MICROWAVE RECEIVERS AND RELATED COMPONENTS

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Library of Congress Catalog Card Number:
84-062847
ISBN: 0-932146-10-4

Printed in the United States
of America

PREFACE

This book is dedicated to my wife Susan, our mothers and in memory of our fathers.

The purpose of this book is to provide a broad introduction to microwave receivers and the microwave components used in a microwave receiver. Although it is intended for microwave receiver design engineers, it should be of interest to engineers and scientists working in the electronic warfare, radar, and communications fields. This book is also suitable for a one semester microwave course for senior or first year graduate students in electrical engineering. The rapid development of radar, communication systems, and their applications to electronic warfare generated an urgent requirement for many special kinds of microwave receivers. The advances in microwave technology and discovery of new components provided new receiver design concepts. They also renewed the interest of some receiver designs which were considered impractical. About one third of the book is devoted to microwave receivers and two thirds to components. The receiver portion includes different types of receivers, their principles of operation, and special characteristics. The discussion on microwave components is basically from a system point of view. In addition to the operational principle of the components, their applications to a receiver system are emphasized.

The material in this book was a result of many years of working experience on microwave receivers in the Avionics Laboratory of the Air Force Wright Aeronautical Laboratories (AFWAL), Wright-Patterson Air Force Base, Ohio. Many different types of receivers have been developed by the Laboratory through both in-house and contracted projects. In addition to the modern research facility, the management provided excellent guidance in the research and development of microwave receivers. There are many knowledgeable engineers working in the microwave area with whom I can discuss and consult with regularly. The AFWAL Technical Library provided much valuable assistance in searching articles and technical reports. I am very appreciative of this research environment.

This book was inspired by Dr. Charles Krueger and accomplished with the help of Mr. William Bahret and Mr. Joseph Hoffmann from the Avionics Laboratory. Thanks are extended to Mrs. Cynthia McMillan (Editor), Mr. Kenneth Zimmerman, Mr. Michael Dureiko, Mr. Thomas Myers, and Mr. James Johnson of the Scientific and Technical Information Office of AFWAL. The author would like to thank Mrs. Helen Shaffer and Mrs Adele Pitsinger of the Reprographics Division, Aeronautical Systems Division for the printing. I also wish to thank Mr. Eugene Salzman of the Avionics Laboratory and Mr. Frank Baxley of Systems Research Laboratories, Inc. for preparing the draft manuscript; Mrs. Christine Carter for preparing some special documents related to the book; Mr. Rudy Shaw who helped generate some of the curves used in Chapter 2; and also the following individuals who reviewed portions of the manuscripts and made valuable suggestions: Mr. M. Hamilton, Dr. Chern Haung, Mr. John Cotton, Mr. Robert Davis, Mr. Gerd Schrick, Lt. Kevin Allen, and Mr. Willie Brumfield, Mr. Joseph Caschera and Prof. Jack Bourquin of University of Missouri at Rolla; Prof. J.J. D'azzo of the Air Force Institute of Technology. Many of my colleagues gave me generous assistance and consultation.

Many people from industry have discussed different kinds of receivers and worked closely with me. I would like to thank them all. Among these people are: Dr. I.C. Chang of the Applied Technology Division of ITEK Corporation; Mr. Robert Hilquest, formerly with the Watkins-Johnson Company; Dr. Harry Hewitt, formerly with SRI International; and Dr. Gordon Little of System Research Laboratories, Inc.

Last, but certainly not least, I wish to thank my wife, Susan. Without her encouragement and understanding, it would have been impossible to write this book.

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INTRODUCTION

1.1 HISTORICAL REVIEWS(1-3)

In 1864 James Clerk Maxwell collected and unified a few previously known relationships to generate four famous equations often referred to as the Maxwell's equations. From these equations electromagnetic energy propagating through free space was postulated. Between 1884 to 1886, Heinrich Rudolph Hertz verified this phenomena through a laboratory experimental setup. In his experiment he used a rapidly oscillating electric spark to produce electromagnetic waves which caused similar electrical oscillations in a distant wire loop. His discovery opened the field of wireless communications. Since Marconi produced a practical wireless telegraph system in 1895, many new devices (i.e., vacuum tubes and transistors) and technology have been developed. Today, radio communications and television are expanding continuously at such tremendous speed that they almost become an integral part of everyday life.

During World War II radar was invented and used in military operations. Today radar is used in airports to guide airplanes to safe landings in fog or storms. Airplanes and ships also use radar as a guidance system through poor visibility conditions. Weathermen use radar in weather forecasting. In military applications radar has become a vital equipment. It is not only used in the search and detection of hostile aircrafts, ships, and vehicles, but also to guide weaponry. The extension of the applications of electrical communication and radar systems in the future is almost beyond imagination.

All of the communication and radar systems discussed above contain two major parts: the transmitter and receiver. The transmitter and the receiver form an inseparable unit. They must be designed together as a pair. In a communication system, the transmitter and the receiver are installed at different locations. The message is sent from the transmitter to the receiver. In a radar system the transmitter and the receiver are located very close together. The transmitted signal is reflected by a target (or targets) to the receiver, thus the information about the target (i.e., range and velocity) is obtained by the radar. In both cases, the frequency, bandwidth, and special codes, if used, must be properly matched between the transmitter and the receiver in order to optimize the performance. That is why the transmitter and receiver are discussed as a unit. If the transmitter signal is specially coded such as frequency modulation (FM) chirp, biphase shift keying, the receiver must have the same coded waveform to correlate with the input signal to produce the desired processing gain. There are few articles and books dealing solely with the receiver subject. "Microwave Receivers" by Van Voorhis contains a great deal of information; however, it was written before the invention of transistors (Reference 1). There are other books that have chapters dedicated to receivers (References 2 and 3). Most of the receivers discussed in these books are radar receivers.

Along with the development of communication and radar systems for use in military application, a highly interesting area called electronic warfare (EW) was also developed. The purpose of EW is to defeat or disturb the hostile military operation. In EW applications, receivers are used to intercept signals of limited information from a hostile transmitter, while a jamming transmitter is used to generate false information or noise to mask the true signal received by the possible hostile radar receiver. The received information could be used to establish jamming criterion (i.e., priority and jamming modes). In this kind of operation, although some information on the radar transmitter is available, the intercept receiver cannot be designed according to the transmitter parameters because the radiating source is a noncooperative one. The parameters of these systems may be alternated intentionally in order to avoid the reception of the intercept receiver. Under such circumstances, the receiver must be designed somewhat independently of the transmitter. In other words, the receiver must be able to receive signals from a number of transmitters. Therefore, the receiver itself has become an independent subject.

1.2 RECENT DEVELOPMENTS IN RECEIVERS(4)

Intercept receivers are often operated in dense electronic environments. There are various signals in a battlefield such as hostile and friendly radar signals, as well as communication signals in the environment. The receiver must be able to receive these signals in a short time interval, encode, and sort them. Decisions must be made and action taken against the lethal hostile radar. These desired capabilities constitute some stringent requirements on the receiver system. Receivers designed with these capabilities have received considerable attention.

Recent advances in component development have made many different types of receiver systems possible. For example, solid-state amplifiers up to the 20 GHz frequency range with relative low noise figures made microwave receivers with high sensitivity possible. Microwave integrated circuits (MIC) made complicated, bulky receivers portable. Research and accomplishments in surface acoustic wave (SAW) filters have rekindled the practicality of building a channelized receiver which contains a large number of filters (Reference 4). The SAW filters have the potential to make a channelized receiver in a manageable size and weight. The accomplishment in SAW dispersive delay lines have made the compressive receiver very attractive, and the development in SAW nondispersive delay lines created a number of new approaches in receiver designs. The development in high speed and versatile logic circuits also have direct impact on receivers. Some of the wide bandwidth receivers can collect an enormous amount of information in a short time. A powerful digital processor must be used at the output of the receiver to analyze the information.

Without a digital processor, the information collected by the receiver will not be utilized effectively. The logic circuits and digital control also add versatility to the receiver.

Microwave receivers can be divided into the following groups according to their structures: crystal video, superheterodyne (superhet), instantaneous frequency measurement (IFM), channelized, compressive (also called microscan), and Bragg cell receivers. Most research and development is concentrated on the last three types of receivers, because their performances are not fully reaching the predicted levels. For electronic warfare applications, the performance of the latter three types of receivers will be far better than that of the former three types in terms of bandwidth, probability of intercept and simultaneous signal handling capability.

Recent developments in superhet receivers are in the area of digital control. The tuning speed of the receiver has been improved because of advances in oscillator capability. A superhet receiver is shown in Figure 1.1. Most of the modern receivers have digital display to indicate the frequency and other parameters of the input signal.

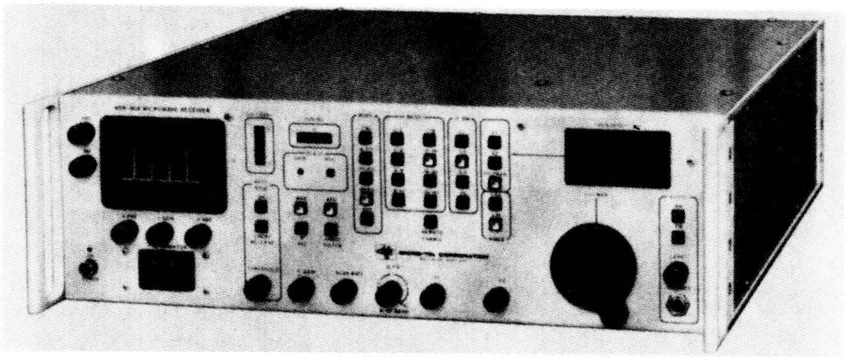

Figure 1.1. Manually Tuned Superheterodyne Receiver (Courtesy of Micro-Tel Corp.)

Figure 1.2 shows a channelized receiver. The idea of building channelized receivers is not new. In the past, it was not practical to build such a receiver because the large number of filters used in the receiver made it bulky. The MIC and SAW filter developments made this kind of receiver feasible. The channelized receivers provide good performance in terms of intercepting and encoding radar signals. Thus, they have the high potential to be used as electronic warfare receivers. Figure 1.3 shows a wide-band intercept system. The system basically contains a channelized receiver, preprocessor, some display units, and a recording unit.

Compressive receivers are becoming realistic because of high speed logic developments. The outputs from the receiver are closely packed short pulses (nanoseconds in width). The density of the output pulses depends on the input signal conditions. Handling these short pulses requires fast digitizing circuits. Developments in microwave components and SAW technology also have positive impacts on the compressive receivers. New approaches to build the delay lines and oscillators will reduce the complexity of the receiver and improve its performance.

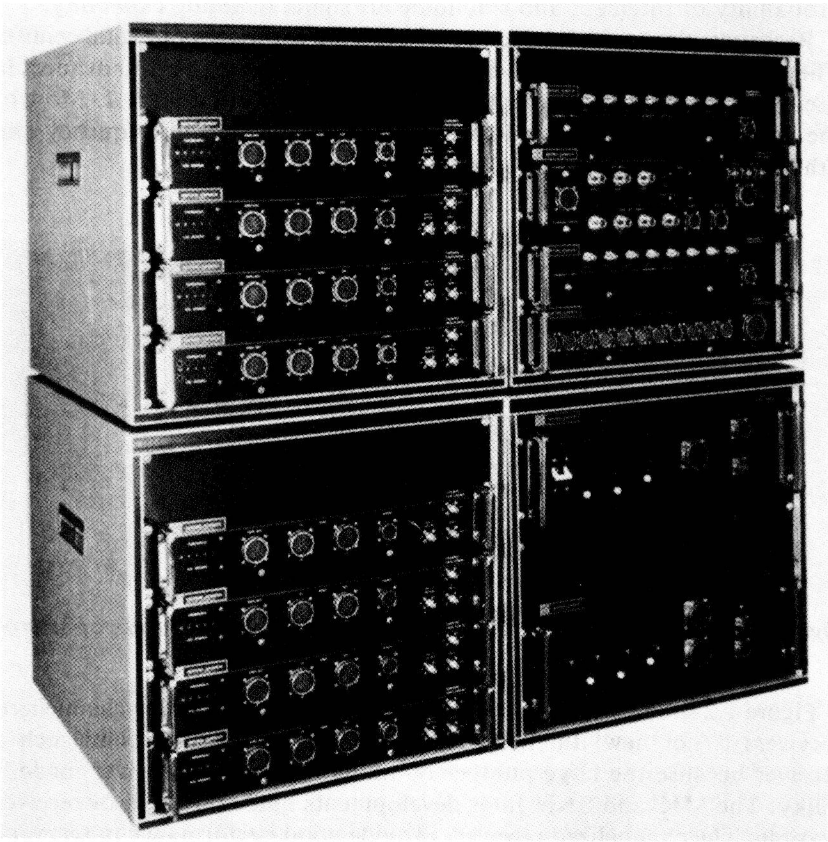

Figure 1.2. Channelized Receiver (Courtesy of U.S. Air Force Wright Aeronautical Laboratories)

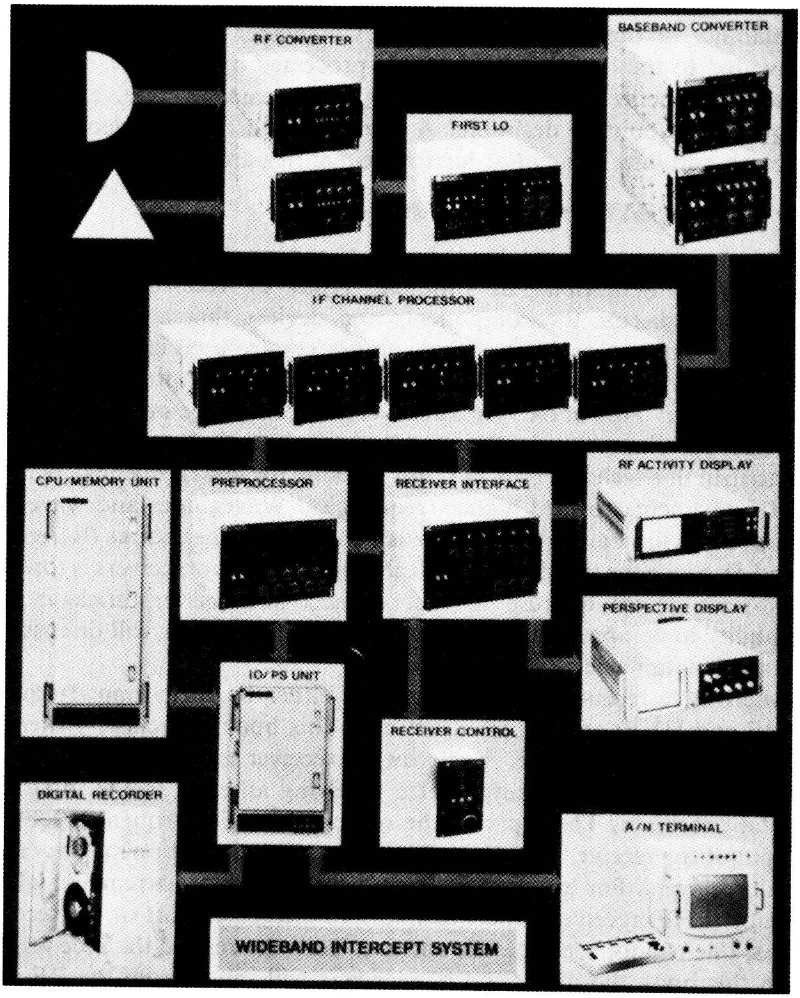

Figure 1.3. Wide-band Intercept System (Courtesy of Watkins-Johnson Co.)