and *EW 102*, and the solutions are real solutions, with all of the important steps——not just answers.
- Appendix B: A cross-reference of the chapters of both the *EW 101* and *EW 102* books to the *EW 101* columns covering the same material.
- Appendix C: A list of reference books in electronic warfare and associated disciplines. Although not an exhaustive list of the books available on the subject, they are an excellent starting point for further, in-depth study of the field.

Like the first book in the series, and like the monthly tutorial articles from which both sprang, this book is intended to provide a top-level view of the broad, important and fascinating field of electronic warfare. Here are some generalities about the book:

- It is not intended for experts in the field, although it is hoped that experts in other fields and experts in subfields within electronic warfare may find it useful.
- It is intended to be easy to read. Technical material (contrary to popular opinion) does not need to be boring to be useful.

The coverage of technical material in this book is intended to be accurate as opposed to precise. The formulas, in most cases, are accurate to 1 dB, which is accurate enough for most system level design work. Even when much greater precision is required, almost all old-hand systems engineers run the basic equations to 1 dB first, then turn loose the computer experts to drive to the required precision. The problem with highly precise mathematics is that you can get lost down in the details and make mistakes of orders of magnitude. These mistakes are sometimes incorrect assumptions or (more often) an incorrectly stated problem. Order of magnitude errors get you (and probably your boss) into big trouble; they are worth avoiding.

When you work the problem to 1 dB, using the simple decibel form equations in this book, you will quickly derive a set of approximate answers. Then, you can sit back and ask yourself if the answers make sense. Compare the results to the results of other, similar problems…or just apply common sense. At this point, it is easy to revisit the assumptions or clarify the statement of the problem. Then, when you apply the considerable facilities, staff time, money, and (perhaps) stomach acid required to complete the detailed calculations they have an even chance of coming out right the first (or nearly the first) time.

1.1 Generalities About EW

Electronic warfare is defined as the art and science of preserving the use of the electromagnetic spectrum for friendly use while denying its use to the enemy. The electromagnetic spectrum is, of course, from dc to light (and beyond). Thus electronic warfare covers both the full radio frequency spectrum, the infrared spectrum, the optical spectrum, and the ultraviolet spectrum.

As shown in Figure 1.1, EW has classically been divided into:

- Electromagnetic support measures (ESM)—the receiving part of EW;
- Electromagnetic countermeasures (ECM)—jamming, chaff, and flares used to interfere with the operation of radars, military communication, and heat-seeking weapons;
- Electromagnetic counter-countermeasures (ECCM)—measures taken in the design or operation of radars or communication systems to counter the effects of ECM.

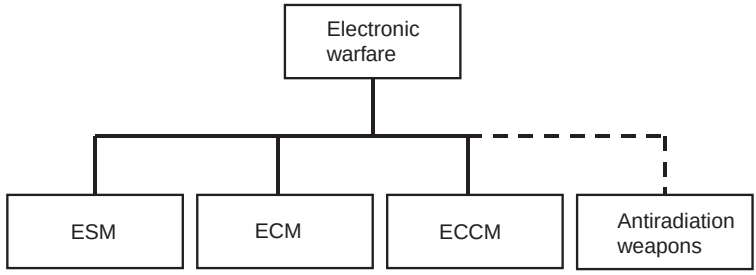

Figure 1.1 Electronic warfare has classically been divided into ESM, ECM, and ECCM. Antiradiation weapons were not part of EW.

Antiradiation weapons and directed energy weapons were not considered part of EW, even though it is well understood that they are closely allied with EW. They are differentiated as weapons.

In the last few years, the subdivisions of the EW field have been redefined as shown in Figure 1.2 in many (but not all) countries. Now the accepted definitions (in NATO) are:

- Electronic warfare support (ES)—which is the old ESM.
- Electronic attack (EA)—which includes the old ECM (jamming, chaff, and flares) but also includes antiradiation weapons and directed-energy weapons.
- Electronic protection (EP)—which is the old ECCM.

ESM (or ES) is differentiated from signal intelligence (SIGINT) [(which comprises communications intelligence (COMINT) and electronic intelligence (ELINT)], even though all of these fields involve the receiving of enemy transmissions. The differences, which are becoming increasingly vague as the complexity of signals increases, are in the purposes for which transmissions are received.

- COMINT receives enemy communications signals for the purpose of extracting intelligence from the information carried by those signals.
- ELINT receives enemy noncommunication signals for the purpose of determining the details of the enemy's electromagnetic systems so we

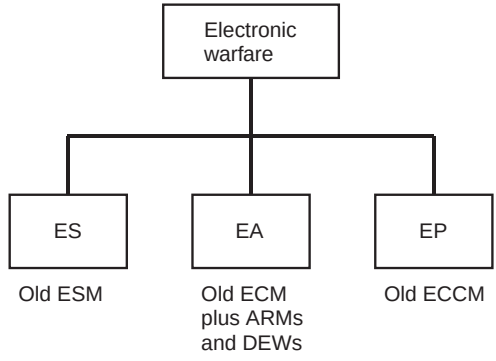

Figure 1.2 Current NATO electronic warfare definitions divide EW into ES, EA, and EP. EA now includes antiradiation and directed-energy weapons.

can develop countermeasures. Thus, ELINT systems normally collect lots of data over a long period of time to support detailed analysis.

- ESM/ES, on the other hand, collects enemy signals (either communication or noncommunication) with the object of immediately doing something about the signals or the weapons associated with those signals. The received signal might be jammed or its information handed off to a lethal response capability. The received signals can also be used for situation awareness, that is, identifying the types and location of the enemy's forces, weapons, or electronic capability. ESM/ES typically gathers lots of signal data to support less extensive processing with a high throughput rate. ESM/ES typically determines only *which* of the known emitter types is present and where they are located.

1.2 Information Warfare

A significant change that has occurred since the publication of *EW 101*, is the association of EW with information warfare (IW). EW is considered an integral part of information warfare—the action part. Information warfare includes actions taken to preserve the integrity of one's own information system from exploitation, corruption, or disruption, while at the same time exploiting, corrupting, or destroying an adversary's information system, as well as the process of achieving an information advantage in the application of force.

Figure 1.3 shows the so-called pillars of IW: psychological operations (PSYOPS), deception, electronic warfare, physical destruction, and operational security (OPSEC). These elements interfere with the enemy's ability to effectively use their military as shown in Figure 1.4. The OODA (observe, orient, decide, act) loop, shown in Figure 1.5 is the process required to take effective

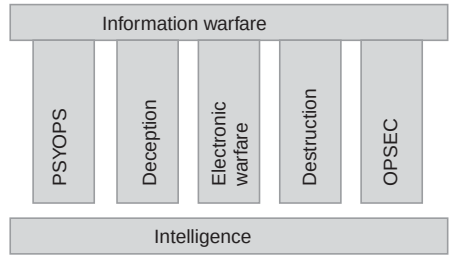

Figure 1.3 The pillars of information warfare are PSYOPS, deception, EW, destruction, and OPSEC, all supported by intelligence.

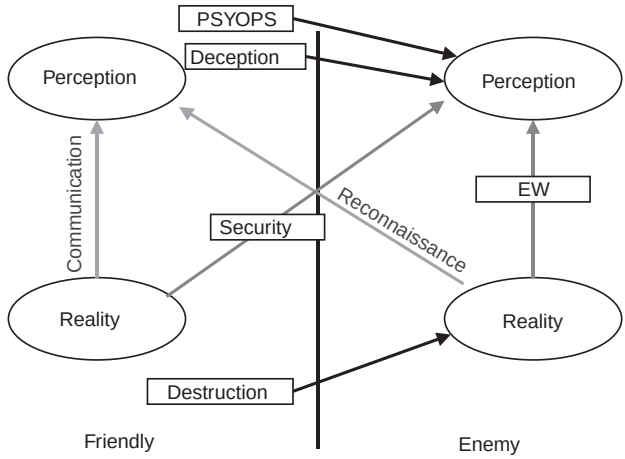

Figure 1.4 The elements of information warfare deal with friendly and enemy reality, and perception of reality.

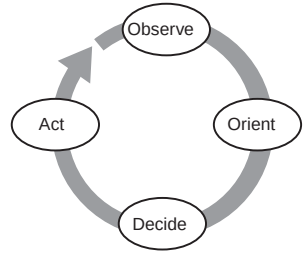

Figure 1.5 The OODA loop is the process involved in taking military action. IW interferes with the first three elements in the enemy's process.

military action. IW interferes with the first three steps in the OODA loop—with electronic warfare as the "action" element. This book focuses on EW, so we will not discuss IW further here, but it is important to understand the relationship between EW and IW in order to use EW techniques effectively in the current military environment.

1.3 How to Understand Electronic Warfare

It is the contention of the author that the key to understanding EW principles (particularly the RF part) is to have a really good understanding of radio

propagation theory. If you understand how radio signals propagate, there is a logical progression to understanding how they are intercepted, jammed, or protected. Without that understanding, it seems (to the author) that it is almost impossible to really get your arms around EW.

Once you know a few simple formulas, like the one-way link equation and the radar range equation in their dB forms—you will most likely be able to run EW problems in your head (to 1-dB accuracy). If you get to that point, you can quickly cut to the chase when facing an EW problem. You can quickly and easily check to see if someone is trying to break the laws of physics. (OK, a piece of scratch paper is allowed as long as it is crudely torn from a pad—your colleagues will still class you as an EW expert when you get them out of trouble.)

2

Threats

Electronic warfare is, by its nature, reactive to threats. EW receivers are designed to detect, identify, and locate threats, and EW countermeasures are designed to reduce the effectiveness of those threats. In this chapter, we look at threats in general: the classes of threats, the platforms they threaten, the signals associated with them, and the classes of countermeasures used against them.

2.1 Some Definitions

Like most fields, electronic warfare is practiced by professionals who use their own special language. Unfortunately, this language is often a variance with proper usage in the native tongue of the land. To avoid confusion in later discussions, here are some important definitions associated with EW threats.

2.1.1 Threats Versus Threat Signals

Threats are the actual destructive devices and systems. In EW, we normally deal with the signals associated with the threat systems, so we often define a "threat" as a signal associated with the actual threat. While this can be confusing, it is the way people in our profession express themselves—a grammatical "sin" we have been committing for many years—and will continue to commit throughout this book.

2.1.2 Radars Versus Communication

We often divide threat signals into radar and communications classifications. The differentiation is that radar signals are used to measure location, distance, and velocity—while communication signals carry information from one point to another. While they have totally different functions, the two types of signals can have similar parameters. Radar signals can be either pulsed or continuous wave while communication signals are, by their nature, continuous (except for rare special cases). Radar signals are typically in the microwave frequency range, but can be as low as high VHF and extend up into the millimeter range. Communications signals can carry voice or data. They are typically considered to be in the HF, VHF or UHF frequency range. However, they can be found from VLF to millimeter wave. (There will be more about frequency ranges a little later.)

2.1.3 Types of Threats

Figure 2.1 is an overview of the types of threats to assets protected by various electronic warfare techniques. Note that this chart is somewhat controversial since some new threats cross the normal classification divisions. The purpose of this chart is to show the normally expected threat applications. As shown, radar-guided weapons are primary threats to aircraft and ships. The primary threats to ground mobile and fixed sites are weapons that home on laser-designated targets. Heat-seeking missiles are a primary threat to aircraft.

Lethal communication is described in Section 2.1.7. It is a primary threat to aircraft and fixed site assets—enabling a variety of types of weapons.

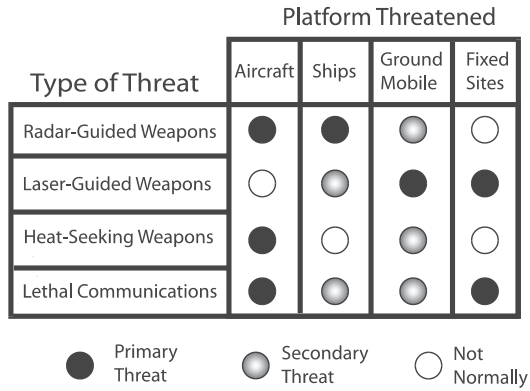

Figure 2.1 The various types of threats are normally threatening to these types of assets that are protected by EW systems.

2.1.4 Radar-Guided Weapons

As shown in Figure 2.2, radar is used to locate targets and to predict their paths of travel. A missile is guided to intercept the target. Note that the missile can be a rocket or a projectile (or many projectiles) from a radar-controlled gun. There are four basic guidance schemes that can be applied to radar-controlled weapons. Each has a different radar (or passive sensor) configuration and has strengths and weaknesses associated with the types of targets for which it is appropriate.

Ships are most commonly attacked by radar-controlled weapons. An aircraft (or other platform) locates a ship and identifies it as a target. Then, a missile is launched against the ship. Usually, the platform from which the missile is launched then leaves the engagement. When the missile gets close enough to the target to acquire it by radar, the missile homes on the ship, tracking its movement. The missile either attacks the target ship at the water line or makes a last minute vertical motion to strike it straight down through the deck.

2.1.5 Laser-Guided Weapons

Figure 2.3 shows an attack on a ground mobile target. The same technique can be used to attack a fixed asset, for example the pier of a bridge (the part most difficult to repair). In this type of attack, the laser must track the target so that a missile (which is typically fired by another platform) homes on the scintillation of the laser from the target. The designating platform can be either a manned or unmanned aircraft. It must remain within line of sight of the target during the whole attack.

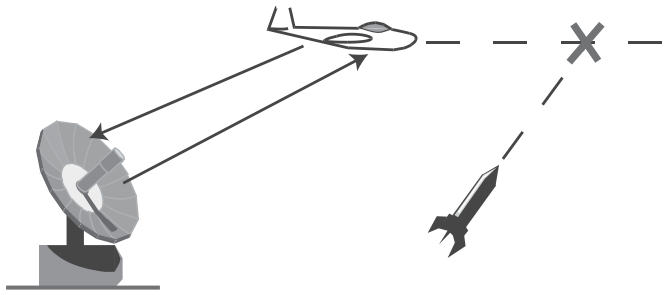

Figure 2.2 A radar-guided antiair threat determines the location and motion vector of a target aircraft to predict its flight path and cause a missile to intercept that flight path using one of several guidance approaches.

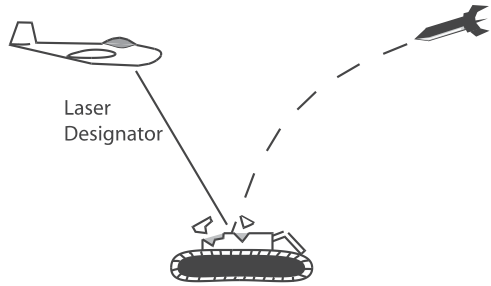

Figure 2.3 A laser-guided threat homes on the scintillation of a laser designator from a fixed or mobile target.

2.1.6 Infrared Energy: Guided Weapons

Everything emits some level of infrared energy (IR); the hotter the object, the more energy it emits. Since a jet aircraft engine is very hot, it provides a lucrative target for heat-seeking missiles. Early missiles attacked from behind the aircraft and homed on this high-heat target. Note that small, handheld weapons firing infrared missiles can be lethal to low-flying aircraft. IR missiles are used in air-to-air, ground-to-air, and air-to-ground attacks. Modern missile sensors can detect and home on the IR energy from targets at considerably lower temperature than that of a jet engine.

2.1.7 Lethal Communications

Lethal communications sounds like a contradiction in terms, since communication is merely the transfer of information. However, in almost all weapons above individual firearms, the information about the target's location and the ability to guide a weapon to the target are in different places. Thus, the sensor must transfer its information to some type of attack coordination center and that center must transfer acquisition and/or guidance commands to the actual weapon. The communication that transfers that information is extremely lethal.

Consider a simple example of lethal communication as shown in Figure 2.4. Artillery has killed more soldiers than any other type of weapon, and cannot typically engage targets without communication. The guns apply nonline-of-sight fire in response to calculated elevation, windage, and powder charge commands from a fire-control center. The fire-control center modifies its commands to the guns in response to communicated inputs from a forward observer who can see the target and the strikes of the rounds fired. Both communication paths are extremely lethal.

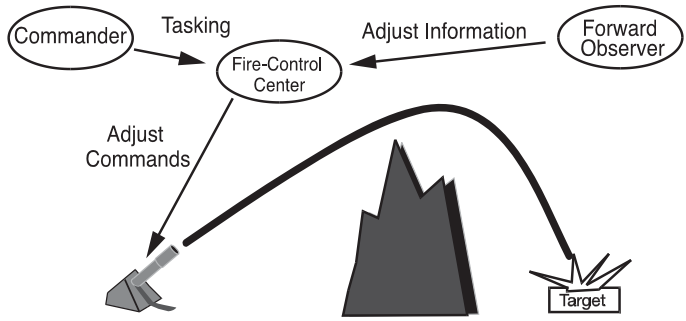

Figure 2.4 Artillery fire is adjusted to the target through lethal communication between a forward observer and a fire-control center and between the fire-control center and the guns.

2.1.8 Radar Resolution Cell

The resolution cell of a radar is the geometrical volume in which it cannot distinguish multiple targets. If there are multiple targets within the resolution cell, the radar will assume that only one target is present—at the weighted centroid of the individual target locations.

2.2 Frequency Ranges

Figure 2.5 shows the common names for frequency bands in the important threat range of 1 MHz to 100 GHz. This figure has three different columns, showing the three most common ways that frequency ranges are described. The left-hand column shows the common scientific notation. You will note that these bands divide at multiples of three. This is because each covers an order of magnitude of wavelength. For example, VHF is from 30 to 300 MHz—which corresponds to wavelengths from 1m to 10m.

The relationship of frequency to wavelength is given by the formula: $f\lambda = c$, where f is the frequency in hertz, λ is the wavelength in meters, and c is the speed of light (3×10^8 m/s).

The right-hand column shows the electronic warfare bands. The frequencies of threat radars are normally described in terms of these band designations. For example, D-band covers 1 to 2 GHz.

The middle column shows the official radar bands. Note that components (antennas, amplifiers, receivers, oscillators) are designated in catalogs in terms of these bands. It is also common to describe communications in terms of these bands. For example, satellite television broadcasting is done in C- or Ku-bands.