COMMUNICATIONS TECHNICIAN T 3 & 2

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSE NAVPERS 10234

PREFACE

This book has been written to aid enlisted personnel of the United States Navy and Naval Reserve in preparing for advancement to the rates of Communications Technician, Technical Branch, 3 & 2.

The subjects with which the striker must be familiar and the skills he must acquire before he can qualify for advancement to Communications Technician, Technical Branch, 3 & 2, are outlined officially in the *Manual of Qualifications for Advancement in Rating for Communications Technicians*, Naval Security Group Headquarters Activity Instruction PO2573.3 series. Before beginning to study for the rating, the striker should check the currently effective edition of the instruction.

Those who work in the technical branch are aware how fast procedures and publications change. This book was up to date when published, and it will, from time to time, be revised. Between revisions some obsolescence is unavoidable. For this reason it is suggested that the student with access to official publications use them as much as possible in his study.

The specialized subjects with which the CT T must be familiar will be discussed in a Naval Security Group addendum to this manual.

As one of the Naval Security Group Training Courses, *Communications Technician, Technical Branch, 3 & 2* was prepared by the U. S. Naval Security Group Headquarters in cooperation with the Bureau of Naval Personnel.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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ACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS *	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	† E7 to E8	‡ E8 to E9
SERVICE	4 mos. service—or completion of recruit training.	6 mos. as E-2.	6 mos. as E-3.	12 mos. as E-4.	24 mos. as E-5.	36 mos. as E-6.	48 mos. as E-7. 8 of 11 years total service must be enlisted. Must be permanent appointment.	24 mos. as E-8. 10 of 13 years total service must be enlisted.
SCHOOL	Recruit Training.		Class A for PR3, DT3, PT3.			Class B for AGCA, MUCA, MNCA.		
PRACTICAL FACTORS	Locally prepared check-offs.	Records of Practical Factors, NavPers 760, must be completed for E-3 and all PO advancements.						
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.					
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.					
EXAMINATIONS	Locally prepared tests.		Service-wide examinations required for all PO advancements.				Service-wide, selection board, and physical.	
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed. See NavPers 10052 (current edition).					Correspondence courses and recommended reading. See NavPers 10052 (current edition).	
AUTHORIZATION	Commanding Officer		U.S. Naval Examining Center			Bureau of Naval Personnel		
	TARS are advanced to fill vacancies and must be approved by CNARESTRA.							

* All advancements require commanding officer's recommendation.
† 2 years obligated service required.
‡ 3 years obligated service required.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS *		E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	E8	E9
	FOR THESE DRILLS PER YEAR								
TOTAL TIME IN GRADE	48	6 mos.	6 mos.	15 mos.	18 mos.	24 mos.	36 mos.	48 mos.	24 mos.
	24	9 mos.	9 mos.	15 mos.	18 mos.	24 mos.	36 mos.	48 mos.	24 mos.
	NON-DRILLING	12 mos.	24 mos.	24 mos.	36 mos.	48 mos.	48 mos.		
DRILLS ATTENDED IN GRADE †	48	18	18	45	54	72	108	144	72
	24	16	16	27	32	42	64	85	32
TOTAL TRAINING DUTY IN GRADE †	48	14 days	14 days	14 days	14 days	28 days	42 days	56 days	28 days
	24	14 days	14 days	14 days	14 days	28 days	42 days	56 days	28 days
	NON-DRILLING	None	None	14 days	14 days	28 days	28 days		
PERFORMANCE TESTS				Specified ratings must complete applicable performance tests before taking examination.					
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)		Record of Practical Factors, NavPers 760, must be completed for all advancements.							
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Completion of applicable course or courses must be entered in service record.							
EXAMINATION		Standard exams are used where available, otherwise locally prepared exams are used.						Standard EXAM, Selection Board, and Physical.	
AUTHORIZATION		District commandant or CNARESTRA					Bureau of Naval Personnel		

* Recommendation by commanding officer required for all advancements.
† Active duty periods may be substituted for drills and training duty.

CHAPTER I

THE COMMUNICATIONS TECHNICIAN, TECHNICAL BRANCH

THE COMMUNICATIONS TECHNICIAN RATING

During World War II, the duties of the present Communications Technicians were performed by a selected group of men from several then existing ratings. Realizing the need for a special rating, the Navy established, in April 1948, the Communications Technician (CT) rating, which now includes five branches: Technical (T), Administrative (A), Maintenance (M), Communications (O), and Collection (R). You will seldom hear the five branches referred to by their full titles; rather you will hear reference to the T, A, M, O, or R Branch.

As a Communications Technician, you will be assigned to the Naval Security Group (NAVSECGRU). The accuracy, reliability, and efficiency with which you perform your assigned duties in the T Branch will affect the work not only of all personnel of the NAVSECGRU but of all Navy personnel.

MILITARY RESPONSIBILITIES

In studying and preparing for the Communications Technician rating, as for any other advancement in the Navy, your first responsibility is to fulfill your military requirements by studying either directly or through a correspondence course based on the manual *Military Requirements for Petty Officer 3 & 2*, NavPers 10056. Military requirements for a petty officer differ from those which you met for previous advancements. Although you still are required to learn some individual operations, the emphasis has changed to directing and supervising operations performed by others. Thus you are definitely entering the field of military leadership; as you ascend the rating ladder, you will be given increasing responsibility, usually in supervisory positions over junior petty officers and strikers.

CT T BRANCH PROFESSIONAL SUBJECTS

In addition to your military responsibilities, you as a Navy petty officer will be a skilled worker in a specialized field. This, as applied to the CT of the T Branch, means that you are on your way to becoming an individual who knows how to perform certain operational tasks of a technical nature without detailed direction or close supervision. As you demonstrate competence in these skills, you will be entrusted with the supervision and training of strikers who are learning them.

This chapter is designed to assist you in selecting the sources and methods you should use in preparing yourself for advancement, and discusses briefly the personal traits you will need. The following chapters will contain detailed discussions of individual procedures and areas of knowledge pertinent to the T Branch qualifications.

This text and the *NAVSECGRU Addendum* will be your general texts for fulfilling professional requirements and are based on the knowledge factors and practical factors as outlined in the *Quals Manual.* By consulting it, you will learn what specific skills and knowledges are required at each step of the CT T Branch rating ladder. You will note that, if qualified, a CT T may advance to Limited Duty Officer, Cryptology.

PERSONAL QUALITIES

In addition to knowledge of your subject matter and the capacity to perform your tasks well, you, as a CT T need certain personal characteristics. Some are general qualities which help ensure success in any rating; others are especially important to the CT T Branch. The important personal qualities derive largely from your attitude toward you work, toward other people, and toward yourself.

MILITARY BEARING

All petty officers have an obligation to conduct themselves with dignity and in such a manner as to reflect credit on the U. S. Navy. Dignity can exist only where the individual has a proper sense of his own worth and the worthiness of his cause. The individual who possesses true dignity will also respect the dignity of others. Military bearing is dignity within military relationships. It exists when the individual is proud of his military organization and of his part in it. He not only respects his seniors and is guided by the example of those he admires most among them, he also respects his juniors and tries to provide an example they will be proud to follow. Whether you are squaring your hat, rendering a salute, carrying out your assigned duties, or going on liberty, your manner says that you are proud of the Navy and are doing your best to make the Navy proud of you.

COURTESY

When you check the qualifications for advancement in rating, you will not find courtesy actually listed; but it is implied. Most situations require some courtesy, and unless you display what is required, you are in trouble. Actually, courtesy goes far beyond the minimum requirements; in fact, it is totally different in character because courtesy comes from within and is a voluntary expression of respect for others' rights and feelings. "The greater the man, the greater the courtesy." Your job will involve not just you but others with whom you will be working. Courtesy on your part can smooth the way not only for you but for the officers and petty officers with whom you work.

ATTENTION TO DETAIL

A CT T's work must be correct in every detail, and the details are numerous. No matter what your assigned duties are, you will need to concentrate on getting them done correctly. A careless job or error on your part could result not only in damage to equipment but could also delay the work of other personnel of the Naval Security Group. There is an old saying which is particularly applicable here, "Any job that is worth doing is worth doing right."

DISCRETION

As a CT T, you will be handling both equipment and information that MUST NOT BE DISCUSSED OUTSIDE THE WORKING SPACES. A responsible CT T can be relied upon to keep this information to himself and not yield to the temptation of loose talk. Detailed information concerning the topic of security will be contained in the following chapter.

SOURCES OF INFORMATION AND EDUCATION

There are two classified publications with which you need to be thoroughly familiar as you set about preparing yourself for advancement in rating. The first publication is the *Manual of Qualifications for Advancement in Rating for Communications Technicians*, NSGINST PO2573.3 series, usually referred to as the *Quals Manual*. There are two sections of the manual with which you are concerned. The first section outlines the professional qualifications which are applicable to ALL branches of the Communications Technician rating. These practical factors and knowledge factors are identified by the letter "P." The second section of the *Quals Manual* specifically concerns you; in it are outlined all the qualifications for the CT T Branch.

The second classified publication which is important to you in preparing for advancement is the *List of Training Publications for Communications Technician Examinations*, NSGINST 02573.2 series, often referred to as the *Study List*. The *Study List* is, of necessity, revised from time to time. Therefore, you should check the following three parts of the currently effective edition of this instruction:

Part I	Military Requirements
Part II	Professional Requirements for all Branches
Part III	T Branch Requirements

As you begin your study of this Navy Training Course, you will note that a number of chapters are devoted to unclassified material pertinent to certain T Branch qualifications. In addition to the textual material, the following four appendixes have been included as supplementary material:

Appendix I	contains answers to the quizzes at the end of each chapter
Appendix II	contains the International Morse Code plus helpful hints for fulfilling proficiency requirements

Appendix III discusses time zones as used in communications and includes sample problems in time zone conversion

Appendix IV provides a review of mathematical terminology and functions pertinent to the study of electronics and communications

Although this training course will be your general textbook, you will note, from consulting the *Study List*, that there are other publications, pertinent to the work of the CT of the T Branch, which you will be expected to study.

You are also urged to avail yourself of other opportunities for continuing your general and professional education. Such opportunities include NAVSECGRU special communications correspondence courses, Navy correspondence courses, college extension services, USAFI courses, and locally sponsored I & E courses.

HOW TO STUDY

Your success in preparing for your rating may well depend on your ability to study. This is true whether you receive your training in a formal school setting or are required to study for advancement while training on the job. In the school setting, you have the advantage of being given specific study assignments; if you are studying while on the job you are pretty much on your own. You should find the following points helpful in developing good study habits:

1. Use any spare time wisely. If you only have a short time for study, concentrate intensively on a small unit of subject matter and learn that thoroughly.
2. When you are reading study materials, read several paragraphs, then stop and ask yourself what you have learned. Do not proceed until you are certain that you can explain what you have already read.
3. Look up unfamiliar words in a dictionary. If you have difficulty understanding the content of what you are reading, ask for help from one of your seniors.
4. Never be content merely to memorize the content or questions and answers. Always be sure that you can rephrase the material in your own words; this is your assurance that you really understand what you have read.
5. Consistent use of the quizzes at the end of chapters will be most helpful in preparing you for your advancement examinations.
6. Whenever this text makes reference to official publications, try to obtain them for examination and study.
7. Put into actual practice what you learn from studying.
8. Try to keep current with any changes in policy or procedure which may have occurred since the publication of this text. This means that you must keep familiar with the current directives and instructions.

QUIZ

1. To which group within the Navy organization will a Communications Technician be assigned?
2. What is your first responsibility in fulfilling the qualifications for CT 3?
3. As you advance to a petty officer rating, how will your military requirements differ from your present requirements?
4. Qualified CTs may be appointed as Limited Duty Officers in which category?
5. Which term means "dignity within military relationships"?
6. Why is discretion an important personal qualification for the T Branch CT?
7. What publication should you consult to determine the practical factors you must complete for advancement in the CT rating?
8. What publication should you consult to determine the publications which should be studied in preparation for examinations for advancement in the CT rating?

CHAPTER 2

SECURITY

INTRODUCTION

Your most important task as a Communications Technician will be safeguarding the classified information entrusted to you. In your daily work you will be handling classified documents, letters, publications, messages, and other classified material. It will be your personal responsibility to protect the contents of all the classified material you handle.

Security is a means, not an end. All the rules and regulations which are spelled out in the many directives and publications on the subject of physical security, communication security, and personal censorship will not guarantee results. You must learn to exercise discretion in carrying out all your duties so that maintenance of security at all times and under all circumstances becomes an automatic and integral part of your work.

There are certain laws and regulations which define the various aspects of security and set forth the penalties for violations. Each quarter all NAVSECGRU personnel are required to read the Atomic Energy Act, the Espionage and Censorship Act, and other pertinent laws and regulations.

In order to carry out your responsibilities, you will also need to be familiar with the effective editions of the following publications and consult them, whenever necessary, on the subject of security:

U. S. Naval Communications Instructions, DNC 5, Chapter 5

Communication Instructions Security, ACP 122

Navy Regulations, 1948, Chapter 15

Department of the Navy Security Manual for Classified Information, OPNAVINST 5510.1

United States Navy Physical Security Manual, OPNAVINST P5510.45

SECURITY CLASSIFICATIONS

Classified information is official information which requires protection in the interests of national defense and which is classified for such purpose by responsible classifying authority. Classified material is any matter, document, product, or substance on or in which classified information is recorded or embodied.

Three general categories of classification are authorized for such material. They are, in descending order of importance, Top Secret, Secret, and Confidential (including Confidential-Modified Handling Authorized).

TOP SECRET

The use of the classification Top Secret is limited to defense material or information which requires the highest degree of protection and is applied only to information or material of which the defense aspect is paramount. It is of such a nature that its unauthorized disclosure could result in EXCEPTIONALLY GRAVE DAMAGE to the Nation, such as:

1. Leading to a definite break in diplomatic relations affecting the defense of the United States, an armed attack against the United States or its allies, or a war.
2. The compromise of military or defense plans, or intelligence operations, or scientific or technological developments vital to the national defense.

SECRET

The use of the classification Secret is limited to defense information or material the unauthorized disclosure of which could result in SERIOUS DAMAGE to the Nation, such as:

1. Jeopardizing the international relations of the United States.

2. Endangering the effectiveness of a program or policy of vital importance to the national defense.

3. Compromising important military or defense plans, or scientific or technological developments important to national defense.

4. Revealing important intelligence operations.

CONFIDENTIAL

Information or material classified Confidential is such that its unauthorized disclosure could be PREJUDICIAL TO THE DEFENSE INTERESTS of the Nation.

Certain types of Confidential information may be identified by the term Confidential-Modified Handling Authorized. This is material which, although falling in the group described by Confidential, has been designated by the originator for slightly lesser safeguards in stowage and transmission. This is done only after careful consideration of its content and only for the purpose of making it more easily available to those who need to use it. Examples of this kind of material are textbooks, manuals, maps, and photographs whose content makes it permissible and desirable to use them for training purposes.

If you wish to understand more thoroughly the various categories of classified matter, you will find several examples of each type in the *Security Manual*, but the most important thing for you to learn at this time is that each category represents a degree of damage to the Nation that could result from letting this material get into the hands of unauthorized persons. The category also determines how the material shall be handled and the measures used for its protection.

RESTRICTED DATA

The term Restricted Data is not a category of classification but is assigned because of the general subject of the documents. It is applied to all data concerning (1) the design, manufacture, or utilization of atomic weapons; (2) the production of special nuclear material; or (3) the use of special nuclear material in the production of energy—unless such data or material have been declassified or removed from the category by the Atomic Energy Commission. Information marked Restricted Data is classified (Top Secret, Secret, or Confidential) according to the protection it should receive. It is declassified when the Atomic Energy Commission decides it may be published without undue risk to the defense and security of the Nation.

FOR OFFICIAL USE ONLY

Certain other official information, not included in the categories of classified matter and not discussed in the *Security Manual*, may also require protection in accordance with law and public interest. Such information, according to SECNAV INSTRUCTION 5570.2A, should be designated For Official Use Only.

Among documents you might see bearing the For Official Use Only designation are certain personnel documents, and tests and examinations of various kinds, such as those used for entrance on duty, classification, qualification, advancement, or promotion.

The For Official Use Only designation is appropriately used for information relating to the operations and activities of the Department of Defense such as bids from civilian firms on contracts, advance information on plans that should not be released until a later date, and other types of information which if generally disclosed would have a bad effect on morale, efficiency, or discipline, or would give certain individuals an unfair advantage over others.

SECURITY CLEARANCES

An appropriate clearance is required for access to classified information. In order for personnel to be eligible for a clearance they must be:

1. Of unquestionable loyalty, integrity, and trustworthiness.

2. Of excellent character and of such habits and associations as to cast no doubt upon their discretion and good judgment in the handling of classified information.

TYPES OF INVESTIGATIONS

To determine whether an individual meets the criteria for a security clearance, two types of personnel security investigations are employed—the National Agency Check (NAC) and the Background Investigation (BI).

National Agency Check

A National Agency Check consists of the investigation of records and files of the following agencies as appropriate:

1. Federal Bureau of Investigation
2. Office of Naval Intelligence
3. Assistant Chief of Staff, Intelligence, Department of the Army
4. Office of Special Investigations, Inspector General, U. S. Air Force
5. Civil Service Commission
6. Immigration and Naturalization Service
7. Central Index Personnel and Facility Security File
8. Bureau of Naval Personnel and/or Headquarters, U. S. Marine Corps
9. Other agencies as determined by the Chief of Naval Operations (Director of Naval Intelligence)

Background Investigation

The Background Investigation is much more extensive than a National Agency Check. It is designed to develop information as to whether the access to classified information by the person being investigated is clearly consistent with the interests of national security. It inquires into the loyalty, integrity, and reputation of the individual. It consists of the following elements:

1. National Agency Check.
2. Verification of birth records.
3. Education, including verification of last school or college attended, checking school records, and interviewing people who knew the individual while at school.
4. Employment, including examination or records of present and past employment to determine period of service and efficiency record. Fellow employees are interviewed to determine character and reputation.
5. References, including interviews of those persons listed as references, plus others who may have knowledge of subject's background and activities.
6. Neighborhood investigation as deemed necessary to substantiate or disprove derogatory information.
7. Criminal records including police and law enforcement agency records in areas where individual has resided for substantial periods.
8. Milltary service, including length of service and type of discharge.
9. Foreign connections which an individual may have had with foreigners or foreign organizations both in the U. S. and abroad.
10. Citizenship status.
11. Foreign travel. State Department and Central Intelligence Agency (CIA) records are checked to determine reasons for travel.
12. Credit record. Credit agencies and credit references are checked whenever necessary.

INTERIM CLEARANCE

A personnel security clearance is an administrative determination that an individual is eligible, from a security standpoint, for access to classified information of the same or lower category as the clearance being granted. Of the two types of clearances (interim and final), an interim clearance is granted as the result of a lesser investigative process and is a determination of temporary eligibility for access to classified information. Certain requirements must be met which vary with the classification category. These requirements are defined in chapter 15 of the *Security Manual*. An interim clearance is granted only when the delay in waiting for completion of the necessary steps for final clearance would be harmful to the national interest. Procedures to effect a final clearance are initiated simultaneously with the initiation of the procedures for an interim clearance.

FINAL CLEARANCE

A final clearance is granted when it has been determined that an individual is eligible, from a security standpoint, for access to classified information in the category of clearance being requested. To be eligible for a final clearance, an individual must meet the clearance criteria and full investigative requirements as set forth in chapter 15 of the *Security Manual*. The ultimate authority for granting a clearance, which authorizes access to classified information, rests with the commanding officer, who is responsible for the security of the information or material within his command.

CERTIFICATE OF CLEARANCE

Each clearance, final and interim, is evidenced by the issuance of a Certificate of Clearance. Certificates of Clearance are made a matter of record and become a permanent part of an individual's service record.

Cryptographic clearances shall be indicated on Certificates of Clearance. However, Certificates of Clearance do not need to be executed for personnel authorized to handle Confidential information unless the basis for authority is a Background Investigation or a National Agency Check.

Remember that merely because an individual has been cleared for access to information of a certain classification category, it does not mean that he may have access to all classified information within that category. Classified information is made available to appropriately cleared personnel on a "need-to-know" basis.

SPECIAL HANDLING

In addition to the classification categories and clearance procedures discussed in the preceding sections, you will have access to certain sensitive information unique to the NAVSECGRU. Separate instructions for the SPECIAL HANDLING of this information are promulgated by the Director, NAVSECGRU and are administered at each activity by the Special Security Officer (SSO). This subject will be discussed further in the NAVSECGRU classified addendum to this manual.

TYPES OF SECURITY

As a basic responsibility, it is mandatory that all CT personnel comply with all security directives for classified information. You have learned that you must be appropriately cleared to handle classified information. You must also be familiar with all the rules and regulations governing security. The types of security of interest to you may be grouped into the following three broad categories:

1. COMMUNICATION SECURITY, including Cryptographic Security and Transmission Security, prevents the enemy from obtaining information from United States and Allied communications.
2. PHYSICAL SECURITY keeps classified matter solely in the possession of properly authorized individuals who are entitled to make official use of it.
3. PERSONAL CENSORSHIP prevents betrayal of official secrets through private conversations, correspondence, and so on.

COMMUNICATION SECURITY

The two words COMMUNICATION SECURITY mean the precautions and the measures taken to prevent the enemy from (or delay the enemy in) getting information from our communications. The aim of communication security is to prevent the obtaining of intelligence by the enemy through cryptanalysis and the study of traffic trends. This is a big order. Your billet takes on new meaning when you realize there can be no half-way measures in practicing communication security. It is all or nothing. You can't specialize in that phase of security which seems to apply to your rating and neglect the remainder. The enemy doesn't operate that way. His methods are thorough—planting agents within the naval organization, attempting to photograph and steal documents, tapping telegraph or telephone lines, intercepting radio transmissions, solving codes and ciphers, and questioning or overhearing personnel when off duty. In order to combat these efforts, you have to practice SECURITY and know the regulations that govern all types of SECURITY in the Navy.

Cryptographic Security

Cryptographic Security is that component of communication security which is achieved by the correct use of technically sound cryptosystems. The secure and efficient operation of the cryptocenter, proper training of personnel engaged in cryptoduties, and thorough familiarization with pertinent instructions will provide the best defense against cryptoanalysis and preclude the possibility of endangering cryptosecurity.

Cryptography is the science of cloaking information in codes and ciphers. A CODE is a system whereby words, phrases, numbers, or syllables are replaced by numbers, letters, or codewords. The codeword for the Normandy landings, Operation OVERLORD, is an example of a code used to prevent betrayal of intentions, dates, or geographical locations if a document associated with the invasion had fallen into enemy hands.

A CIPHER is a system in which individual letters of a message are replaced, letter for letter by other letters rather than by complete words, phrases, or numbers. Cipher texts are frequently transmitted in 5-letter groups.

The enemy is constantly and paintakingly studying our codes and ciphers in an attempt to discover the keys to our many cryptographic systems. This technique is known as cryptanalysis. The best defense against this type of enemy intelligence is cryptosecurity—the careful use of technically sound cryptosystems.

The cryptoboard, under the direction of the communications officer, is responsible for the proper encryption and decryption of messages. Reliable petty officers may be appointed to this board, along with officers assigned communication duties. Members of the board, known as cryptographers, must be proficient in the use of all codes and ciphers held by the command.

An especially grave compromise results from the loss of a cryptographic publication or the transmission of a faulty encryption. Since it must be assumed that the enemy has received enough information to recover the key to the system, such a cipher must be discontinued and immediately replaced, for subsequent transmissions in the same system might be little better than plain language. The work and expense of superseding a cipher system, though great, are insignificant compared to the consequences of compromising highly classified information.

Transmission Security

Transmission Security is that component of communication security which results from all measures designed to protect transmission from interception, traffic analysis, and imitative deception. Every means of transmission is subject to interception.

In the case of transmission, it must be assumed that all transmissions are intercepted. Today, each message sent by radio is open to reception by any friend or foe who has the necessary equipment and is within the reception range. You can expect unauthorized interception any time a transmitter is placed in operation.

How does the enemy take advantage of our radio activity? What are his ways of getting information? In the first place, an enemy copies the traffic intercepted by his listening posts. This material is then subjected to expert cryptanalysis. If the volume of traffic enciphered in any one system is great enough, and there are errors in drafting and encryption, the chances of breaking the system are better.

When his cryptanalysts fail him, the enemy can get important information just from the study of the volume of radio traffic. The peaks and valleys in the number of messages transmitted can be indications of a major operation, on the one hand, and routine activity on the other. When hitherto little-used circuits suddenly become very active, the enemy cannot be far wrong in assuming that something unusual is afoot.

You can also expect the enemy to study the DIRECTION of the flow of traffic. If, for instance within a short period of time, a radio message is transmitted from point Bravo to Quebec, another to Victor, another to a unit of the fleet operating off Whiskey, and a fourth to a unit off Oscar, the enemy may logically assume that a convoy from Bravo to Quebec is being planned.

These transmissions are probably arranging for the convoy's escort. The enemy is almost certain to draw this conclusion if his traffic records show that rarely are messages transmitted to these four addressees simultaneously, especially if his records further show that similar coincidences of this nature were followed by the arrival of a convoy at Quebec.

One of the most important steps you can take to prevent the enemy from gaining radio intelligence is the practice of proper CIRCUIT DISCIPLINE. This requires more than a blind obedience to the rules. A good operator develops an active imagination which explores the possible deductions the enemy might make from the manner in which the circuit is being used. You must do everything within your power to prevent the enemy from learning anything of value about the messages you transmit. Constant alertness, coupled with intelligent observance of instructions, are essential for transmission security.

PHYSICAL SECURITY

All the measures designed to keep classified information from physically coming into the possession of persons not authorized to have it are included under the heading of Physical Security. Physical security is based on two principles, constant surveillance of classified material when in use and proper stowage when not in use. It includes the stowage and custody of the material, accounting for its use, disposition, or destruction as required; transmission and dissemination. Each classification category has its own stowage and transmission requirements. In other words, physical security is concerned with ways to prevent unauthorized persons from obtaining physical custody of classified material.

Stowage

Classified material not in actual use by appropriately cleared personnel or under their direct observation should be stowed in a prescribed manner. Stowage facilities for Top Secret material must afford a greater degree of protection than for Secret. Similarly, the stowage requirements are higher for Secret material than for Confidential.

To provide a specific basis for establishing security protection for the various categories of classified material, a numerical evaluation for classified material in stowage has been developed. The system is covered in detail in chapter 6, *Department of the Navy Security Manual for Classified Information* and makes use of two tables:

1. A table of numerical equivalents, which establishes numerical values for various items which individually or collectively may be incorporated in the stowage protection system.
2. An evaluation graph, which establishes minimum levels of required protection based on the classification and the strategic and intrinsic importance of material concerned.

Consult the *Security Manual* for further detailed information concerning stowage requirements.

Handling Precautions

At the close of each working day you must make certain that all classified material you have used has been locked up. Notes regarding classified matter must not be left on memorandum pads or under blotters. Wastebaskets should be checked to see that they contain no classified material, such as notes, carbon paper, excess copies, or rough drafts. These items are to be placed in burn bags with other classified material to be destroyed in accordance with locally established procedures.

Vaults, safes, or lockers used for stowage of classified matter must always be kept locked when not under the supervision of authorized personnel. Cryptographic aids and related classified matter must never be left unguarded by the user. In case of a fire or other emergency, it is your personal responsibility to safeguard all classified matter in your possession.

PERSONAL CENSORSHIP

The most important form of security, and at the same time the hardest to guarantee, is Personal Censorship. Each of us, through indiscreet conversation and thoughtless personal letters, is capable of doing inestimable harm to the security of our country. Personal discussion of official affairs with families or friends, or even careless talk while on duty, in the presence of persons not authorized to have certain information, is dangerous.

There is only one safe conversational policy for you to follow when off duty—say nothing about classified matter, or information, to anyone. There are few places where conversation cannot be overheard.

Through the very nature of your work, you will find yourself in possession of information known only to a small, select group. Because of this, Communications Technicians are looked upon as "people in the know" and, in anticipation of picking up a bit of hot information, others listen closely whenever Communications Technicians speak. In order not to betray your trust, you must constantly be on guard against a slip of the tongue which might reveal information to those who have no need to know.

Official matters should not be discussed even with members of your own family or close friends in whom you have the greatest confidence. Although they would never knowingly reveal information given to them, they could let slip a detail in casual conversation. Even though they don't realize the importance of what they have said, the damage is done. Your best bet is to decline to discuss official matters. If necessary, plead ignorance of the subject under discussion.

Personal censorship also includes telephone conversations, personal correspondence, and personal notebooks. Telephone wires can be tapped, mail can be intercepted by enemy agents, and diaries have proved fruitful sources of information to the enemy. In fact, naval personnel are discouraged from keeping personal diaries for just this reason.

TRANSMISSION OF CLASSIFIED INFORMATION

A communication may be sent by a variety of means. Within the requirements of precedence and security, the most appropriate means of transmission should be selected. The generally available means of transmission, in descending order of security, are:

1. Messenger authorized to carry classified material
2. U. S. registered mail
3. Approved wire circuit
4. Ordinary mail
5. Non-approved wire circuit
6. Visual (such as flashing light)
7. Sound systems
8. Radio

Some of the means of transmitting messages and information and their relative degree of security are discussed on the following pages.

MESSENGER

Classified matter is transmitted by messenger when security, not speed, is the paramount objective. The principal messenger agency for the Department of Defense is the Armed Forces Courier Service (ARFCOS), which is responsible for the safe transmittal of highly classified matter to military addressees and certain civilian agencies throughout the world. ARFCOS courier transfer stations are located in certain designated areas, and every item of classified material sent via ARFCOS is in the physical custody and control of a commissioned officer courier from the time of entry into the system until the addressee or his authorized representative receipts for it. ARFCOS is not used to transmit classified material which may go by registered United States mail.

Guard mail is another type of messenger service used to transmit classified material, although unclassified material is also often delivered by this means. Reliable petty officers as well as commissioned officers are appointed as guard mail messengers. Guard mail is used, for instance, in a naval district for delivery of mail to other military or Government activities located in the same area; it is also used in conjunction with ordinary mail service to and from ships in port.

MAIL

In addition to transmitting unclassified material, the United States postal system is used to transmit classified material. However, the United States postal system may not be used to transmit Top Secret material. Top Secret material is only transmitted in one of three ways: direct personal contact of officials concerned, Armed Forces Courier Service, or electrical means in encrypted form.

Secret material may be transmitted by any of the means authorized for Top Secret and in addition U. S. registered mail may be used.

Confidential material may be transmitted by any of the means authorized for Secret, or by U. S. certified mail. Exceptions: Confidential cryptographic and cryptologic material, Confidential RPS-distributed material, and Confidential material of CENTO, NATO, and SEATO may not be transmitted by U. S. certified mail.

Confidential-Modified Handling Authorized material may be transmitted by ordinary U. S. mail or electrically in unencrypted form over U. S. Government owned or leased landlines. When the originator is uncertain of the location of an addressee, as in the case of an afloat unit. U. S. registered mail must be used.

These rules apply only within the continental United States. Chapter 7 of the *Security Manual* specifies the authorized methods of transmission of classified material outside the continental United States.

The great bulk of the Navy's administrative traffic is sent by mail, thus reserving circuits for operational traffic insofar as possible. Mailable classified material is double-wrapped, as shown in figure 2-1. Top Secret material is prepared in a similar manner but, as stated above, does not go through the mails.

Detailed procedures for transmission of cryptographic and registered material are contained in the current edition of the *Registered Publication Manual, RPS-4.*

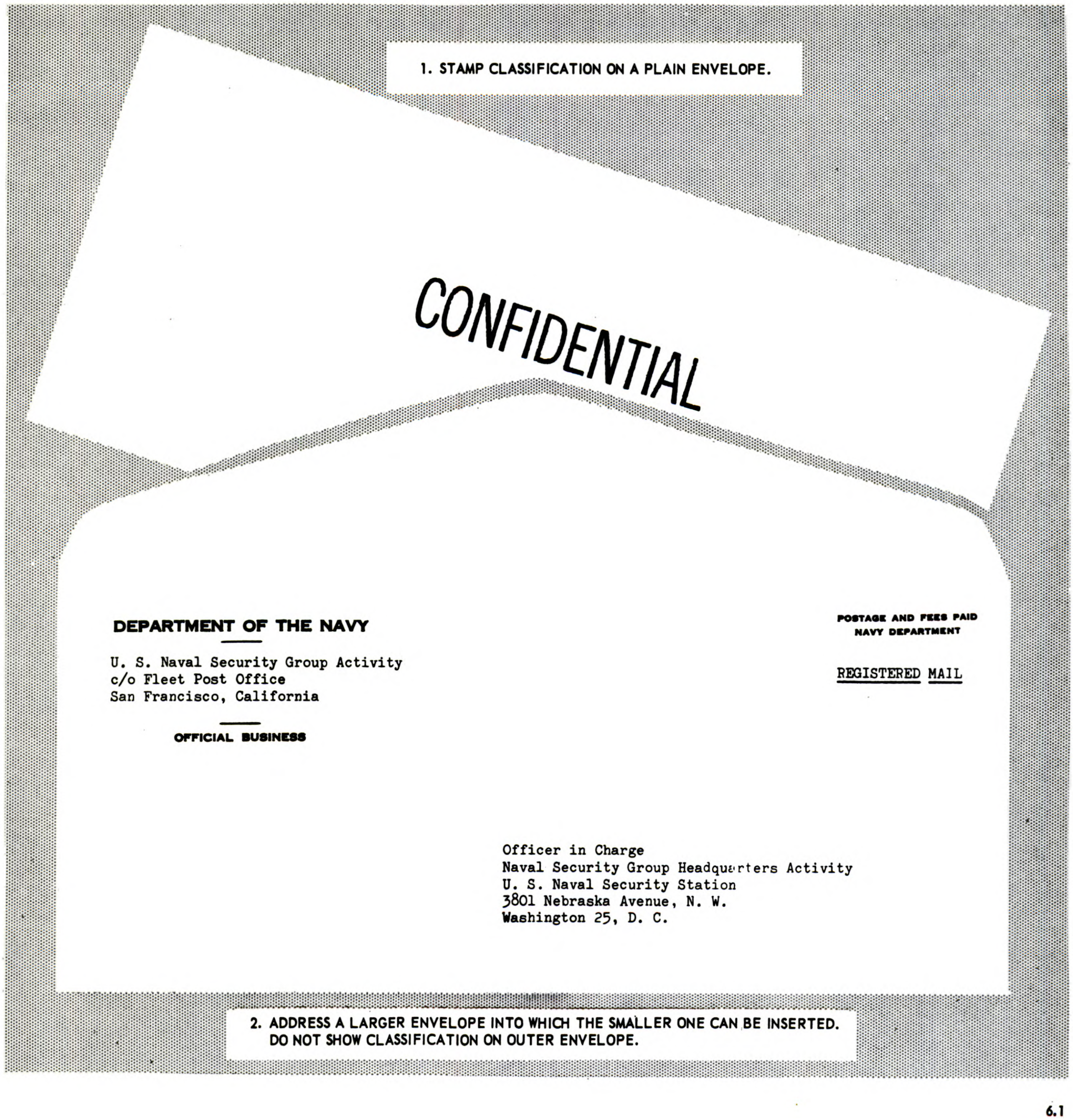


Figure 2-1.—How mailable classified matter is prepared.

WIRE CIRCUITS

When available, wire circuits invariably are used in preference to radio, since they are less susceptible to interception.

There are two types of wire systems: APPROVED and NONAPPROVED. Such wire systems include telephone, telegraph, teletypewriter, and facsimile facilities.

An approved circuit is one designated by appropriate authority as suitable for transmission in the clear of messages classified no higher than Secret.

Approved circuits usually lie entirely on military property.

A non-approved circuit is one which does not lie entirely within military property, has a radio link, or for some other reason is not considered safe enough for transmission of traffic in the clear. It is forbidden to send classified messages in the clear over a non-approved wire, except as specified in the effective edition of ACP 122.

Telephone circuits are normally considered nonapproved and are not used to discuss classified data unless specifically designated as approved. Approved telephone circuits are equipped with security devices to minimize the possibility of tapping.

Tapping may often be discovered by physical examination or by transmission irregularities. Interception by induction, however, can escape detection completely. Supersensitive devices placed near the wire circuit will pick up sounds through a 2-foot wall. Tiny microphones, hidden in telephone receivers, will pick up not only telephone conversations but voices anywhere in the room.

Underwater cables are also liable to unauthorized interception, although they are more difficult to tap than landlines. Submarines are able to make successful interceptions by induction. The point where the cable emerges into shallow water is the most vulnerable.

VISUAL COMMUNICATIONS

Visual communication systems are used in preference to radio, except at night when there is possibility of divulging the ship's position. They are more secure than radio because reception is limited to units in the immediate vicinity of the sender.

Visual communication methods are ranked in order of security according to the distance from which the signals can be seen. In daylight the relative order is semaphore, directional flashing light, panels, flaghoist, pyrotechnics, and nondirectional flashing light. At night the order is infrared, directional flashing light, pyrotechnics, and nondirectional flashing light.

The greatest care must be taken to ensure that signal lights are used only when necessary, and that the minimum of light is employed. An exception is made for recognition signals, which must be sent on a light sufficiently brilliant to be seen at once.

Transmission of plain language messages is kept to a minimum within the vicinity of the beach. Many persons are adept at reading lights and flags.

SOUND SYSTEMS

Whistles, sirens, foghorns, bells, and underwater sound devices are common types of sound systems. They are used by vessels to transmit emergency warning signals (air raid alerts, mine sightings, etc.) and for signals prescribed by the Rules of the Road. Sound systems have the same range limitations as visual methods and are less secure. Their use is largely restricted to maneuvering and emergency situations.

RADIO

Radio is potentially the least secure means of communication. A message sent by radio is open to interception by anyone who has the necessary equipment and is within reception range. Thus in addition to obtaining intelligence through cryptanalysis, the enemy may be able to fix the location of operating forces through direction finding. Through deceptive techniques he may be able to confuse and hamper our communications and, by traffic analysis, forecast the intentions of our forces.

Despite its shortcomings, radio is still the primary means of communication. It is fast, reliable, and often the only method of maintaining contact between distant and highly mobile units. A satisfactory degree of security can be obtained only by its proper and intelligent use.

Radio Silence

The best way to keep a potential enemy from gaining intelligence from radio communications is radio silence. It is apparent that the enemy cannot gain intelligence from radio transmissions if none are sent. Radio silence is placed in effect when it is reasonable to assume that the enemy is ignorant of the location or impending movements of a ship or force.

Conelrad

Control of electromagnetic radiation, abbreviated as CONELRAD, is the deliberate control of equipment capable of emitting electromagnetic radiations for the purpose of reducing the likelihood of enemy interception. In peacetime, CONELRAD is imposed only if required for operational purposes or for training.

Enemy Deception

There are many deceptive techniques an enemy might use to obstruct radio communications. He may, for example—

1. Remove a message from one circuit and introduce it on another circuit to waste time, create confusion, and produce service messages.
2. Intentionally garble the text of a genuine message with the heading of another, with the group count corrected, and introduce it on a different net.
3. Originate and transmit counterfeit plain language messages.
4. Call a unit in the hope of taking bearings when the unit answers.

Authentication

Proper authentication is one of the best defenses against imitative deception by the enemy. An authenticator is a letter, numeral, or group of letters or numerals inserted in a message to prove its authenticity. By its correct use, an operator can distinguish between genuine and fraudulent stations or transmissions.

Whenever an authentication system is promulgated, accompanying instructions specify how and when it is to be used. Procedures may vary with the form of authentication and the means of communication employed.

When authentication procedures have been prescribed and placed into effect it is mandatory to authenticate when:

1. Making initial radio contact.
2. Transmitting operating instructions which affect the communication situation. Example: Closing down a station or watch.
3. Transmitting (except by broadcast method) to a station under radio silence. (Broadcast method: Unit addressed does not answer, thus avoiding disclosure of position.)
4. Calling a unit afloat for the first time and requiring that unit to break the CONELRAD condition of silence in order to answer.

Good judgment sometimes dictates that an operator accept a message of high priority rather than argue over authentication, even though doubt exists as to its being genuine. Such a message should be delivered promptly to the addressee with the operator's notation that is was not properly authenticated. The decision as to its authenticity is made by the addressee.

Other effective defenses against imitative deception are:

1. Thorough training in operating procedures.
2. Alert operators who recognize irregularity in procedure and the minor implausibilities that often characterize enemy deceptive efforts.
3. Direction finding on transmissions of questionable origin.
4. Minimum use of plain language and procedure messages.

Operators who maintain a high degree of circuit discipline also lessen the chances of enemy deception. Circuit discipline includes adherence to prescribed frequencies and operating procedure. Negligence, inaccuracy, and laxity, as well as lack of circuit discipline and operator training, are some common causes of the violations which endanger radio transmission security.

To the Communications Technician, SECURITY is the keyword. Keep in mind this one sentence: No one, FRIEND or FOE, should be permitted to gain intelligence from naval communications without first being entitled to it.

QUIZ

1. Name the categories of classified material in order of descending importance.
2. With what subject does material labeled Restricted Data deal?
3. What are the two types of personnel security investigations?
4. Who usually grants clearance to handle classified information?
5. On what basis is classified information made available to appropriately cleared personnel?

6. Name two subdivisions of communication security and define each.
7. Define ARFCOS.
8. What is the highest classification that may be transmitted through the United States postal system?
9. What is an approved circuit?
10. Which is the least secure means of transmission for classified material?
11. When is radio silence placed in effect?
12. What is one of the best defenses against imitative deception by the enemy?
13. What should you do if you accept a message that is not properly authenticated?

CHAPTER 3

ORGANIZATION OF NAVAL COMMUNICATIONS

INTRODUCTION

As the title of your rating indicates, you as a CT will be vitally concerned with COMMUNICATIONS. Because the Naval Security Group is an integral part of naval communications, it is important that you have a basic understanding of the organization of Navy-wide communications.

Naval communications today is a giant and complex enterprise with thousands of round-the-clock operating personnel and many millions of dollars worth of equipment. It is a highly disciplined effort and the best of its kind in the world.

NAVAL COMMUNICATIONS is a comprehensive term which refers to the concept of communicating. It is not to be confused with the Naval Communication System, which is a worldwide network of communication channels that comprises only one part of the effort.

Naval communications must always be in a condition of readiness. In the event of hostilities, the operating forces would be dependent on communication facilities in existence at the time, for it is most unlikely that a war would allow time for procuring vast amounts of equipment and training thousands of men. Moreover, it is imperative that adequate means for the prompt transmission of warning and intelligence be instantly available. For these reasons the Navy strives to keep its training level high and maintains communication facilities that would not be warranted if the peacetime traffic load were the sole criterion of necessity.

MISSION

The mission of naval communications is to provide and maintain reliable, secure, and rapid communications, based on war requirements adequate to meet the needs of naval command, to facilitate administration, and to satisfy as directed, JCS approved Joint requirements.

POLICY

The policy of naval communications is to:

1. Cooperate with the military services and other departments and agencies of the U. S. Government and Allied nations.
2. Encourage development of the amateur and commercial communication activities of the U. S. for the enhancement of their military value and for safeguarding the interests of the nation.
3. Promote the safety of life at sea and in the air, and maintain facilities for adequate communication with the U. S. merchant marine, aircraft over the sea, and appropriate U. S. and foreign communication stations.

PRIMARY CONCEPT AND SOME BASIC PRINCIPLES

The primary concept of naval communications is to meet the requirements of war. Peacetime methods and procedures must be so organized that very little time and effort would be wasted in shifting to an emergency or war status. For this reason the organization, methods, procedures, facilities, and training in the Navy must be adequate to meet war or emergency requirements and must be flexible in order to provide for rapid expansion.

Based on this concept the following principles have been proved under war conditions:

1. Reliability, security, and speed are the three fundamental requirements of naval communications. Reliability is ALWAYS paramount. It must never be sacrificed or lessened to achieve security or speed. Whenever there is a conflict between the demands of security and speed, the one or the other must be sacrificed in the light of the demands of the situation.

2. Success of operations in a large measure depends upon effective communications which require a basic knowledge and appreciation of how, when, and where to send messages.

3. The most detailed instructional publications and the most up-to-date equipment in no way lessen the need for initiative, common sense, and good judgment in the planning and conduct of naval communications.

4. Correct methods of operation and precise use of established procedures are essential to effective communications.

5. Rapid communications must be limited to the minimum required for the successful accomplishment of the operational task assigned. Proper administrative planning and foresight are required to ensure that rapid communications are employed only when other means of communication will not suffice.

6. Proper choice of frequency is of the greatest importance in establishing and maintaining reliable radio communications.

7. Communications media which are susceptible to interception should not be used in wartime when a more secure means will serve.

ELEMENTS OF NAVAL COMMUNICATIONS

In order to carry out the mission stated earlier in this chapter, naval communications has been organized into six major elements, each of which has specific responsibilities contributing to the overall mission. The major elements of naval communications are:

1. The Office of Naval Communications
2. The Naval Security Group
3. The Naval Communication System
4. U. S. Naval Communication System Headquarters Activity
5. Communication Departments of Activities of the Shore Establishment
6. Communication Organizations of the Operating Forces

THE OFFICE OF NAVAL COMMUNICATIONS

The flag officer responsible for supervision and coordination of all naval communications is the Assistant Chief of Naval Operations (Communications)/Director, Naval Communications (ACNO(COMM)/DNC). The Office of Naval Communications is the staff which supports ACNO(COMM)/DNC in the exercise of his duties which include operational, management, administrative, and technical control over naval communications, providing the necessary coordination and planning to insure efficient communications to meet naval requirements.

ACNO(COMM)/DNC has two deputy directors: (1) Deputy DNC for Communications, who coordinates all matters pertaining to communications, and (2) Deputy DNC for Naval Security Group, who has primary cognizance over the Naval Security Group.

THE NAVAL SECURITY GROUP

The direction, administration, and coordination of the operations of the NAVSECGRU are the direct responsibility of the Deputy DNC, NAVSECGRU, who is also designated Director, NAVSECGRU. The principal staff functions for DIRNAVSECGRU are performed by the NAVSECGRU Headquarters, located at the Naval Security Station, Washington, D.C.

Strategically located area headquarters activities have been established to assist DIRNAVSECGRU in the performance of his functions. DIRNAVSECGRUEUR, located in London, coordinates the activities of all NAVSECGRU elements in the European theater. DIRNAVSECGRUPAC, with headquarters in Hawaii, has cognizance over stations in the Pacific area. Activities in the Atlantic area are controlled by DIRNAVSECGRULANT at Norfolk, Virginia.

The NAVSECGRU performs special operations as directed by the Chief of Naval Operations, including the operation of the Navy High Frequency Direction Finding (HFDF) nets; provides for the protection of naval communications by directing the communication security effort, including the provision of cryptographic equipment for the Navy, Marine Corps, and the Coast Guard; administers the Registered Publication System and its Registered Publication Issuing Offices; supervises the naval portion of the Armed Forces Courier Service (ARFCOS), including the manning and operation of specified ARFCOS Transfer Stations; and administers the Naval Reserve Naval Security Group Program.

Most of the NAVSECGRU functions are performed by components of the Group located at naval communication stations or by independent Naval Security Group activities and Naval Security Group detachments.

The head of a Naval Security Group activity may be designated a commanding officer or an officer in charge. Naval Security Group detachments are under an officer in charge and may be assigned to the staffs of fleet commanders in chief, to various joint military commanders, or to naval task force commanders.

THE NAVAL COMMUNICATION SYSTEM

The Naval Communication System is a fixed, integrated global communication network which forms the worldwide framework of naval communications. It is the means by which all other elements of naval communications are linked. The activities of the Naval Communication System manage, operate, and maintain facilities, equipments, devices, and systems necessary to provide requisite communications for the command, operational control, and administration of the Naval Establishment afloat and ashore.

The staff functions necessary for the supervision, administration and coordination of the activities and operations of the Naval Communication System are performed by one of the major elements of naval communications—the Naval Communication System Headquarters Activity.

The Naval Communication System includes the following types of activities:

1. U. S. Naval Communication Station (NAVCOMMSTA)
2. U. S. Naval Radio Station (NAVRADSTA)
3. U. S. Naval Communication Unit (NAVCOMMU)

Naval Communication Stations

A NAVCOMMSTA carries out the mission of the Naval Communication System by providing essential fleet support and fixed communication services for a specific area. Other tasks that may be assigned to a NAVCOMMSTA are the operation and maintenance of one or more of the following: Naval Security Group facilities, communication support facilities for the headquarters of a specific major command, and primary and secondary air operational support facilities. NAVCOMMSTAS are located in the following strategic areas of the world:

Adak, Alaska	*Pearl Harbor, Hawaii
*Balboa, Canal Zone	*Port Lyautey, Morocco
*Finegayan, Guam	San Diego, California
Kami Seya, Japan	*San Francisco, California
Kodiak, Alaska	San Juan, Puerto Rico
London, England	San Miguel, Republic of the Philippines
Newport, Rhode Island	*Washington, D. C.
Norfolk, Virginia	

*Designated as primary communication centers

Figure 3-1 shows the organizational structure of a primary NAVCOMMSTA. Deviations are permitted to meet local situations; the buildings and spaces may vary widely in arrangement according to the location of the station. When a NAVCOMMSTA is near a naval base, it may utilize the public works and supply departments of the naval base. Sometimes departments are combined when one or all are not of sufficient size to warrant separate departments. At some stations the administration and personnel departments are combined for this reason. The transmitting stations and receiving facilities are often located several miles from the center of the activity.

The commanding officer of a NAVCOMMSTA is usually of the rank of captain or commander. He is responsible for the successful fulfillment of the station's mission. The commanding officer is assisted in the discharge of his responsibilities by an executive officer. The commanding officer is also assisted by a number of department heads who are responsible for such functions as communications, administration, personnel, supply and fiscal, and, when assigned, NAVSECGRU operations.

The executive officer coordinates the activities of the department heads in accordance with the general policies promulgated by the commanding officer. The executive officer organizes the activities of the station; plans the details and procedures of the training and discipline of personnel; and prepares and issues operating orders, notices, and directives as

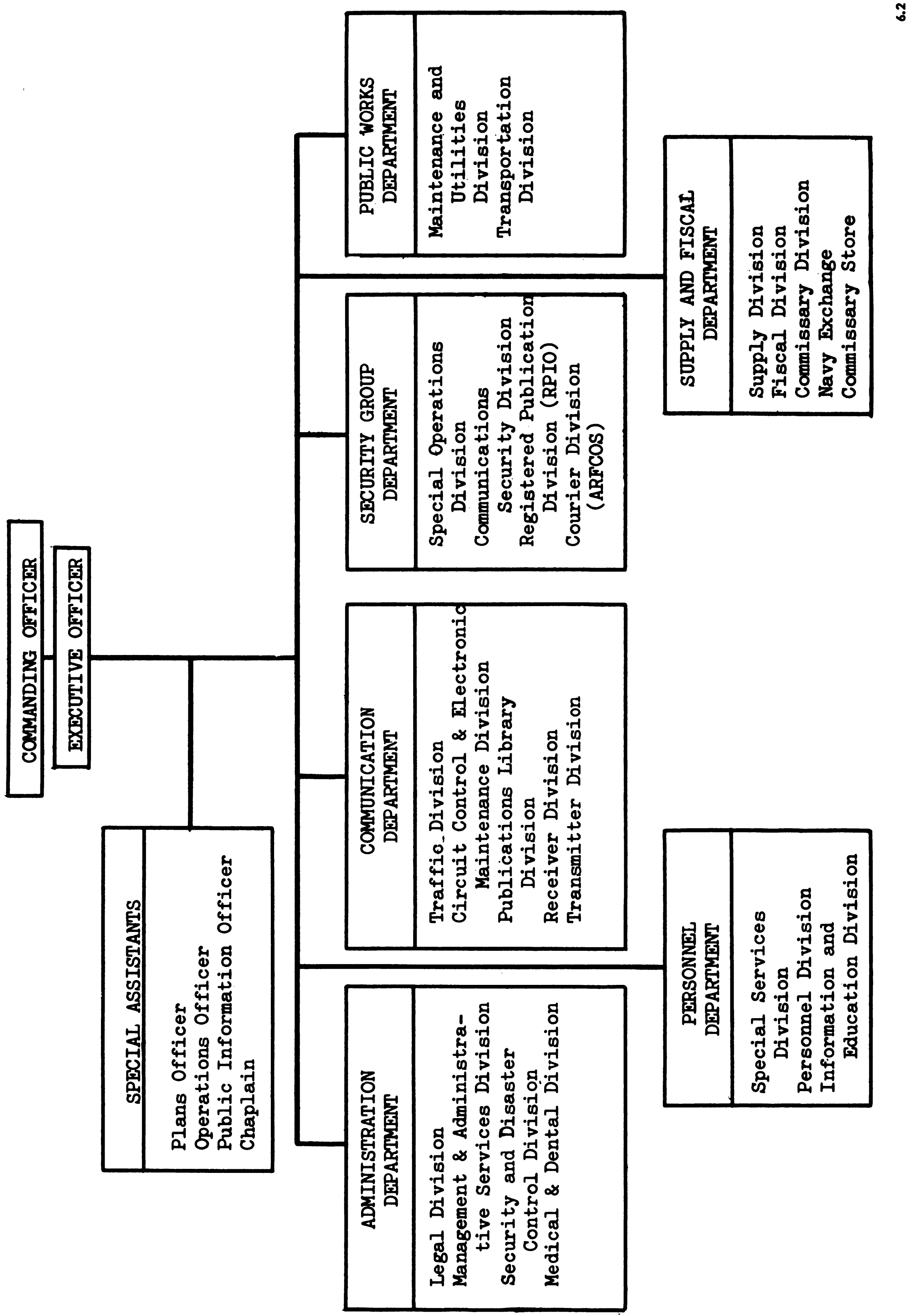


Figure 3-1.—The Organization of a primary NAVCOMMSTA.

required. A typical NAVCOMMSTA has a complement of several hundred personnel—officer, enlisted men, and civilians.

Naval Radio Stations

A NAVRADSTA, generally a remote component of a NAVCOMMSTA, performs radio receiving functions. The transmitting stations are usually located at sites several miles distant from the NAVCOMMSTAS to minimize the possibility of interfering with the radio receiving function.

Naval Communication Units

A NAVCOMMU is usually much smaller, in terms of personnel and facilities, than a NAVCOMMSTA and performs limited or specialized communication functions. It is under an officer in charge rather than a commanding officer. Although most of the work of the Naval Communication System is performed by NAVCOMMSTA, important functions are also performed by the NAVCOMMU.

COMMUNICATION DEPARTMENTS IN THE SHORE ESTABLISHMENT

The organization of the activities of the Shore Establishment generally provides for a communication department. These organizational components of the station or activity which they serve may be located at such activities as naval bases, stations, air stations and facilities, and ammunition depots.

The communication department normally provides local or intra-activity communication services in support of the mission of the parent activity and serves as a link with the worldwide network of the Naval Communication System. The facilities and equipment used by these departments vary in accordance with the requirements of the activity concerned.

Normally the communication department of an activity of the shore establishment provides for a small communication center, consisting of a message center and a cryptocenter. However, when required, it may also provide for a tape relay station, wire and radio center, control center, radio transmitting and receiving facilities, and a visual signal station.

U. S. NAVAL COMMUNICATION SYSTEM HEADQUARTERS ACTIVITY

The U. S. Naval Communication System Headquarters Activity supervises, administers, and coordinates the activities of the Naval Communication System as directed by the ACNO (COMM)/DNC. This activity is located at the Naval Security Station, 3801 Nebraska Avenue, Washington, D. C.

COMMUNICATIONS AFLOAT

Every communication organization of the Operating Forces is an integrated unit of that command. The commanding officer or commander has direct control of communications through the ship or staff organization. The communication organization participates in the exercise of command by the transmission and reception of signals and messages.

All external communications are a function of the operations department of a ship. In a large ship the operations department will contain signal and radio divisions; in a small ship these divisions may be combined, or there may be only an operations division. The number, size, and arrangement of the communication spaces of a ship will vary with the size and mission of the particular ship. In a large ship, the functions of the communication organization will be performed in the following spaces: message center, radio spaces, remote control facilities, cryptocenter, and visual signal spaces.

DEFENSE COMMUNICATIONS

You have learned the mission, policy, and the basic principles of naval communications; you have learned the six organizational elements which comprise the naval communications effort. It is also important for you to know that naval communications, in addition to Navy-wide functions, are a part of the total communication effort of the Department of Defense.

The Defense Communications Agency (DCA) and the Defense Communications System (DCS), established in May 1960, are both under the direction, authority, and control of the Secretary of Defense. The DCA, which is the management agency for DCS, is under the direction and control of the Chief of the Defense Communications Agency. The Chief of the Agency, a military officer of General or Flag rank, is directly responsible to the Secretary of Defense through the Joint Chiefs of Staff.

The mission of the Defense Communications Agency is to exercise operational control and supervision of the Defense Communications System to assure that Defense and Military long-haul, point-to-point communications needs are adequately met in a single Defense Communications System within the Department of Defense. This includes the supervision of the operation of special-purpose communication facilities required to support the President, the Secretary of Defense, and the Joint Chiefs of Staff in providing communications for the exercise of command.

The DCS comprises the major portions of the individual Army, Navy, and Air Force worldwide, long-haul, point-to-point communications complexes brought together under a single system to provide a single-system response to the Department of Defense worldwide communications needs. The DCS does not include: tactical communications which are self-contained within tactical organizations, and land, ship, or airborne terminal facilities for broadcast, ship-to-ship, ship-to-shore, and ground-air-ground systems. The military departments continue to maintain and operate their assigned portions of the DCS, but are responsive to the overall operational control and supervision of the DCA.

The Naval Communication System Headquarters Activity maintains direct liaison with the DCA in matters affecting the operation of certain segments of naval communications and coordinates and supervises the operation of those facilities of the DCS for which operational control has been delegated to the Navy. For the most part, those facilities are organizational components of the Naval Communication System.

QUIZ

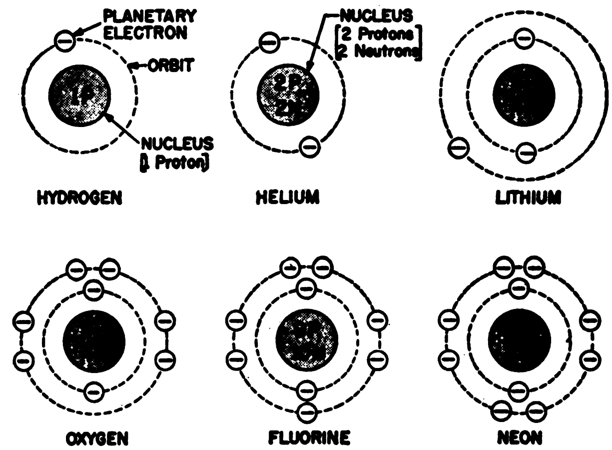
1. The global communications network which comprises a portion of the Navy communications effort is called the ________.
2. What are the three fundamental requirements of naval communications?
3. What fundamental requirement is a primary concern of the NAVSECGRU?
4. Which fundamental requirement is never sacrificed for any other?
5. What is the title of the flag officer responsible for the supervision and coordination of all naval communications?
6. The DIRNAVSECGRU is also designated as ________.
7. Which element of naval communications is responsible for administering the Registered Publication System?
8. Most NAVSECGRU functions are performed by NAVSECGRU components located at ________ or independent NAVSECGRU ________ and ________.
9. The communication facilities of each naval shore station or activity will normally consist of a communication center which includes a ________ and a ________.
10. Name three types of activities included in the Naval Communication System.
11. Why are naval radio stations, which perform transmitting functions, located at sites which are generally remote from naval communication stations?
12. The head of a naval communication unit would be designated a/an ________.
13. Which department of a primary naval communication station includes the RPIO division?
14. Give the correct name and authorized abbreviation of the organization which provides special-purpose communication facilities to support the President and others in the Department of Defense.
15. Which element of naval communications provides liaison with the Defense Communications Agency?

CHAPTER 4

INTRODUCTION TO ELECTRONICS

CT T Branch personnel will spend the greater part of their Navy careers working with electronic and electromechanical equipment. Equipment designated "electronic" is generally considered to have no moving parts, being composed of electronic components such as resistors, capacitors, transistors, and vacuum tubes. Electromechanical equipment is a combination of electronic equipment and mechanical equipment containing moving parts as well as electronic components.

In this chapter, you will study basic electronic theory. Although you will be concerned primarily with the operation of electronic equipment, your task will be much easier if you know the fundamentals of electricity and electronics that were considered when the equipment was designed. Once these fundamentals are understood, you will find it easier to learn why it is necessary for an operator to push a button, turn a particular knob, or open or close a certain switch in order to obtain the desired results from his equipment.



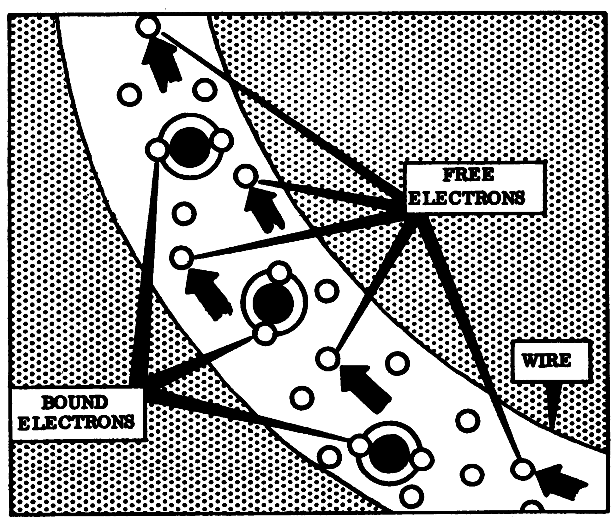
13.1

Figure 4-1.—Atomic structure of elements.

D-C ELECTRICITY

CURRENT

To understand how current flows in an electrical circuit, you need a knowledge of the electrical nature of matter. All matter is made up of minute particles called atoms. Each atom has one or more small negative charges called ELECTRONS in orbit around the center, or nucleus, of the atom. The nucleus is made up of positively charged particles called PROTONS and, in most cases, uncharged particles called NEUTRONS. Generally speaking, the number of electrons and protons in an atom are balanced in number. This relationship is shown in figure 4-1.



13.2

Figure 4-2.—Current flow.

In some materials, electrons can be made to move from one atom to another. Motion of electrons from atom to atom makes up electric CURRENT. Figure 4-2 illustrates this effect. Notice that the electrons are moving from atom to atom in a particular direction. The direction of the current flow is defined as the direction of electron movement.

Some materials are composed of atoms whose electrons are easily moved from atom to atom; these materials are known as CONDUCTORS. Examples of good conductors are silver, aluminum, and copper. Other materials are composed of atoms that do not allow their electrons to be as easily moved from atom to atom as in conductors. Such materials are used as electrical RESISTORS. There are still other materials which do not conduct significant amounts of electric currents. These materials are known as INSULATORS. Some examples of good insulators are mica, glass, and porcelain.

Determining the amount of current flowing in a conductor, such as a copper wire, is accomplished by measuring the number of electrons that pass a point in the wire per given amount of time. The practical unit of electric current is the AMPERE. The instrument used to measure current is called the AMMETER, and is placed in the current path. That is, the meter is placed in the circuit in such a way that the current must flow through the meter, thereby making the meter a part of the circuit. Figure 4-3 shows the arrangement of an ammeter in a circuit.

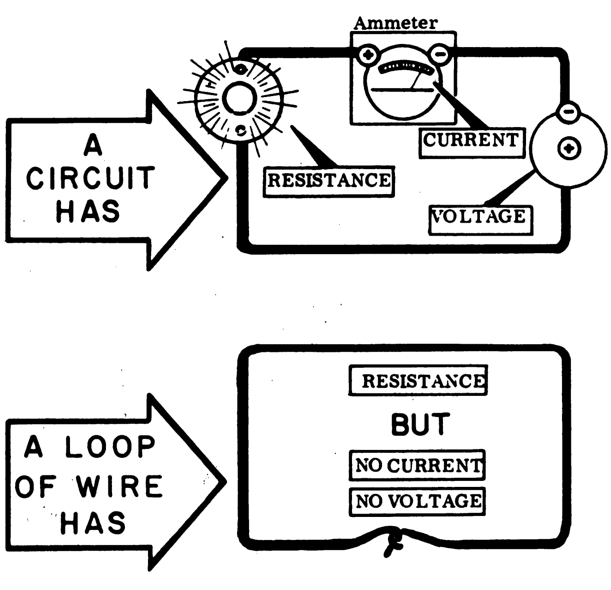


Figure 4-3.—Current in a circuit.

VOLTAGE

In order for current to flow through a conductor, there must exist between the ends of the conductor some type of force which will cause the electrons to move from atom to atom. To explain this force, consider bodies of matter which contain an excess or deficiency of electrons. If an excess of electrons exists, the body is said to have a negative charge. Conversely, if a deficiency exists, the body is said to have a positive charge. When two bodies have different charges, one more negatively or positively charged than the other, an electrical force exists between these bodies. This force is called VOLTAGE and is the force that causes electrons to move in a conductor as an electric current. Voltage is also called (1) ELECTROMOTIVE FORCE (EMF) and (2) a DIFFERENCE IN POTENTIAL.

When a difference in potential exists between two charged bodies that are connected by a conductor, electrons will flow along the conductor. This flow will be from the negatively charged body to the positively charged body until the two charges are equalized and the potential difference no longer exists.

Common sources of direct-current potential (batteries, dry cells, and generators) have one terminal marked negative (-) and the other positive (+). When a conductor is placed between the two terminals, electric current will flow from the negative terminal, through the conductor, to the positive terminal.

The practical unit of potential difference is the VOLT, which is measured with an instrument called the VOLTMETER. The probes of the voltmeter are placed across the two points where the potential difference is to be measured. Figure 4-4 shows a voltmeter measuring the voltage across the two terminals of a light bulb.

Resistance

Every material offers some RESISTANCE, or opposition, to the flow of electric current through it. A good conductor such as copper offers very little resistance. An insulator such as glass offers very high resistance. Since all components in a circuit offer resistance in varying degrees, a knowledge of the amount of resistance is very important.

In general, the amount of resistance in a circuit depends upon the physical size and the type of materials which make up the components in the circuit. The resistance of a wire depends directly on its length and inversely on its

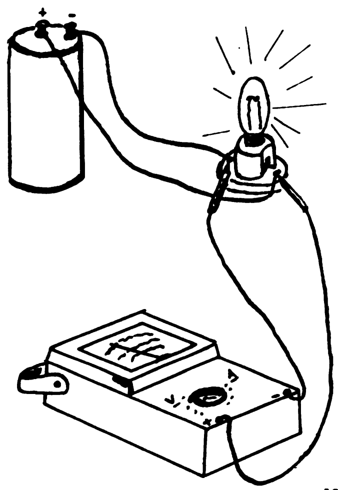


Figure 4-4.—Voltmeter connections.

diameter; that is, the longer the wire, the greater the resistance; the larger the diameter, the lower the resistance. Temperature also affects the resistance of electrical conductors to some extent. In most conductors, the resistance increases as the temperature increases.

To make a circuit function properly, it is often necessary to add or vary the amount of resistance. This is accomplished through the use of manufactured circuit parts containing definite amounts of resistance. These parts are called RESISTORS; their resistance is measured in a practical unit called the OHM. The instrument used to measure resistance is called an OHMMETER. When ohmmeters are used, it is usually necessary to physically disconnect from the circuit the resistance being measured.

READING CIRCUIT DIAGRAMS

To facilitate the study of voltage, resistance, and current in an electric circuit, it is customary to show the electrical components and their interconnecting wires by using schematic circuit diagrams. When diagramming electric circuits, it would be very difficult and time consuming to show each component as an actual picture. Therefore, a system of standard symbols is used in electrical drawings, each symbol representing a particular kind of component. These symbols represent a universal language which is readily understood throughout the world.

The most common symbols used in circuit diagrams are illustrated in table 4-1. As you study this chapter, it will be helpful to refer to this table. Using the table for reference, you will soon learn most of the symbols and how they are used. Although you are not normally required to be able to repair electronic equipment, a knowledge of electrical symbols, plus the ability to "read" simple electrical drawings, will make it much easier for you to understand what is occurring when you operate or adjust a particular piece of equipment in the performance of your duties.

In table 4-1, you will notice several symbols quite similar in appearance to a resistor—the rheostat, potentiometer, and variable resistor. These components are merely special types of resistors.

THE SIMPLE ELECTRIC CIRCUIT

Figure 4-5 is a drawing of a simple electric circuit showing a lamp connected to a power source, which in this case is a dry cell battery. As you learned in the first part of this chapter, whenever a difference of potential exists between components, or whenever two unequal charges are connected by a conductor, current will flow through the completed pathway. In the circuit in figure 4-5, current will flow from the negative terminal of the dry cell, through the lamp, and return to the positive terminal of the dry cell.

As long as the dry cell remains charged, and as long as the pathway for the current flow is unbroken, electrons will move through the components and the circuit is said to be CLOSED. However, if the path is broken at any point, it is an OPEN circuit and no current flows.

The physical pathway for the current flow is actually the circuit, which includes all components. Assuming a constant voltage, the total resistance controls the amount of current flowing through the circuit. If you measure the voltage and current in the circuit, it is a simple process to determine the resistance. In fact, if you know any two of the three quantities—voltage, current, or resistance—you can determine the value of the third quantity without actual measurement. This is done mathematically by the use of OHM's LAW. This law, which is discussed in the following paragraphs, was developed by the German physicist, G.S. Ohm, in the first part of the 19th century.

Table 4-1.—Electrical symbols.

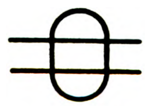
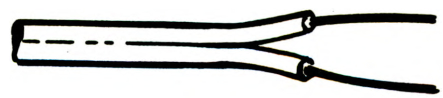
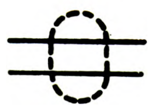
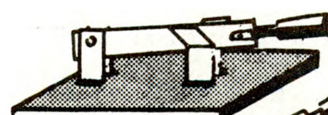
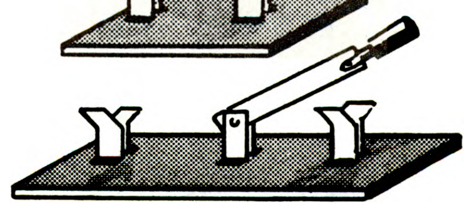
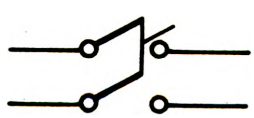
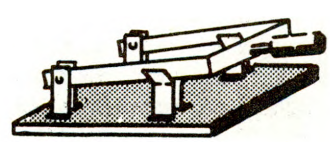
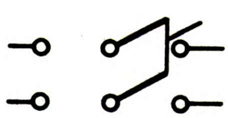
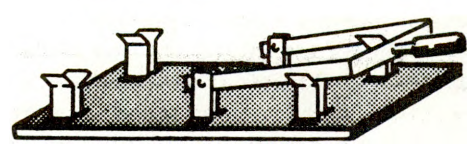
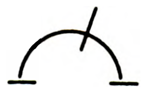
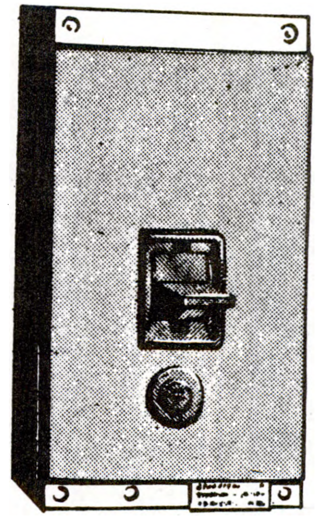
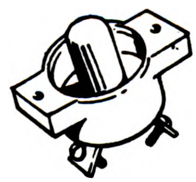
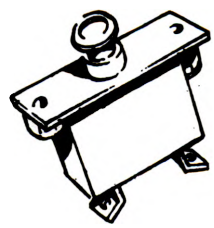
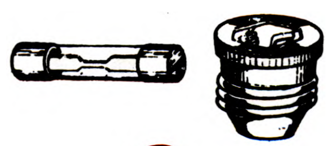
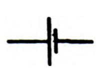
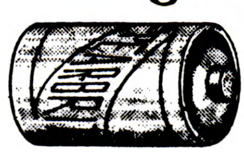
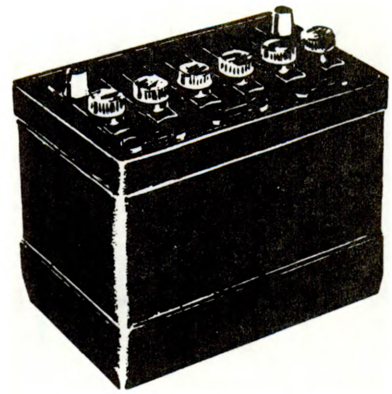
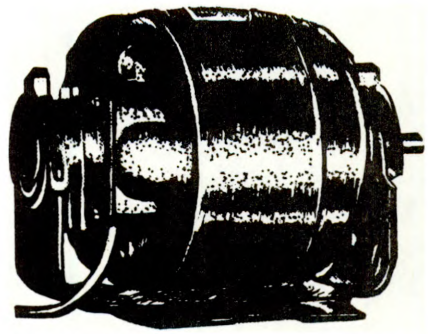
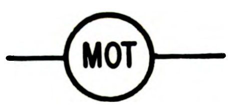
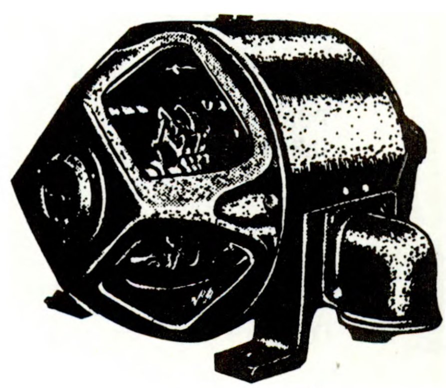
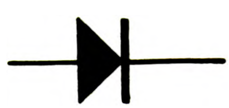
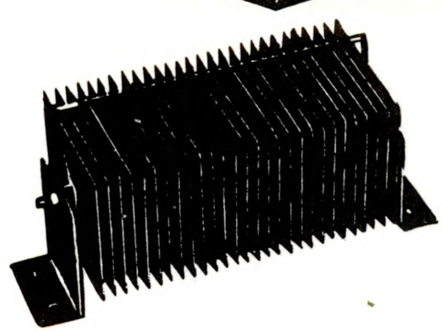
Name	Symbol	Picture
CONNECTION		
NO CONNECTION		
GROUND		
TWO-CONDUCTOR CABLE		
SHIELDED TWO-CONDUCTOR CABLE		
COAXIAL CABLE		
SINGLE POLE SINGLE THROW SWITCH		
SINGLE POLE DOUBLE THROW SWITCH		
DOUBLE POLE SINGLE THROW SWITCH		
DOUBLE POLE DOUBLE THROW SWITCH		

Table 4-1.—Electrical symbols—Continued.

Name	Symbol	Picture
SWITCH CIRCUIT BREAKER		
PUSH CIRCUIT BREAKER		
PUSH-PULL CIRCUIT BREAKER		
FUSE		
LAMP		
CELL (LONG VERTICAL LINE IS ALWAYS POSITIVE)		

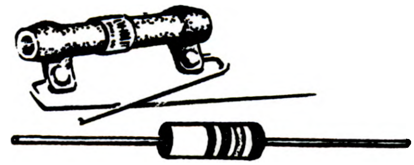
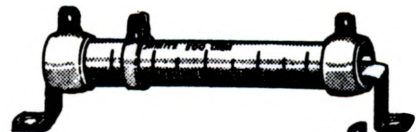
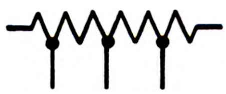
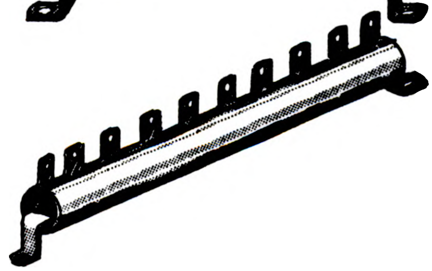
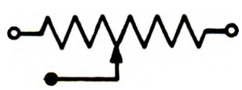
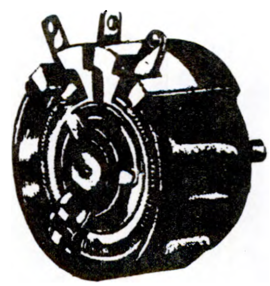
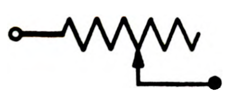
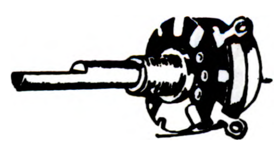
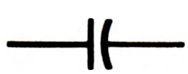
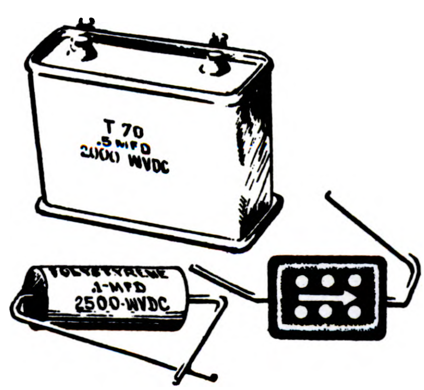
13.6

Table 4-1.—Electrical symbols—Continued.

Name	Symbol	Picture
BATTERY		
GENERATOR (MAY BE A-C OR D-C, DEPENDING ON HOW LABELED)		
MOTOR (MAY BE A-C OR D-C DEPENDING ON HOW LABELED)		
METALLIC RECTIFIER		

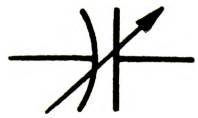
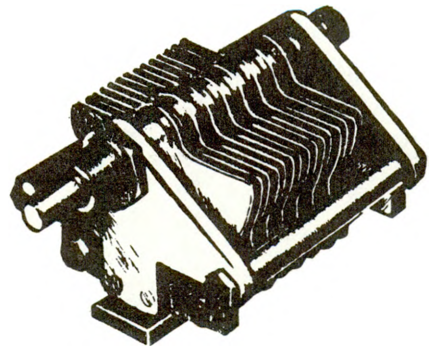
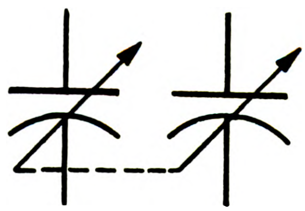
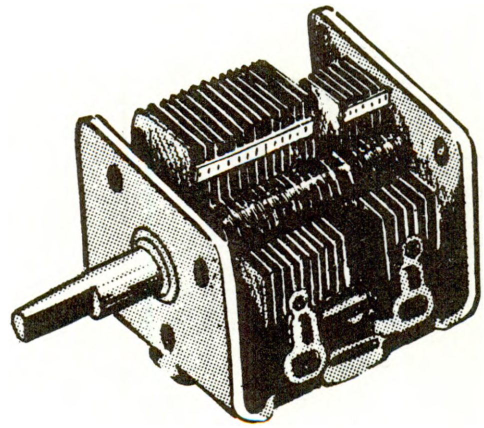
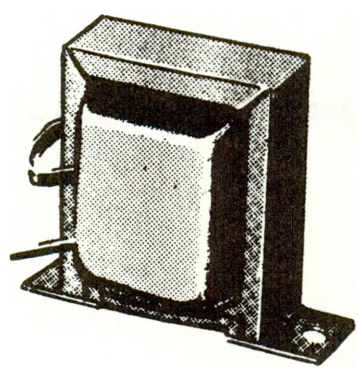
13.7

Table 4-1.—Electrical symbols—Continued.

Name	Symbol	Picture
RESISTOR		
VARIABLE RESISTOR		
TAPPED RESISTOR		
POTENTIOMETER		
RHEOSTAT		
CAPACITOR, FIXED		

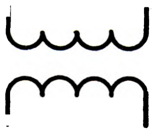
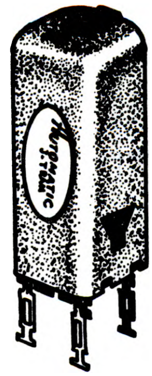
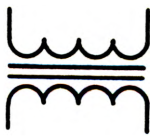
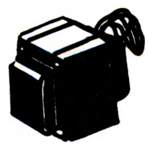
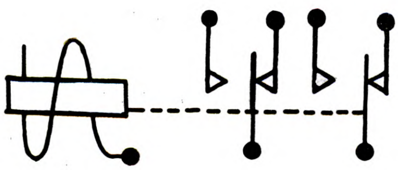
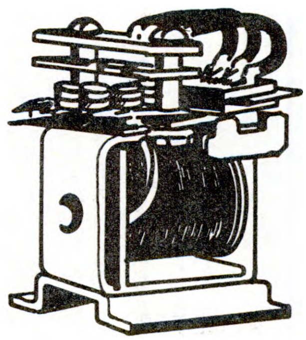
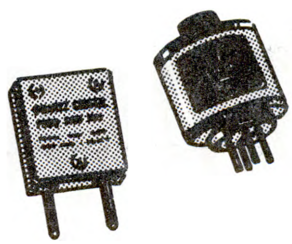
13.8

Table 4-1.—Electrical symbols—Continued.

Name	Symbol	Picture
CAPACITOR, VARIABLE		
CAPACITOR, GANGED		
INDUCTOR, AIR CORE		
INDUCTOR, IRON CORE		

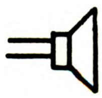
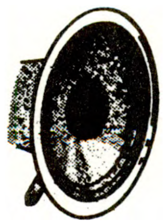
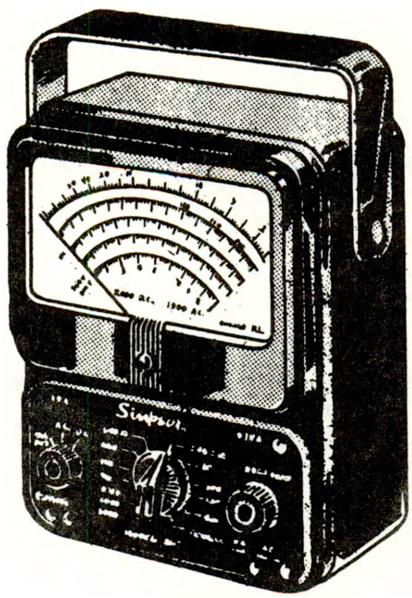
13.9

Table 4-1.—Electrical symbols—Continued.

Name	Symbol	Picture
TRANSFORMER, AIR CORE		
TRANSFORMER, IRON CORE		
RELAY COIL WITH CONTACTS		
PIEZOELECTRIC CRYSTAL UNIT		

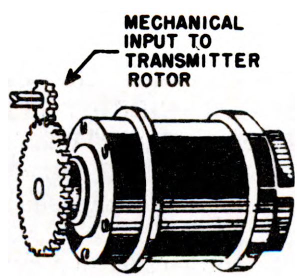
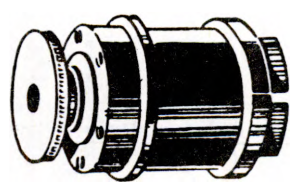
13.10

Table 4-1.—Electrical symbols—Continued.

Name	Symbol	Picture
HEADPHONES		
MICROPHONE		 
LOUDSPEAKER		
VOLTMETER		
AMMETER		
OHMMETER		

13.11

Table 4-1.—Electrical symbols—Continued.

Name	Symbol	Picture
THERMAL RESISTOR (BALLAST LAMP)		
VOLTAGE REGULATOR OR GLOW TUBE (d-c TYPE)		
GLOW LAMP (COLD CATHODE) a-c TYPE		
SYNCHRO TRANSMITTER RECEIVER OR CONTROL TRANSFORMER		
DIFFERENTIAL TRANSMITTER OR RECEIVER		

13.12

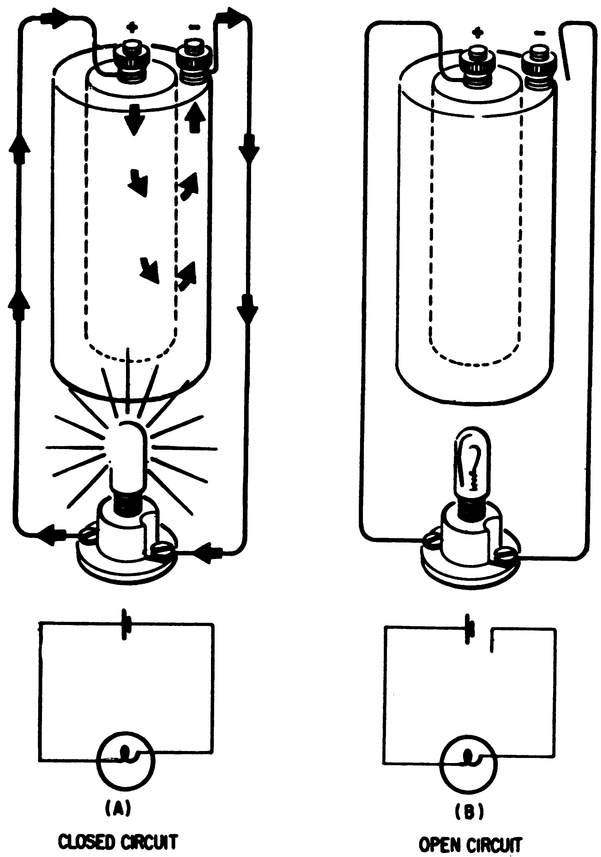


Figure 4-5.—(A) Simple electric circuit (closed).
(B) Simple electric circuit (open).

OHM'S LAW

The law is stated as follows: THE CURRENT (I) IN ANY ELECTRICAL CIRCUIT IS EQUAL TO THE VOLTAGE (E) ACROSS THE CIRCUIT DIVIDED BY THE RESISTANCE (R) OF THE CIRCUIT. The law may be expressed by any one of three equations:

A. Current equals voltage divided by resistance

$$I = \frac{E}{R}$$

B. Resistance equals voltage divided by current

$$R = \frac{E}{I}$$

C. Voltage equals current times resistance

$$E = I \times R$$

where I is the intensity of the current in amperes, E the difference in potential in volts, and R the resistance in ohms.

Application of Ohm's Law

In the diagram shown in figure 4-6, if the voltage (E) read on the voltmeter (V) is 12 volts, and the current (I) indicated by the ammeter (A) is 2 amperes, then the resistance (R) will equal 12 divided by 2, or 6 ohms.

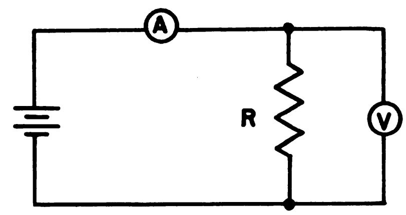


Figure 4-6.—A simple schematic diagram.

Or, if you know that the resistance is 6 ohms, and the ammeter reads 2 amperes, then the voltage in the circuit must be 2 times 6, or 12 volts. And finally, if the voltmeter reads 12 volts, and the resistor has a value of 6 ohms, you know that the ammeter will read a current of 12 divided by 6, or 2 amperes.

Try a practical problem on your own using one of the Ohm's law equations shown above. How much current (I) will flow if a small light bulb containing 27.5 ohms of resistance (R) is connected in a circuit with a 110 volt (E) power source? Use the equation $I = \frac{E}{R}$, since I is the unknown quantity. Your answer should be 4 amperes.

SERIES AND PARALLEL CIRCUITS

There are many different types of circuits used in electrical equipment. If a circuit is arranged so that the electrons have only one possible path through the various parts, the circuit is called a SERIES circuit. If there are two or more paths for current flow, the circuit is called a PARALLEL circuit. The following paragraphs explain the methods of calculating circuit resistance of series and parallel circuits. KIRCHHOFF'S LAW OF VOLTAGES is first discussed to show the conventional method of analyzing series circuits. The remainder of the explanation is based on applications of Ohm's law.

Series Circuits

All conductors have resistance; therefore a circuit made up of nothing but conductors would have some resistance, however small it might be. In circuits containing long conductors, through which an appreciable amount of current is drawn, the resistance of the conductors becomes important. However, for our purposes the resistance of the connecting wires is neglected; only the resistance of each resistor element (which may be any device that has resistance) is considered.

Kirchhoff's Law of Voltages states that the algebraic sum of all the voltages in any complete electric circuit is equal to zero. In other words, the sum of all positive voltages MUST BE equal to the sum of all negative voltages. For any voltage rise there must be an equal voltage drop somewhere in the circuit. A voltage rise (potential source) is usually regarded as the power supply, such as a battery. A voltage drop is usually regarded as the load, such as a resistor. A voltage drop may be distributed across a number of resistive elements, such as a string of lamps or several resistors. However, according to Kirchhoff's Law, the sum of their individual voltage drops MUST ALWAYS equal the voltage rise supplied by the power source.

The statement of Kirchhoff's law can be translated into a truthful equation, from which many unknown circuit factors may be determined. Referring to figure 4-7, note that the source voltage E_S is equal to the sum of the three load voltages E_1, E_2, and E_3. In a formula, this would be written

$$E_s = E_1 + E_2 + E_3$$

This formula may also be transposed to demonstrate that the algebraic sum of all the voltages is zero, as follows:

$$E_s - E_1 - E_2 - E_3 = 0$$

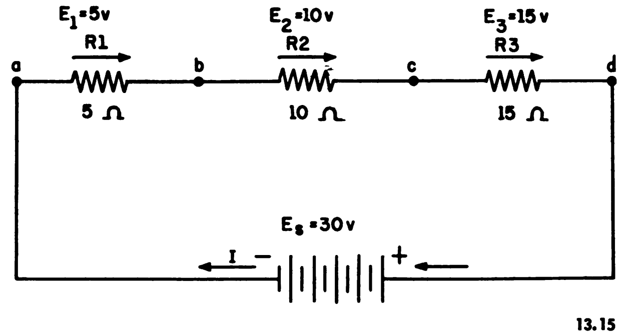


Figure 4-7.—Series circuit for demonstrating Kirchhoff's voltage law.

In order to solve problems applicable to figure 4-7, and others similar to it, the following procedure is suggested:

1. Note the polarity of the source emf (E_S) and indicate the electron flow around the circuit. Electron flow is out from the negative terminal of the source, through the load, and back to the positive terminal of the source. In the example being considered, the arrows indicate electron flow in a clockwise direction around the circuit.
2. To apply Kirchhoff's law, it is necessary to establish a voltage equation. The equation is developed by tracing around the circuit and noting the voltage absorbed (called voltage drop) across each part of the circuit encountered by the trace, and expressing the sum of these voltages according to the voltage law. It is important that the trace be made around a closed circuit, and that it encircle the circuit only once. Thus, a point is arbitrarily selected at which to start the trace. The trace is then made, and the point at which the trace is completed coincides with the starting point.
3. Sources of emf are preceded by a PLUS sign if, in tracing through the source, the first terminal encountered is positive; if the first terminal is negative, the emf is preceded by a MINUS sign.
4. Voltage drops along wires and across resistors (loads) are preceded by a minus sign if the trace is in the assumed direction of electron flow; if in the opposite direction the sign is plus.
5. When solving for circuit current, if the assumed direction of electron flow is incorrect, the error will be indicated by a minus sign preceding the current. The magnitude of the current will not be affected.

The preceding rules may be applied to the example of figure 4-7 as follows:

1. The left terminal of the battery is negative, the right terminal is positive, and electron flow is clockwise around the circuit.
2. The trace may arbitrarily be started at the positive terminal of the source and continued clockwise through the source to its negative terminal. From this point the trace is continued around the circuit to a, b, c, d, and back to the positive terminal, thus completing the trace once around the entire closed circuit.
3. The first term of the voltage equation is E_s.
4. The second, third, and fourth terms are respectively, $-E_1$, $-E_2$, and $-E_3$. Their algebraic sum is equated to zero as follows:

$$E_s - E_1 - E_2 - E_3 = 0$$

Transposing the voltage equation and solving for E_s,

$$E_s = E_1 + E_2 + E_3.$$

Since E = IR from Ohm's law, the voltage drop across each resistor may be expressed in terms of the current and resistance of the individual resistor as follows:

$$E_s = IR_1 + IR_2 + IR_3,$$

where R_1, R_2, and R_3 are the resistances, E_s is the source voltage, and I is the circuit current.

E_s may be expressed in terms of the circuit current and total resistance as IR_t. Substituting IR_t for E_s, the voltage equation becomes

$$IR_t = IR_1 + IR_2 + IR_3.$$

Since there is only one path for current in the series circuit, the total current is the same in all parts of the circuit. Dividing both sides of the voltage equation by the common factor I, an expression is derived for the total resistance of the circuit:

$$R_t = R_1 + R_2 + R_3.$$

Therefore, in series circuits, THE TOTAL RESISTANCE IS THE SUM OF THE RESISTANCES OF THE INDIVIDUAL PARTS OF THE CIRCUIT.

In the example of figure 4-7, the total resistance is

$$5 + 10 + 15 = 30 \text{ ohms}.$$

The total current may be found by applying the equation

$$I_t = \frac{E_t}{R_t} = \frac{30}{30} = 1 \text{ ampere}.$$

Parallel Circuits

In the parallel circuit, each load (or branch), is connected directly across the voltage source, as shown in figure 4-8. As a result, there are as many separate paths for current flow as there are branches. When additional loads are added in the series circuit, total resistance is increased and total current decreased. In the parallel circuit, just the opposite is true. As loads are added in parallel, they simply become additional paths for current flow; therefore, the total current supplied by the source increases as they are added. If total current is increased, total resistance must have been decreased. Therefore, as branches are added in parallel, regardless of their resistances, the total resistance as seen from the voltage source DECREASES.

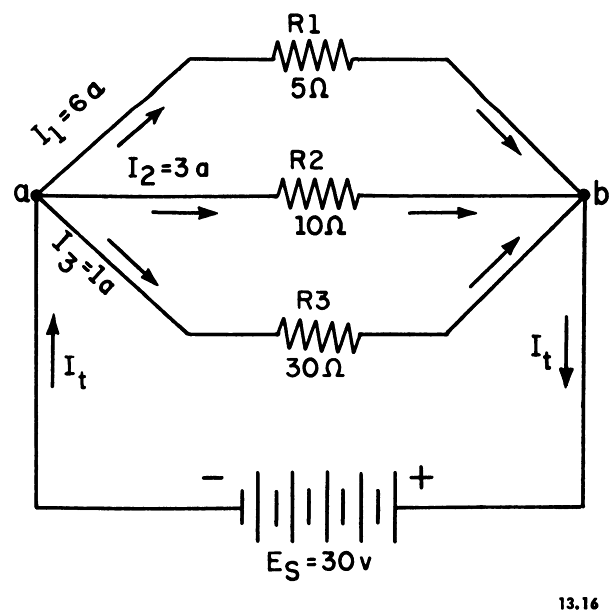


Figure 4-8.—Resistors in parallel.

The voltage across all branches of a parallel circuit is the same because all branches are connected directly to the voltage source. Consequently, the current through each branch is independent of the others and depends only on the resistance of the particular branch at a given voltage. The current through each branch may thus be computed separately by dividing its resistance into the source voltage. The branch currents in figure 4-8 are:

$$I_1 = \frac{E_s}{R_1} = \frac{30}{5} = 6 \text{ amperes,}$$

$$I_2 = \frac{E_s}{R_2} = \frac{30}{10} = 3 \text{ amperes,}$$

$$\text{and} \quad I_3 = \frac{E_s}{R_3} = \frac{30}{30} = 1 \text{ ampere.}$$

The total current, I_t, of the parallel circuit is equal to the sum of the currents through the individual branches. In this case, the total current is

$$I_t = I_1 + I_2 + I_3 = 6 + 3 + 1 = 10 \text{ amperes.}$$

In order to find the equivalent, or total resistance R_t (for simplicity R_t is used instead of R_{eq}), of the combination shown in figure 4-8, Ohm's law is first used to find each of the currents (I_t, I_1, I_2, and I_3). Substituting the Ohm's law equivalent for current ($\frac{E}{R}$) in the current equation, that equation ($I_t = I_1 + I_2 + I_3$) becomes

$$\frac{E_s}{R_t} = \frac{E_s}{R_1} + \frac{E_s}{R_2} + \frac{E_s}{R_3}.$$

This introduces the factor R_t into the equation, which is the quantity you are attempting to determine. Since E_s appears as the numerator in all four factors, it is divided out, and the equation then contains only the desired factor R_t and the known quantities—R_1, R_2, and R_3:

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3},$$

$$= \frac{1}{5} + \frac{1}{10} + \frac{1}{30},$$

$$= 0.2 + 0.1 + 0.033,$$

$$\frac{1}{R_t} = 0.333,$$

$$R_t = \frac{1}{0.333},$$

$$= 3 \text{ ohms (approx).}$$

A useful rule to remember in computing the equivalent resistance of a d-c parallel circuit is that THE TOTAL RESISTANCE IS ALWAYS LESS THAN THE SMALLEST RESISTANCE OF ANY OF THE BRANCHES.

There are two shortcuts that may be used in solving for the equivalent resistance of a parallel circuit.

The first applies only to any number of parallel resistors all of which have THE SAME VALUE OF RESISTANCE. The equivalent resistance is determined by dividing the resistance of one resistor by the number of resistors in parallel. Thus, the equivalent resistance of five 10-ohm resistors connected in parallel is

$$R_t = \frac{10}{5} = 2 \text{ ohms.}$$

The second shortcut applies when two, and only two, resistors of different value are connected in parallel. The equivalent resistance is equal to their product divided by their sum. For example, if two resistors having resistances of 3 ohms and 6 ohms are connected in parallel, the equivalent resistance is

$$R_t = \frac{R_1 \quad R_2}{R_1 + R_2} = \frac{3 \times 6}{3 + 6} = \frac{18}{9} = 2 \text{ ohms}$$

In addition to adding the individual branch currents to obtain the total current in a parallel circuit, the total current may be found directly by dividing the applied voltage by the equivalent resistance, R_t. For example, in figure 4-8

$$I_t = \frac{E_s}{R_t} = \frac{30}{3} = 10 \text{ amperes.}$$

POWER

You have perhaps noticed that when an electric current is passed through a resistance, such as an ordinary light bulb, the resistance material becomes warm. When electric current passes through resistance, the rate at which heat is lost is referred to as power.

The standard unit of electrical power is the WATT. The power, in watts, in a d-c circuit is equal to the product of the emf in volts and the current in amperes—P (watts) = EI. Using Ohm's law, E = IR, and substituting this expression for E in the power equation, we find the relationship P (watts) = I^2R. By using the Ohm's law equation $I = \frac{E}{R}$, we find that power can also be expressed as P (watts) = $\frac{E^2}{R}$. Consider the following examples:

1. What is the power required for a 110-volt light bulb that draws a current of 0.91 ampere?

Substitute in the equation—

$$P = EI = 110 \times 0.91 = 100 \text{ watts.}$$

2. What is the power supplied to a 20-ohm load if the current through it is 3 amperes?

Substitute in the equation—

$$P = I^2R = (3)^2 \times 20 = 180 \text{ watts.}$$

3. What is the power supplied to a 100-ohm device if the voltage across it is 50 volts?

Substitute in the equation—

$$P = \frac{E^2}{R} = (50)^2/100 = 25 \text{ watts.}$$

A-C ELECTRICITY

A direct current has been described as the movement of electrons from atom to atom along the conductor. The electrons flow out of the negative terminal of the source, through the load, and back to the positive terminal. The direction of current flow is always one way in all parts of the circuit.

An alternating current consists of electrons that move first in one direction and then in the other. The direction of flow changes periodically. Because most of the theory of electric power and communications deals with currents that surge back and forth in a particular manner known as a sine-wave variation, the sine wave will be discussed in more detail.

SINE WAVES

Figure 4-9 is a plot of an alternating current. The rate of electron flow (current) is plotted vertically and time is plotted horizontally. The horizontal axis represents zero current. Values of current above the horizontal axis represent electron flow in one direction; and values of current below the horizontal axis, electron flow in the other direction. A curve of the form represented in figure 4-9 is called a sine curve. When a quantity such as current varies in this manner, it is said to have sine-wave variation.

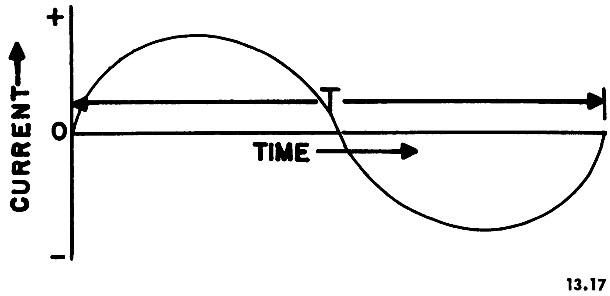


Figure 4-9.—Sine wave.

The CT should become familiar with some of the basic terminology and definitions associated with sine curves. For example, a CYCLE is the term that describes the variation of the current from a starting point on the curve to a maximum value, back to zero, to a maximum value in the opposite direction, and back to a point on the curve that is identical to the starting point. In the figure shown, the entire curve represents one cycle.

The time in seconds, or portions of a second such as milliseconds or microseconds, which is required to complete one cycle is known as the PERIOD of the sine wave, and is labeled T in figure 4-9.

The FREQUENCY of the sine wave is the number of cycles that take place per second. Since the period of the sine wave is defined as the time for one cycle, the reciprocal of the period $(\frac{1}{T})$ is equal to the frequency of the wave.

CAPACITANCE

In simple form, a capacitor (figure 4-10) consists of two parallel metal plates separated by an insulating material such as air, paper, oil, or mica. This insulating material is called a DIELECTRIC. When the plates are shorted (figure 4-10A), no difference in potential exists across them; both plates have the same number of electrons evenly distributed on them. However, if the plates are connected to a battery (figure 4-10B), a transient flow of electrons

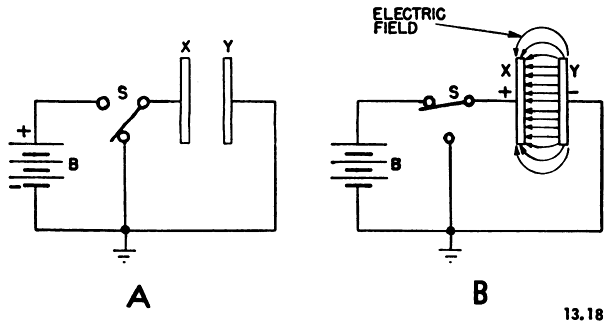


Figure 4-10.—Simple capacitor.
A. Shorted;
B. Charged.

takes place clockwise around the circuit as the capacitor acquires a charge. Because of the battery emf, electrons are removed from plate X and added to plate Y. Thus a voltage is built up across the plates as the capacitor is being charged. When the voltage across the plates equals the battery voltage, electron flow ceases because these two voltages are in opposition. The transient electron flow takes place around the capacitor—not through it. Electrons cannot flow through the capacitor because the dielectric is a good insulator. A capacitor, therefore, cannot pass direct current. If an a-c voltage is placed across the capacitor, an a-c current will flow in the circuit around the capacitor because electrons travel through the circuit, from plate-to-plate, reversing direction just as the voltage across the capacitor reverses direction.

The standard unit of capacitance is the FARAD. Capacitance is usually designated by the letter C. Because the farad is too large for practical use, actual values of capacitance in circuits will usually be given in values of microfarads (10^{-6} farads) or micro-microfarads (10^{-12} farads). The symbol used to show capacitors in circuit diagrams is shown in table 4-1.

CAPACITIVE REACTANCE

The ratio of the a-c voltage across the capacitor to the value of a-c current in the circuit is called CAPACITIVE REACTANCE. The value of reactance will depend on two factors: the value of the capacitance and frequency of the a-c source. Increasing either capacitance or frequency will decrease capacitive reactance.

INDUCTANCE

Whenever a conductor carries electric current, it has been found that a magnetic field is formed around the conductor. The strength of the magnetic field is dependent on the value of current in the conductor, a larger current resulting in a stronger field. It should be noted that if an a-c current is present in the conductor, the resulting magnetic field will be constantly changing—increasing to a maximum value, decreasing to zero, increasing to a maximum value, decreasing, etc. If the conductor is wound to form a coil, the magnetic field inside the coil is much stronger than the magnetic field around a single conductor carrying the same amount of current. It has also been found that if a magnetic material, such as iron, is placed inside the coil, the magnetic field is much stronger than if the coil core were air. This principle is the basis for electromagnets.

Another property associated with conductors and magnetic fields is INDUCTANCE. The principle of induction is this: If a conductor is moved in such a way that it "cuts" a magnetic field, a voltage is induced across the conductor. The results are the same when a magnetic field moves in such a manner that it is cut by a stationary conductor.

The principle of inductance is of considerable importance when there are coils of wire in a-c circuits. Coils have the property of SELF-INDUCTANCE. When an a-c voltage is placed across the coil, the varying magnetic field resulting from the a-c current in the coil causes a voltage to be induced across the coil. This self-induced voltage always opposes the applied voltage and tries to prevent any change in the current flowing through the coil. Because of the property just described, coils are referred to as INDUCTORS. The practical unit of inductance for coils is the HENRY, which is a measure of how well a coil induces a voltage in itself under a standard condition.

When an a-c voltage is placed across a coil, the current is limited because the voltage induced in the coil opposes the applied a-c voltage. Therefore, we can define a reactance associated with coils in a-c circuits in the same manner as for capacitors. The ratio of the a-c voltage across a coil to the value of a-c current through the coil is called the INDUCTIVE REACTANCE of the coil. Inductive reactance depends on the value of inductance of the coil and the frequency of the applied voltage. Reactance increases if either of these two quantities is increased.

Inductors find many uses in communication circuits. The tuning circuits of radio receivers will all contain inductors. For many uses, inductors are known by names that describe their function; for example, r-f chokes and inductive filters.

IMPEDANCE

The total opposition to the flow of alternating current in a circuit that contains resistance and reactance is known as IMPEDANCE. This term is often encountered in dealing with antenna inputs, characteristics of transmission lines and coupling of electronic circuits where there is a necessity for matching the impedances of circuits to obtain maximum efficiency. The symbol for impedance is the letter Z.

In a-c circuits, voltage, current, and impedance are related by an $E = IZ$ relationship similar to the Ohm's law relationship, $E = IR$, for d-c circuits. However, a-c voltage, a-c current, and impedance are vector quantities which require special techniques for computation. They cannot be added, subtracted, multiplied, and divided in the algebraic manner used in d-c calculations. This is also true in combining resistances and reactances to calculate values of impedance. Since vector calculations are beyond the scope of this training course, a discussion of a-c circuit calculations has not been included.

TRANSFORMERS

Other electrical components that are commonly found in a-c circuits are TRANSFORMERS. Transformers are closely related to inductors in that transformers consist of coils and operate on the principle of induction. A simple transformer is two coils placed near each other in such a manner that when an a-c voltage is placed across one coil, called the PRIMARY, the varying magnetic field that results from this voltage is cut by the second coil called the SECONDARY. Because the second coil, in effect, cuts a moving magnetic field, it will have a voltage induced in it. By varying such factors as the ratio of turns on the two coils and the usage of the same core or separate cores, it is possible to make the secondary voltage have any desired amplitude (within practical limits).

Transformers may be used to step up or to step down voltage. They can also be used to step up or to step down current. However, both these actions cannot be performed at the same time. If there is an increase in voltage from primary to a secondary, there will be a corresponding decrease in current and vice versa.

Transformers are often designated by names that actually describe their circuit functions—input transformers, output transformers, and audio transformers.

TUNED CIRCUITS

A CT will often encounter the term "tuned circuits" in his association with electronic equipment. For example an operator "tunes" his receiver to a frequency. Although it is beyond the scope of this manual to explain the theory of what happens within a circuit when it is tuned, the CT T should know the characteristics and some of the uses of the two basic types of tuned circuits.

When capacitance and inductance were discussed earlier in this chapter, it was noted that both capacitive reactance and inductive reactance depend upon frequency. When capacitance and inductance are combined in an a-c circuit, they interact in such a way that there will be one particular frequency at which the impedance of the combination is either significantly higher or lower than at any other frequency, depending upon the type of circuit in use. This particular frequency is called the RESONANT FREQUENCY. When the inductance-capacitance combination is fed a signal at the resonant frequency, the circuit is said to be at RESONANCE. The phenomenon of resonance always occurs at the frequency which makes the value of inductive reactance in the circuit exactly equal to the value of capacitive reactance.

Series-Tuned Circuits

If a capacitor and an inductor are placed in series, the combination is known as a SERIES-TUNED CIRCUIT. (See figure 4-11.) THE CHARACTERISTIC OF A SERIES-TUNED CIRCUIT IS THAT, AT ITS RESONANT FREQUENCY, THE IMPEDANCE OF THE CIRCUIT IS MINIMUM. At this point let us consider what the effect would be if a series-tuned circuit were placed in series with a signal current. The series-tuned circuit would present a high impedance to all signals which have a frequency other than the resonant frequency. In practical circuits the impedance is usually low for a band of frequencies about the resonant frequency. Thus, the series-tuned circuit forms a basic band-pass filter; that is, one which will pass only signal currents which are within a frequency band surrounding the resonant frequency of the series-tuned circuit.

Parallel-Tuned Circuits

If a capacitor and inductor are placed in parallel, the combination is known as a PARALLEL-TUNED CIRCUIT. They are also commonly referred to as TANK CIRCUITS, or simply, TANKS. See figure 4-12 which illustrates the arrangement of a capacitor and inductor to form a tank circuit.

THE CHARACTERISTIC OF A TANK CIRCUIT IS THAT, AT ITS RESONANT FREQUENCY, THE IMPEDANCE OF THE CIRCUIT IS MAXIMUM. As was true in series-tuned circuits, resonance occurs at the frequency where capacitive reactance is equal to the inductive reactance.

Signal currents which have a frequency not close to the resonant frequency will be confronted with only a very low impedance and will pass through the tank circuit. However, those signals which have frequencies near or at the resonant frequency of the tank will be opposed by a high impedance and will develop a large voltage across the tank. This voltage may be used as the output of the circuit.

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Figure 4-11.—Series-tuned circuit.

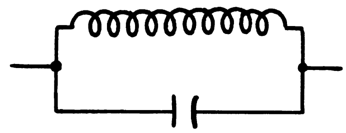

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Figure 4-12.—Parallel-tuned circuit.

Tank circuits find many applications in communications equipment. In most radio receivers, when the operator changes the setting of the tuning dial, he is actually changing the capacitance in one or more tank circuits in the receiver. Changing the capacitance changes the resonant frequency of the tuned circuits.

ELECTRON TUBES

The electron tube is considered primarily responsible for the rapid evolution of electronics to its present stage. It is one of the basic components of almost every piece of electronic equipment. Since most of your duties will be in connection with the use of radio and communication equipment, it should be apparent that a knowledge of the operating principles of electron tubes is important.

The electron tube is made up of a highly evacuated glass or metal shell which encloses several elements. These elements consist of the cathode, the plate, and sometimes one or more grids depending on the use for which the tube is designed. It is necessary to maintain a high vacuum around the elements of an electron tube in order for it to function properly, hence the term "vacuum tube" is usually used in reference to electron tubes. There are many types and designations of vacuum tubes and they can be made to perform many functions. For example, they can be made to (1) convert ac to dc (RECTIFIERS), (2) amplify weak signals with minimum distortion (AMPLIFIERS), and (3) generate high frequencies (OSCILLATORS).

To understand how electron tubes work, we will first consider the phenomenon of electron emission. Certain metals exhibit the property that, when subjected to given conditions, electrons leave the surface of the metal. Liberation of electrons from the surface of a material is known as ELECTRON EMISSION. Electron emission due to high temperature is known as THERMIONIC EMISSION. Certain metals will give off electrons when subjected to light of prescribed characteristics. This is called PHOTOELECTRIC EMISSION. Electrons will leave the surface of many metals if the surface of the metal is bombarded with high velocity electrons from another source. This is known as SECONDARY EMISSION. There are several other methods of obtaining electron emission, each requiring a certain metal to be placed under prescribed conditions.

Thermionic emission is the basic principle for the operation of nearly all electron tubes used in radio equipment. Only a few substances can be heated to the high temperatures that are required to produce satisfactory electron emission without melting. Tungsten, thoriated-tungsten, and oxide-coated emitters are the substances commonly used in electron tubes. As a general rule, the hotter the emitter, the greater will be the number of electrons emitted.

Electron tubes contain an element known as the cathode which emits electrons. The cathode may be heated in two ways—(1) directly and (2) indirectly. Figure 4-13 shows the two types of cathodes. The directly heated cathode receives its heat by passage of a current through a filament, which itself serves as the cathode. The indirectly heated cathode is a metal sleeve that surrounds the filament but is electrically insulated from it. The sleeve serves as the cathode emitter, receiving most of its heat by radiation.

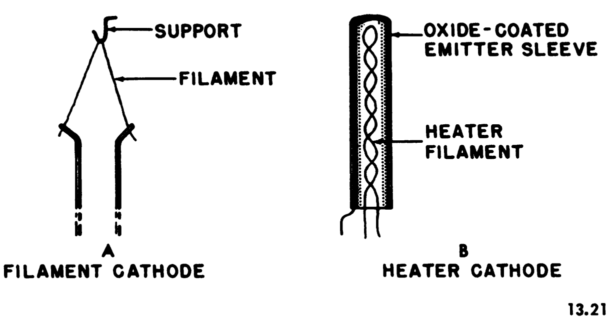

Figure 4-13.—Methods of heating the cathodes in electron tubes.

DIODES

Electron tubes containing two elements, a cathode and a plate, are called DIODES. The plate collects electrons from the cathode and provides a connection to the external circuit. Figure 4-14A shows a cut-away view of a filament cathode type diode and figure 4-14B shows a similar view of a separate heater type diode.

In a circuit such as 4-15, the tube acts in the manner of a valve. The opening and closing of the valve occurs when the source of plate voltage changes from positive to negative. Figure 4-15A shows the circuit of a diode used as a rectifier for changing ac to dc, (B) represents the a-c voltage source which is impressed across the circuit, and (C) is the current flowing in the plate and load circuit.

Alternating voltage is impressed on the plate but a pulsating direct current flows to the load. (Pulsating dc is defined as current with a single polarity but with varying amplitude.) The change from ac to dc is due to the fact that when the source voltage is negative (the negative portion of the a-c sine wave) no current flows because the plate is negative and will not attract electrons being emitted from the heated cathode. When the source voltage is positive (the positive portion of the a-c sine wave), the plate is positive and will attract electrons from the cathode, thus causing current to flow. The result is a current flow to the load during the positive half of the a-c source voltage as shown in figure 4-15C. The pulsating dc can be filtered to form a smooth dc if required. One of the most common uses of the diode tubes is in power supplies, commonly called RECTIFIERS, where an a-c source voltage is converted to dc for operation of component circuits of electronic equipment. Another important use of diodes is in detector circuits of radio receivers. Functional descriptions of rectifier and detector circuits will be presented later in this chapter.

TRIODES

The triode or 3-element electron tube is similar in construction to the diode except that a grid of fine wire is added between the plate and the cathode. Figure 4-16 shows the construction features of a typical triode.

The grid in a triode may be considered as an electronic control valve that regulates the flow

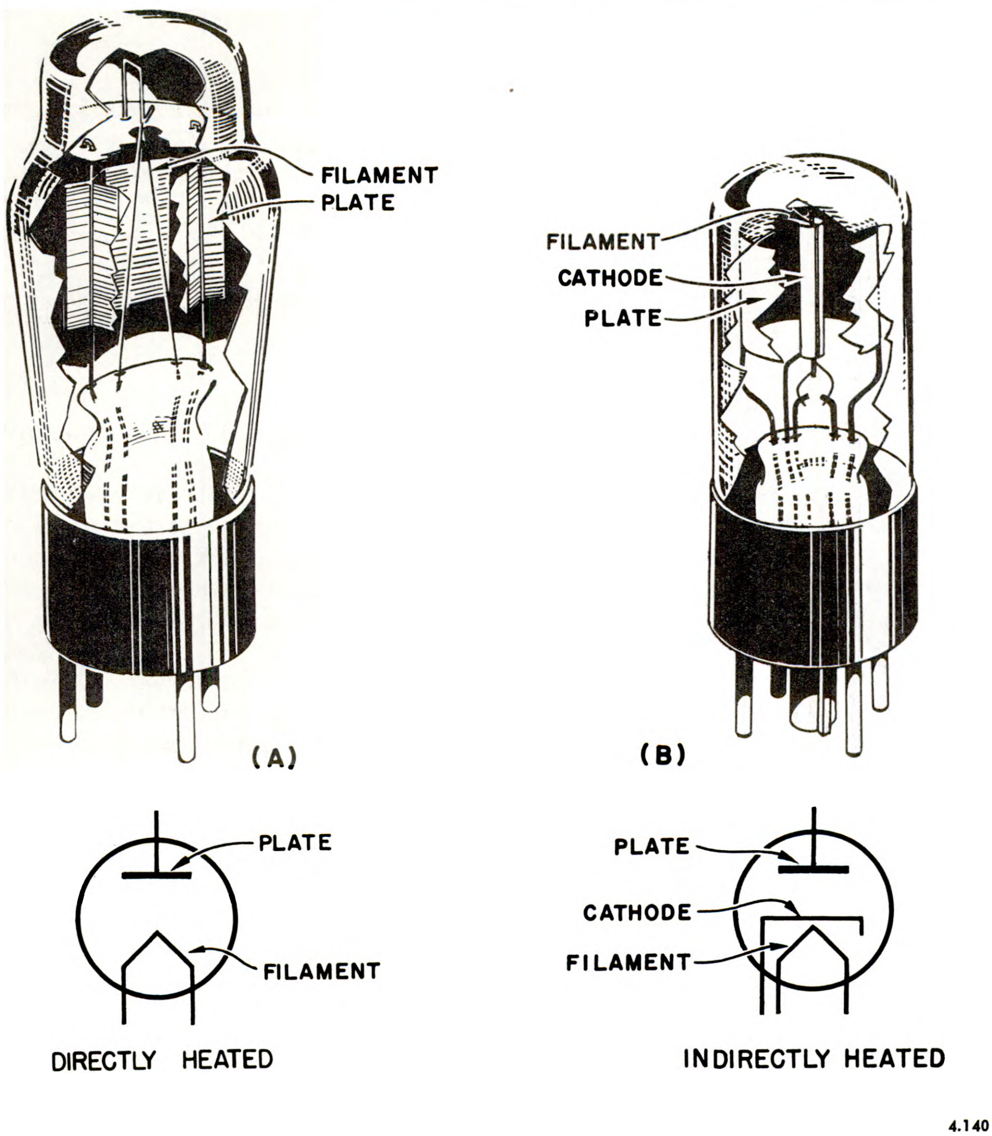

Figure 4-14.—Cut-away of 2-element tubes.

of electrons through the tube and through the load in the plate circuit. Consider an a-c source applied to the grid of a triode. The grid is placed much closer to the cathode than to the plate. A small variation in grid voltage input results in a relatively large variation in the output current (plate current). Thus the voltage applied to the grid is said to be amplified in the plate circuit. Figure 4-17 shows a triode amplifier and the difference in the signal of the grid at input and in the plate circuit. (A) shows the amplitude of the input voltage to the grid; (C) shows the amplitude of the signal after it has passed through circuit (B) and has been amplified by the action of the triode. A functional description of amplifiers will be presented later in this chapter.

MULTIELEMENT TUBES

Many desirable characteristics may be attained in electron tubes by the use of more than one grid. Multielement tubes include TETRODES which contain 4 elements (a plate, a cathode, and 2 grids), and PENTODES which contain 5 elements (a plate, a cathode, and 3 grids). Others containing as many as eight elements are available for certain applications.

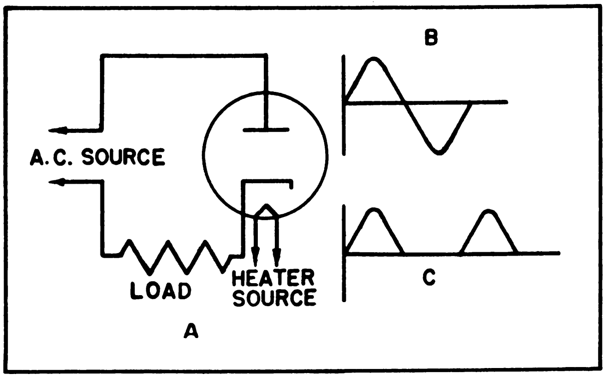

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Figure 4-15.—Diode rectifier.

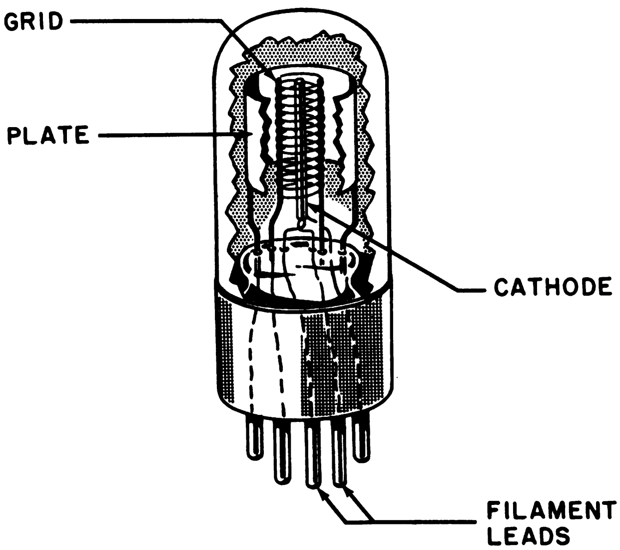

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Figure 4-16.—Typical triode.

As you become more familiar with electronic equipment, you will notice that many multi-element tubes are used, the pentode being one of the most common.

CATHODE-RAY TUBES

The cathode-ray tube is a special type vacuum tube in which electrons emitted from the cathode are shaped into a narrow beam and accelerated to a high velocity before striking a phosphor-coated glass screen. Because the screen fluoresces or glows at the point where the electron beam strikes, it provides a visual

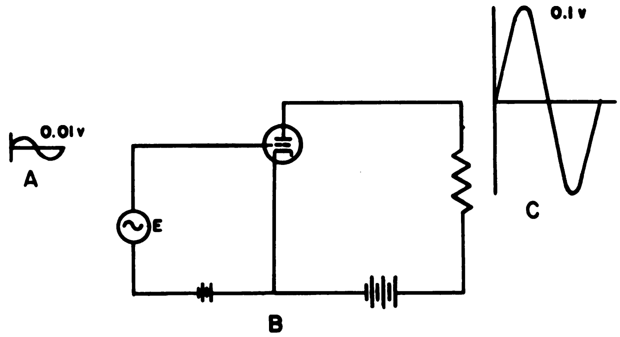

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Figure 4-17.—Triode amplifier.

indication. The tube is used as the indicating device for display of information obtained by many types of electronic equipment. For example, radars, radio direction finders, tuning aids, and waveform analysis equipment all use cathode-ray tubes. They are also used extensively in test equipment to provide a visual presentation of circuit waveforms which show the operating efficiency level of a portion of a circuit, a complete circuit, or a complete equipment.

GAS-FILLED TUBES

In the manufacture of high-vacuum tubes, as much of the air as possible is removed from the envelope. In some cases, however, low-vacuum tubes are designed for particular purposes. Low-vacuum tubes ordinarily contain a gas other than air (usually nitrogen, neon, argon, or mercury vapor). Some types of gas-filled tubes which you may encounter in your work are: gas-diode rectifiers, neon glow lamps, V-R (voltage regulators), and thyratrons.

SPECIAL ULTRAHIGH-FREQUENCY TUBES

As the operating frequency is increased, the capacitive reactance between electrodes in an electron tube decreases. At frequencies higher than approximately 100 mc, the interelectrode capacitance of an ordinary tube provides a low impedance path which shunts the external circuit. Certain other adverse effects also deteriorate or modify signals in the tube circuits at ultrahigh frequencies. These undesirable features can be minimized by constructing very small special uhf tubes with the electrodes placed close together.

ELECTRONIC BUILDING BLOCKS

In the preceding sections of this chapter you have been introduced to the fundamentals of electricity and the various types of components that comprise electrical circuits. Engineers use the basic components (resistors, capacitors, inductors, and vacuum tubes) to design basic circuits, each having one functional purpose. Then to design a particular piece of equipment, these basic circuits become building blocks, so to speak, which are connected to form the complete unit of equipment.

The basic circuits required for most communication equipment, such as transmitters and receivers, are the following: amplifiers, rectifiers, detectors, mixers, oscillators, modulators, and filters. Although the CT T is not required to know the design of each of these circuits, it will be helpful to know the function of each. The following paragraphs briefly describe the functions of each basic circuit.

RECTIFIERS

Rectifier circuits are used to change a-c voltage and current into d-c voltage and current. (This includes both steady d-c levels and pulsating dc.) Rectifier circuits usually contain one or more diodes. The diodes themselves are often referred to as rectifier tubes, or simply rectifiers. Almost every piece of electronic gear will contain at least one rectifier circuit that changes a-c outlet power into the d-c power required for circuits containing vacuum tubes.

AMPLIFIERS

The function of amplifiers is to increase the amplitude of a signal current or voltage. They may be used to increase the very minute voltage from a receiver antenna to a larger voltage. Amplifiers can be used to change small current signals into the large currents necessary to drive loudspeakers or other terminal equipment.

OSCILLATORS

Oscillators are actually sources of a-c voltage or current. One can think of an oscillator as a vacuum tube circuit that changes d-c power from a power supply into an a-c signal at any desired frequency. Depending on the design of the oscillator, it may generate one particular frequency, or it may be designed in such a way that its frequency can be changed (within practical limits). Receivers will usually contain an oscillator called the LOCAL OSCILLATOR or sometimes called the VARIABLE FREQUENCY OSCILLATOR (VFO). Most receivers contain another oscillator called the BEAT FREQUENCY OSCILLATOR (BFO).

MIXERS

Mixers are special purpose circuits which are often used in radio equipment. A mixer is a device that has two inputs and one output. The input terminals receive signals of two different frequencies. Let us call these frequencies f_0 and f_1, where f_0 is higher than f_1. The output will be a signal that contains several frequencies including the two input frequencies, f_0 and f_1, and the combinations of $f_0 + f_1$, and $f_0 - f_1$. This process of mixing frequencies is called heterodyning.

MODULATORS

Modulators are special purpose circuits used in radio transmitters. Modulators have two inputs and one output as do mixers. One input receives a high frequency a-c signal, commonly referred to as the r-f signal or carrier. The other input receives an intelligence signal which may be a voice, printer pulses, etc. Within the circuitry of the modulator, either the frequency or amplitude of the r-f carrier is caused to vary according to the intelligence signal input. This modified r-f signal is the output of the modulator and is referred to as the modulated signal or the modulated carrier.

DETECTORS

Detectors are also special-purpose circuits commonly used in receivers. The function of detectors is to act on a modulated signal in such a way that the intelligence previously added to the signal in a modulator is taken out (detected) for further amplification and use. Although there are several types of detectors, all are designed for this one basic function.

FILTERS

Band-Pass Filters

As has been pointed out earlier, band-pass filters can be constructed of tuned circuits. The characteristic of a band-pass filter is that it exhibits high impedance, thereby blocking signal currents over all but a specific band of frequencies.

In figure 4-18, which shows a typical band-pass filter circuit and its band-pass characteristic curve, the lower cutoff frequency is approximately 92 kc and the upper cutoff frequency is approximately 98 kc. The band of frequencies between the cutoff frequencies is referred to as the PASS BAND of the filter (92-98 kc).

Some band-pass filters will be constructed in such a manner that the pass band is fixed.

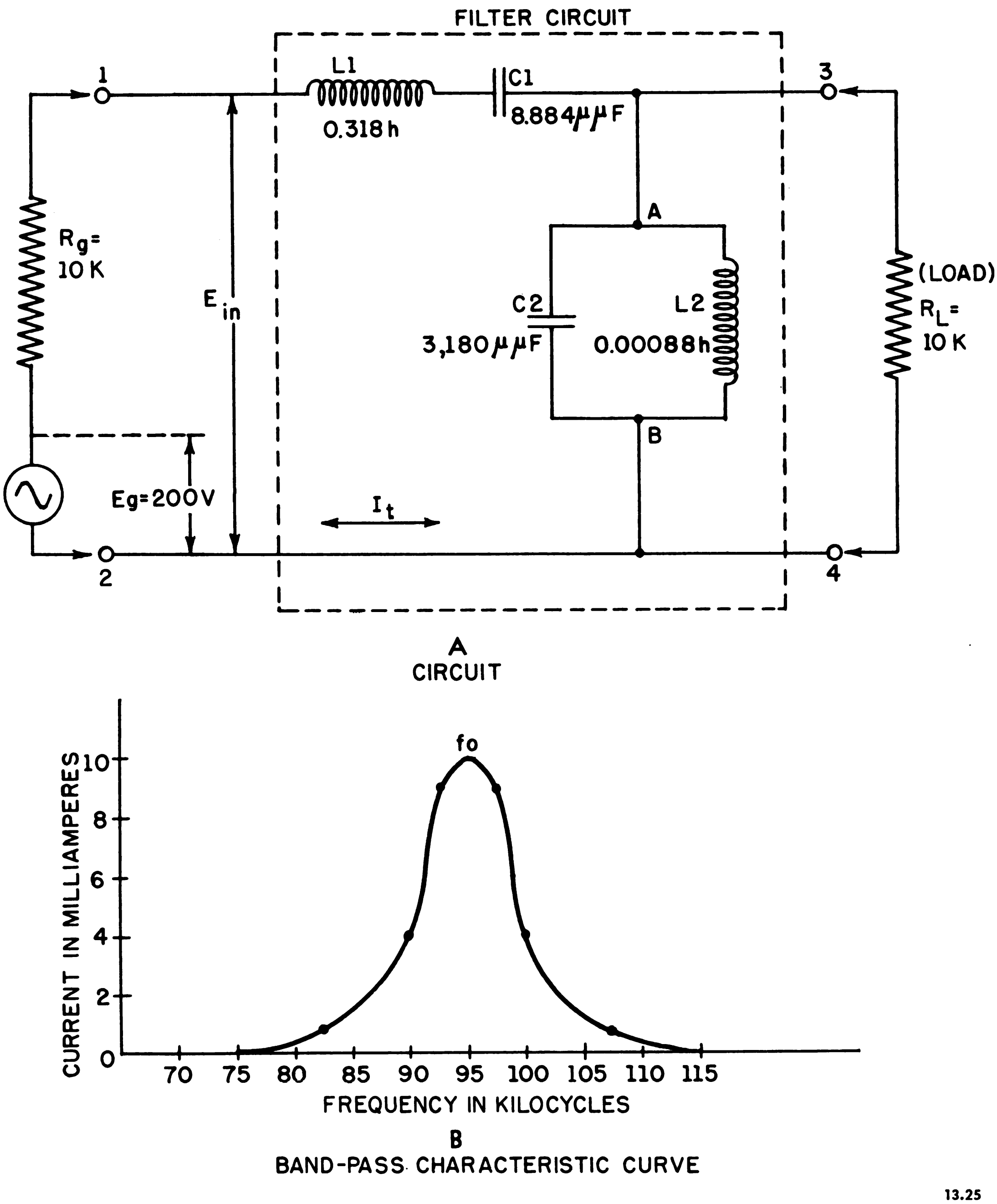


Figure 4-18.—Band-pass filter.

Others are constructed in such a manner that the values of the electrical components (capacitors and/or inductors) can be varied, thereby making it possible to change the cutoff frequencies and pass band.

High-Pass and Low-Pass Filters

Two variations of the band-pass filter are also quite common in communication work. The first is called a LOW-PASS FILTER. A low-pass filter is one which will pass all signals having a frequency less than the filter cutoff frequency. The other variation is called a HIGH-PASS FILTER. A high-pass filter is one which will pass signals having a frequency greater than the filter cutoff frequency. High-pass and low-pass filters may be constructed so that the cutoff frequency is fixed, or they may be constructed in such a manner that the operator can vary the cutoff frequency.

Band-Rejection Filters

A band-rejection filter is one which will pass only signals that are either higher or lower than a given band of frequencies. Band-rejection filters are often referred to as WAVE TRAPS.

GENERAL SAFETY PRECAUTIONS REGARDING ELECTRICAL EQUIPMENT

Because of the possibility of injury to personnel, damage to material, and the danger of fire, all repair and maintenance work on electrical equipment should be performed only by duly authorized and assigned personnel.

When electrical equipment is to be worked on, the main supply switches or cutout switches in each circuit from which power could possibly be fed should be secured in the open position and tagged to indicate that the switch is not to be closed until repairs are completed. The covers of fuse boxes and junction boxes should be kept securely closed except when work is being done. Safety devices such as interlocks, overload relays, and fuses should never be altered or disconnected except when making replacements. Safety or protective devices should never be changed or modified in any way without specific authorization. The interlock switch, which is ordinarily wired in series with the power-line leads to the power supply unit, is installed on the lid or door of the equipment case or enclosure so as to break the circuit when the lid or door is opened.

Fuses should be removed and replaced only after the circuit has been deenergized. When a fuse blows, it should be replaced only with a fuse of the same current and voltage ratings. When possible, the circuit should be carefully checked before making the replacement, since the burned-out fuse is often the result of a faulty circuit.

HIGH-VOLTAGE PRECAUTIONS

Personnel should never work alone near high-voltage equipment. Tools and equipment containing metal parts should not be used in an area where any exposed electric wiring exists. Do not work on any type of electrical apparatus with wet hands or while wearing wet clothing, and do not wear loose or flapping clothing. Before working on electronic or electrical equipment, remove all rings, wristwatches, bracelets, badges suspended from chains, and similar metal items. Care should be taken that clothing does not contain exposed zippers, metal buttons, or any type of metal fasteners.

PRECAUTIONS WITH CHEMICALS

Volatile liquids such as insulating varnish, lacquer, turpentine, and kerosene are dangerous when used near energized electronic or electrical equipment because of the danger of igniting the fumes by sparks. When these liquids are used in spaces containing nonoperating equipment, be sure that there is sufficient ventilation to avoid an accumulation of fumes and that all fumes are cleared before the equipment is energized.

Alcohol should never be used for cleaning electrical equipment since it not only constitutes a fire hazard but it also results in damage to many kinds of insulation. Neither should carbon tetrachloride be employed as a cleaning agent. Unlike alcohol, the use of carbon tetrachloride does not create a fire hazard; but it is dangerous because of the injurious effects of breathing its vapor. Careless use of carbon tetrachloride can result in headache, dizziness, and nausea. If the fumes are inhaled in poorly ventilated spaces, the effect may be loss of consciousness or even death. Also, it forms an insulating film on the material to which it is applied. For these reasons, the use of carbon tetrachloride as a solvent or cleaner has been specifically prohibited in Navy maintenance operations. When cleaning electrical or electronic equipments or parts, always use an approved cleaning agent such as Dry Cleaning Solvent, Federal Specifications P-S-661.

SAFETY FROM FIRE

Preventing Fires

General cleanliness of the work area and of electronic apparatus is essential for the prevention of electrical fires. Because oil, grease, and carbon dust can be ignited by electrical arcing, equipment should be kept absolutely clean and free of all such deposits.

Wiping rags and other flammable waste material must always be placed in tightly closed metal containers which must be emptied at the end of the day's work. Containers holding paints, varnishes, cleaners, or any volatile solvents should be kept tightly closed when not in actual use. They must be stored in a separate building or in a fire-resistant room, which is well ventilated, and where they will not be exposed to excessive heat or to the direct rays of the sun.

Firefighting

In case of electrical fires, the following steps should be taken:

1. Deenergize the circuit.
2. Call the fire department.
3. Control or extinguish the fire, using the correct fire extinguisher.
4. Report the fire to the appropriate authority.

For combating electrical fires, use a CO_2 (carbon dioxide) fire extinguisher and direct it toward the base of the flame. Carbon tetrachloride should never be used for firefighting since it changes to phosgene (a poisonous gas) upon contact with hot metal; even in open air it creates a hazardous condition. The application of water to electrical fires is dangerous; foam-type fire extinguishers should not be used since the foam is electrically conductive.

In cases of cable fires, in which the inner layers of insulation or insulation covered by armor are burning, the only positive method of preventing the fire from running the length of the cable is to cut the cable.

When selenium rectifiers burn out, fumes of selenium dioxide, which causes an overpowering stench, are liberated. These fumes are positively poisonous and should not be breathed. If a rectifier burns out, deenergize the equipment immediately and ventilate the room. Allow the damaged rectifier to cool before attempting any repairs. If possible, move the equipment containing the rectifier out-of-doors. Do not touch or handle the defective rectifier while it is hot; contact might result in a skin burn through which some of the selenium compound could be absorbed.

Fires involving wood, paper cloth, or explosives should be fought with water. Because water works well on them, advantage is taken of its inexpensiveness, availability, and safety in handling.

A steady stream of water does not work in extinguishing fires involving substances such as oil, gasoline, kerosene, or paint, because these substances will float on top of the water and keep right on burning. Also, a stream of water will scatter the burning liquid and spread the fire. For this reason, foam or fog must be used in fighting such fires.

FIRST AID

Treatment for Electric Shock

Electric shock is a jarring, shaking sensation resulting from the passage of an electric current through the body or a portion of the body. The victim usually feels that he has received a sudden blow; and if the voltage is sufficiently high, he may become unconscious. Severe burns may appear on the skin at the place of contact; muscular spasm can occur, causing the victim to clasp the apparatus or wire which caused the shock and be unable to release it. Electric shock can kill its victim by stopping the heart, by stopping breathing, or both. It may sometimes damage nerve tissue resulting in a slow wasting away of muscles, a deterioration that may not become apparent until several weeks or months after the shock was received.

The following procedure is recommended for rescue and care of shock victims:

1. Remove the victim from electrical contact at once, but DO NOT ENDANGER

YOURSELF. Removal can be accomplished by (1) throwing the switch if it is nearby; (2) cutting the cable or wires to the apparatus, using an ax with a wooden handle while taking care to protect your eyes from the flash when the wires are severed; (3) using a dry stick, rope, leather belt, coat, blanket, or any other nonconductor of electricity.

2. Determine whether the victim is breathing. If he is, keep him lying down in a comfortable position. Loosen the clothing about his neck, chest, and abdomen so that he can breathe freely. Protect him from exposure to cold, and watch him carefully.

3. Keep him from moving about. In cases of electric shock, the heart is very weak; any sudden muscular effort or activity on the part of the patient may result in heart failure.

4. Do not give stimulants or opiates. Send for a medical officer at once; do not leave the patient until he has adequate medical care.

5. If the victim is not breathing, apply artificial respiration without delay, even though he may appear to be lifeless.

Resuscitation from the Effects of Electric Shock

Artificial respiration is the process of promoting breathing by mechanical means. It is used to resuscitate persons whose breathing has stopped, not only as a result of electric shock, but also from causes such as drowning, asphyxiation, strangling, or the presence of a foreign body in the throat.

When an electric shock victim must be revived, begin artificial respiration as soon as possible. If there is any serious bleeding, stop it first, but do not waste time on anything else. Seconds count; the longer you wait to begin, the less are the chances of saving the victim.

Personnel in all rates and ratings, E-2 and above, are required to be able to administer artificial respiration. Detailed coverage of the Navy's standardized procedures for artificial respiration is given in the *Standard First Aid Training Course*, NavPers *10081*.

Treatment of Burns and Wounds

In administering first aid for burns, the objectives are to relieve the pain, to make the patient as comfortable as possible, to prevent infections, and to guard against shock which often accompanies burns of a serious nature. Minor wounds should be washed immediately with soap and clean water, dried, and painted with a mild, non-irrating antiseptic. Apply a dressing if necessary. Larger wounds should be treated only by medical personnel. For purposes of first aid, merely cover the wound with a dry sterile compress and fasten the compress in place with a bandage.

QUIZ

1. Atoms are comprised of negative charges called________ in orbit around a nucleus of positively charged________and uncharged________.

2. Materials composed of atoms whose electrons are easily shifted from atom to atom are, electrically, good________.

3. The practical unit of electric current is the________.

4. The practical unit of electromotive force is the ________.

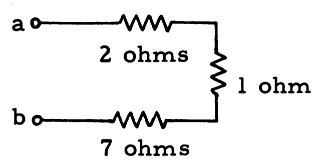
5. If you were constructing a resistor by winding a fine wire on an insulator bobbin, to increase the resistance would you increase or decrease the number of turns?

6. What is the resistance of a circuit component if 10 volts across the component causes 5 amps of current to flow through it?

7. How much current will result if 240 volts are placed across a 100 ohm resistor?

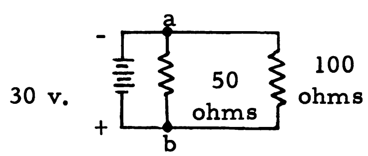
8. What potential would be required to cause 0.5 amp of current to flow through a 25 ohm resistor?

The figure below is used for questions 9, 10, and 11.



9. Are the resistors shown in series or in parallel?
10. If a 40 volt battery were connected, the positive battery terminal to point a and the negative terminal to point b, which direction would current flow around the circuit and what would its amplitude be?
11. What voltage would be indicated on a voltmeter if the voltmeter probes were placed on the terminals of the 1-ohm resistor? Which of the 1-ohm resistor terminals would appear to be positive with respect to the other?

The figure below is used for questions 12, 13, 14, and 15.



12. Is the circuit shown a series circuit or a parallel circuit?
13. How much current will flow out of the negative battery terminal?
14. How much current will flow through the 50 ohm resistor?
15. What is the equivalent resistance between points a and b?
16. How much power is supplied to a 100 ohm resistance if 110 volts is placed across it?
17. If a current of sine-wave variation completes a period in 16.67 milliseconds (10^{-3} seconds), what is the frequency of the sine wave?
18. What is the period of a 400 cps sine wave?
19. Why doesn't a capacitor pass d-c current?
20. What property of a coil causes a voltage across the coil which opposes any change in current through the coil?
21. The total opposition to a-c current flow through a circuit, whether the opposition is due to resistance, reactance, or a combination of resistance and reactance, is called ________.
22. When a circuit contains an inductance-capacitance combination, the frequency at which inductive reactance equals capacitive reactance is called the ________ of the circuit.
23. Which type of tuned circuit exhibits maximum impedance at one particular frequency?
24. In most cases, which type of electron emission is the basis of electron-tube operation?
25. Name the elements of a triode.
26. A/an ________ circuit is used to change ac to dc.
27. A/an ________ circuit is used to provide a high-frequency a-c signal from d-c power.
28. The type filter circuit which passes all but a band of frequencies is called a/an ________.
29. Why is it advisable to check equipment circuitry before replacing a burned-out fuse in the equipment?
30. Which type fire extinguisher should be used in case of fire in an electronic equipment?
31. If you discover someone who has just suffered a severe electric shock, what should be your first action?

CHAPTER 5

RADIO WAVE PROPAGATION

INTRODUCTION

As a CT you will be concerned with communications that are accomplished, at least in part, by radio waves. Although not required to understand the physical theory of radio wave propagation, you will find it helpful to know the effects of the earth and the earth's atmosphere on radio wave propagation and how these effects are advantageous or disadvantageous. The purpose of this chapter is to present some fundamentals and problems of radio wave propagation and some factors that must be considered when transmitting or receiving electromagnetic waves.

RADIATION

Radio waves are a form of radiant energy similar to light and heat. Radio waves normally travel through space at approximately the speed of light: 300,000,000 meters per second. Radio waves are generated by the excitation of radiators, commonly called antennas, with a source of alternating electrical current.

THE RADIO FREQUENCY SPECTRUM

The frequency of the current used to excite the radiator is called the CARRIER FREQUENCY of the wave. Because of physical considerations involved, the frequency of the carrier must be sufficiently high before an antenna will radiate. Frequencies above the minimum frequency (approximately 10 kc) up to the frequencies near that of infrared light are known collectively as the R-F SPECTRUM. The r-f spectrum, which extends from approximately 0.01 megacycle to 30,000 megacycles, is subdivided into eight bands as shown in figure 5-1. Each frequency band has certain propagation characteristics which identify it, and to some extent, also determine the operation of radio equipment in each band.

WAVELENGTH

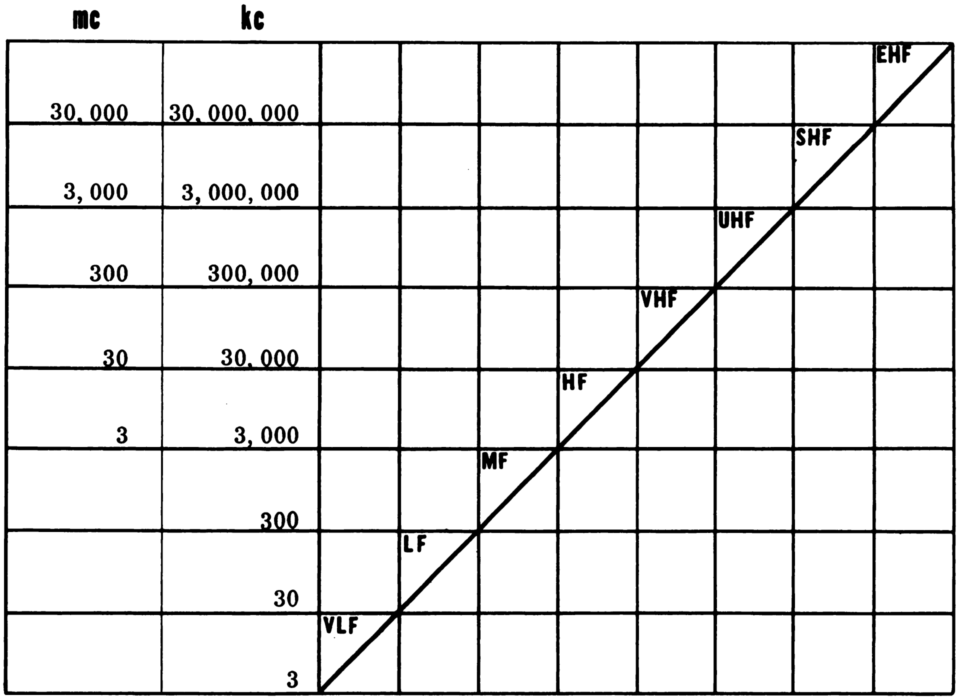
Radio frequency waves in space have a WAVELENGTH which can be compared to the wavelength defined by the distance between peaks of waves in water. The wavelength of a radio wave in free space is determined by the ratio of the velocity of wave propagation in free space divided by the frequency of the wave. Therefore, the wavelength in meters of a radio wave will equal 300,000,000 divided by the frequency in cycles per second, or 300 divided by the frequency in megacycles.

POLARIZATION AND FIELD STRENGTH

Although it is difficult to visualize an energy wave in space, it is necessary that you recognize certain properties of these waves. The concept of wavelength has already been mentioned. Another concept with which you should be familiar is that radio waves are polarized; that is, they have a direction associated with them. It is sufficient for you to know that the polarization of the radio wave is determined by the physical and electrical characteristics of the radiator (antenna). In general, a radio wave emitted by a horizontal antenna element is said to be horizontally polarized; a wave emitted by a vertical antenna element is vertically polarized.

One important consequence of radio waves being polarized is that a horizontally polarized wave is best received by horizontal antennas, a vertically polarized wave by vertical antennas. It should be noted that there are also complex variations of polarization other than horizontal and vertical; but in most instances, you will encounter applications of either simple horizontal or vertical polarization.

Another term that is often used in radio wave discussion is that of FIELD STRENGTH. A radio wave moving through space has a given value of energy at any point at a given instant in time. If an antenna is placed in



RADAR BANDS

BAND	FREQUENCY RANGE	BAND	FREQUENCY RANGE
A	157 to 187 mc	X	5200 to 11000 mc
C	194 to 212 mc	K	11000 to 36 kmc
P	225 to 390 mc	Q	36 to 46 kmc
L	390 to 1550 mc	V	46 to 56 kmc
S	1550 to 5200 mc		

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Figure 5-1.—Radio frequency spectrum chart.

space with the proper polarity, the radio wave induces a voltage in the antenna as the wave is cut by the antenna. The amount of voltage induced in a standard antenna in space is a measure of the FIELD STRENGTH of the radio wave. The field strength measured at a point in space is actually a measure of the amount of energy in the radio wave at the point where the measurement is taken.

PROPAGATION OF RADIO WAVES

When a vertical antenna is energized by an r-f current, a radio wave leaves the antenna and expands radially in all directions. In the vertical plane, part of the wave moves outward in contact with the ground to form the GROUND WAVE, and the rest of the wave moves upward and outward to form the SKY WAVE. If field strength were measured at all points of a vertical plane in space, and the points of equal strength were drawn as a solid line, the radiation pattern would appear to be similar to that shown in figure 5-2.

The ground and sky portions of the wave are responsible for two different methods of propagating electromagnetic waves from a radio

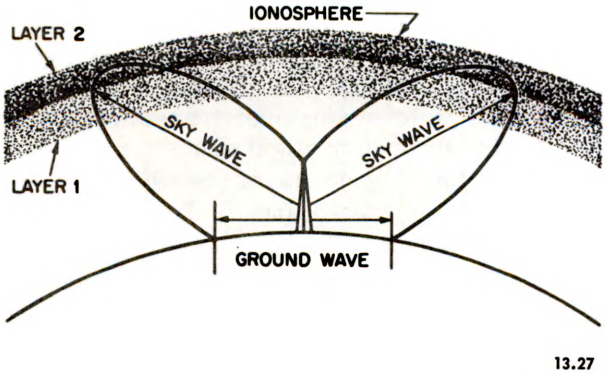

Figure 5-2.—Formation of the ground wave and sky wave.

transmitter to a radio receiver. The ground wave is used both for short-range operation at high frequencies with low power, and for long-range operation at low frequencies with very high power. Reception from most nearby commercial broadcast stations is a result of the ground wave. The sky wave is used primarily for long-range, high-frequency operation. At night, the sky wave provides a means for long-range operation at somewhat lower frequencies.

THE GROUND WAVE

By definition, the ground wave is that portion of a radio wave which travels along the surface of the earth and is affected by the earth and its terrain features. Normal ground wave transmission is not affected by the IONOSPHERE, which consists of ionized layers of atmosphere high above the earth's surface. (See figure 5-2.)

The ground wave is considered to be made up of two parts, a surface wave and a space wave. The surface wave portion of the ground wave travels along the surface of the earth. It is considerably influenced by the electrical properties of the earth. The surface wave is least attenuated and thus travels further over earth having good electrical conductivity and a smooth surface. Radio wave transmission which relies on the surface wave portion of the ground wave is therefore most successful over sea water, and is fairly good over flat loamy soil. Transmission is poor over rough, rocky terrain and is essentially unusable in jungle territories.

The frequency used determines the maximum distance within which the surface wave is effective; it is most effective at lower frequencies. Therefore, most radio wave propagation in the lower half of the MF band and below relies on the surface wave portion of the ground wave for propagation. In the LF and VLF bands, effective propagation over thousands of miles is made possible by the use of high power transmitters.

In the space immediately above the earth's surface, the space wave travels in two paths—one directly from the transmitter to the receiver, the other a path in which the space wave is reflected from the ground before it reaches the receiver. Because the two paths are of different lengths, the two signal components may arrive out of phase with each other, causing cancellation, or they may arrive in phase causing reinforcement of the signal. Propagation relying on the space wave portion of the ground wave is ordinarily limited to distances only slightly greater than the line of sight between transmitting and receiving antennas.

At the upper end of the r-f spectrum, the surface wave is not effective for more than negligible distances, much less than the line of sight. Therefore, VHF and UHF transmissions rely on the space wave portion of the ground wave for propagation. Since distance is essentially limited to line of sight; it is usually not advantageous to use more than a small amount of power for VHF and UHF applications.

Although VHF and UHF radio wave propagation is ordinarily limited to relatively short ranges, under some circumstances unusual ranges of VHF and UHF occur. Such occurrences result from an atmospheric condition known as temperature inversion. Ordinarily the air next to the earth's surface is warmer than the air above it. However, sometimes warm layers of air occur above cool layers; this phenomenon is called a temperature inversion. When a temperature inversion exists, unusual refraction (bending) of the space wave occurs, causing it to be "ducted" within boundaries of the air layers thus extending the range considerably beyond the line of sight. Ducting often results when surface winds blow seaward over junctures of land and water or when certain other atmospheric conditions exist. In addition to ducting, unusual reception in the VHF band occasionally results from certain dense patches in the ionosphere. These patches are called SPORADIC-E ionizations.

THE SKY WAVE

The SKY WAVE is that part of the radio wave which moves upward and outward and is not in contact with the ground. It behaves differently from the ground wave. For certain frequencies, some of the energy of the sky wave is refracted by the ionosphere by such an amount that the wave returns to the earth. A receiver located in the vicinity of a returning sky wave will receive strong signals even though several hundred miles beyond the range of the ground wave.

THE IONOSPHERE

The ionosphere is that part of the atmosphere which begins approximately 40 miles above the earth's surface and extends upward to approximately 350 miles. It differs from the lower atmosphere in that it contains a much higher number of positive and negative ions (charged particles), which are produced by the ultraviolet radiation from the sun.

The ionosphere is constantly changing. Some of the ions are combining to form neutral atoms, while other atoms are being ionized by the removal of electrons from their outer orbits. The rate of recombination and formation of ions depends on the amount of air present and the strength of the sun's radiations. At altitudes above 350 miles, the particles of air and gas are too scarce to permit large-scale ion formation. Below about 40 miles altitude, the rate of recombination is great and there is little ultraviolet radiation because the ultraviolet rays are absorbed in the upper layers of the ionosphere. Consequently, at altitudes below 40 miles, too few ions exist to affect the sky wave.

The ionosphere appears to have layers because the density of ionization varies from one level to another. Actually there is thought to be no sharp dividing line between layers, but for the purpose of discussion a sharp demarcation from layer to layer is indicated.

The ionized atmosphere at altitudes between 40 and 50 miles is called the D LAYER. Its ionization is low, and it has little effect on the propagation of radio waves except for the absorption of energy from the radio waves as they pass through it. The D layer is present only during the day. Its presence greatly reduces the field strength of transmissions that must pass through daylight zones.

The atmospheric layer between 50 to 90 miles is designated the E LAYER. It is a well-defined band with greatest density at an altitude of about 70 miles. This layer is strongest during the daylight hours; it is also present but much weaker at night. The maximum density of the E layer appears at about noon, local time.

The F LAYER extends from approximately the 90-mile level to the upper limits of the atmosphere. At night, only one F layer is present; but during the day, especially when the sun is high, this layer often separates into two parts, F_1 and F_2, as shown in figure 5-3. As a rule, the F_2 layer is at its greatest density during the early afternoon hours, but there are many notable exceptions of maximum F_2 density existing several hours later. Shortly after sunset, the F_1 and F_2 layers recombine into a single F layer.

Ionospheric Variations

As has been noted, the ionospheric layers vary regularly from daylight to darkness. They also vary in different areas of the globe as the seasons of the year change. There is a fairly regular variation which has approximately an 11-year cycle due to sunspot activity. In addition to the regular variations, erratic patches of ionized atmosphere occur at E-layer heights. These are the sporadic-E ionizations mentioned earlier. Other abnormal variations in the

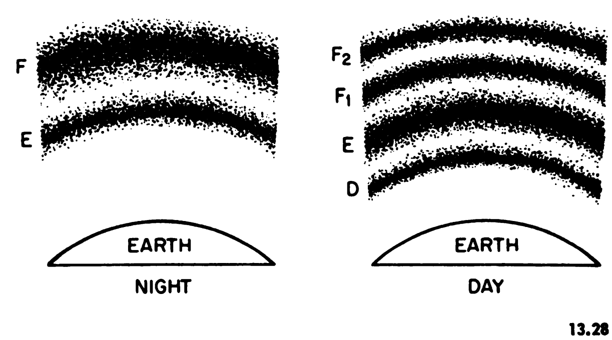

Figure 5-3.—E layer and F layer of the ionosphere.

ionospheric layers occur because of unusual sun spot activity and "ionospheric" and "magnetic" storms. These sporadic variations sometimes occur in considerable strength at varying altitudes and actually prove harmful to reliable radio wave propagation.

Effects of the Ionosphere on the Sky Wave

The preceding section described the mediums that are encountered by a sky wave as it travels through space. In an atmosphere (or space) of unvarying ion density, the space wave travels in straight lines; but when an ionospheric layer is encountered, the space wave is altered. At lower frequencies, nearly all the energy of the space wave is absorbed in the lowest ionospheric layer. If the frequency is raised, the radio wave is not absorbed by the D layer but passes to the next layer which has a higher ion density. As the wave passes through a change in ionospheric density, the path of the wave is bent back toward the earth. This process is called refraction. If the frequency is gradually raised, the path is not bent quite so much; and if the frequency becomes high enough, the radio wave will pass through the layers almost unaffected. Because of these frequency considerations, radio propagation by sky waves is usually confined to the upper third of the MF band and the HF band. Actually, because of absorption, the upper third of the MF band is not normally usable during daylight hours.

Refraction of the sky wave is not only dependent on changes in density (layers) of the ionosphere and the frequency of the radio wave; it is also dependent on the angle at which the wave enters the ionosphere. More will be said about this later.

If the conditions of sufficient ionospheric density, correct frequency, and proper angle are met, the sky wave from an antenna will enter the ionosphere, eventually emerge, and return to earth. If a receiver is located at either of the points designated B in figure 5-4, the transmission from point A will be received. (Note: The height of the antenna is not drawn to scale.)

Next consider figure 5-5. In this figure, the sky wave is divided into three groups of rays which are identified according to their angle of elevation. The angle at which the

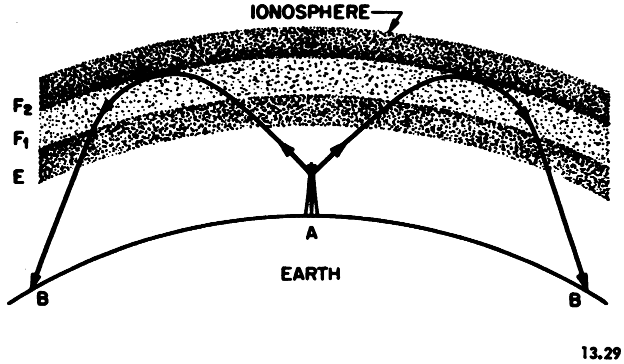

Figure 5-4.—Refraction of the sky waves by the ionosphere.

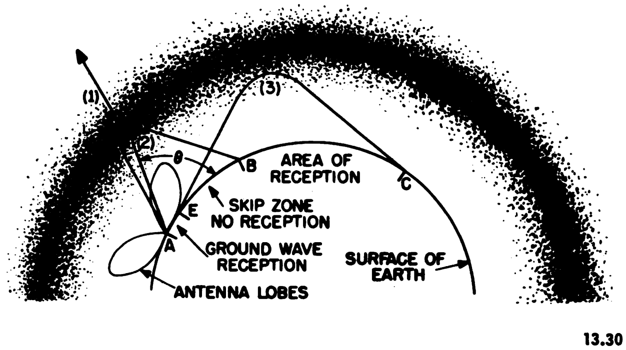

Figure 5-5.—Effect of the angle of departure on the area of reception.

group-1 rays strike the ionosphere is too nearly vertical for the rays to be returned to the earth. The rays are bent out of line, but pass completely through the ionosphere and are lost.

The angle made by the group-2 rays is called the CRITICAL ANGLE for that frequency. Any ray that leaves the antenna at an angle greater than this angle will pass through the ionosphere.

Group-3 rays strike the ionosphere at the smallest angle that will be refracted and still return to the earth. At any smaller angle, the rays will be refracted but will not return to the earth.

As the frequency increases, the critical angle decreases. Low-frequency waves can be transmitted vertically, and will return to earth. The highest frequency that can be transmitted vertically and still be returned to the earth is called the CRITICAL FREQUENCY. At sufficiently high frequencies, regardless of the angle at which the rays strike the ionosphere, the wave will not be returned to the earth. The critical frequency is not constant, but varies from one locality to another with the time of day, season of the year, and the sunspot cycle.

Because of this variation in critical frequency, nomograms and frequency tables are issued which predict the MAXIMUM USABLE FREQUENCY (MUF) for every hour of the day for every locality in which transmission are made. When transmissions are made, a frequency somewhat less than the MUF is used. The frequency most often used is called the OPTIMUM WORKING FREQUENCY (OWF). OWF is the frequency from which most consistent communication would be expected. OWF is sometimes referred to as the OPTIMUM FREQUENCY FOR TRANSMISSION (FOT).

Referring again to figure 5-5, you see that a receiver at any point between B and C will receive a transmission by means of the sky wave. A receiver at any point between A and E will receive transmission by ground wave. Receivers located between E and B in this figure will not receive transmissions from point A because neither the ground wave nor the sky wave will reach this area. This area (E to B in the figure) is called the SKIP ZONE. Another term called SKIP DISTANCE is often used. Skip distance is the distance between the transmitter and the nearest point where a usable refracted wave returns to earth.

Multiple Refraction

The radio wave may be refracted many times between the transmitter and receiver locations, as shown in figure 5-6. In this example, the radio wave strikes the earth at location A with sufficient energy remaining in the wave to be reflected back to the ionosphere and once again be refracted back to the earth. Frequently a sky wave has sufficient energy to be refracted and reflected several times, thus greatly increasing the range of transmission. Because of this so-called MULTIPLE-HOP action, transoceanic and around-the-world transmission is sometimes possible with moderate transmitter power.

Fading

When a received signal varies in intensity over a relatively short period of time, the effect is known as fading. There are several causes

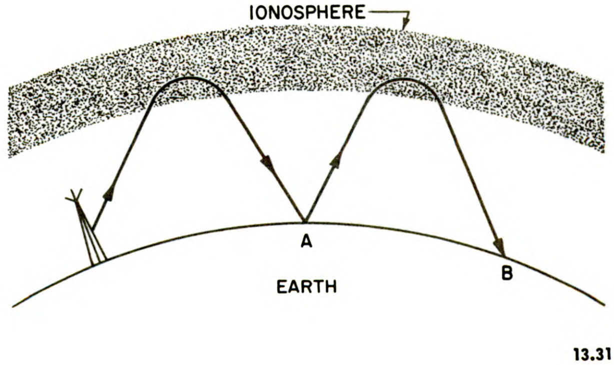

Figure 5-6.—Multiple refraction and reflection of a sky wave.

of fading; some are easily understood and others are more complicated.

A type of fading, called INTERFERENCE FADING, results when a signal arrives at a receiver by two paths of propagation; for example, a signal arrives by one multi-hop path and by one single-refraction path. If the signals of the two paths are out of phase, they tend to cancel each other; when in phase, they reinforce each other. The same effect occurs when the ground wave and the sky wave come in contact with each other. Actually, signal fluctuations are greater when there is interference between the ground wave and the sky wave than when there is interference between sky waves.

If a receiver is located at the very edge of the skip zone, severe fading often results because the sky wave alternately strikes and skips over the area. This type of fading sometimes causes the signal to fade completely.

Another type of fading occurs in the transmission of audio information, resulting in distortion of the "side bands" of the signal and subsequent distorted reception. This type of fading, called SELECTIVE FADING, results from the slight difference in transmission paths of the side bands because of a difference in their frequencies.

One method used to overcome fading is known as SPACE DIVERSITY RECEPTION. This method employs two antennas, set apart from each other, feeding separate receivers. The output of the receiver with the best signal is automatically selected by a device called a comparator. Space diversity reception will not however, relieve fading resulting because a receiver is located on the edge of the skip zone. To relieve such a condition, it would be necessary to use a somewhat lower frequency or possibly to change the angle of transmission.

Frequency Blackouts

Frequency blackouts are related to certain types of fading. During frequency blackouts, radio propagation is interrupted completely on certain frequencies. Changing conditions in the ionosphere shortly before sunrise and after sunset sometimes cause blackouts at certain frequencies. The higher frequencies pass through the ionosphere during these conditions; the lower frequencies are completely absorbed.

Ionospheric storms (turbulent conditions in the ionosphere) may also cause erratic conditions or blackouts in radio wave propagation. Some frequencies become completely blacked out and others are strengthened. Sometimes ionospheric storms will develop in only a few minutes, and sometimes gradually over a period of hours. The storm itself may last several hours.

When frequency blackouts occur, the critical frequency is lowered. At the same time, greater absorption takes place at lower frequencies. Thus the actual band of frequencies which is usable will be quite narrow if propagation can be accomplished at all.

NOISE CONSIDERATIONS

In general, electronic or radio noise can be classified as either man-made or natural (static) noise. Although natural noise can be annoying, and at times so severe that it will curtail some radio transmissions, little can be done about it. Static is sporadic and dispersed throughout the frequency spectrum. Therefore, about all that can be done is to use as narrow a frequency band as possible, thereby reducing the amount of static that is allowed to enter the receiving equipment. Certain methods of impressing the intelligence on the radio wave and consequently recovering it at a receiver are less vulnerable to atmospheric noise than other methods.

It has also been determined that interference from natural noise is decidedly worse in some geographic areas than others, being worst in the polar regions. Therefore, this is one important consideration when planning the location of communication stations.

Man-made noise is generally produced as a result of the action of other electrical and electronic equipment. Man-made noise is spread throughout the frequency spectrum, just as static, but can often be recognized because it appears in some periodic fashion. Common sources of man-made noise are high-voltage power lines, electric motors and appliances, generators, engine ignitions, and diathermy machines.

Those sources of noise that are present at a receiver installation can generally be located by the maintenance technicians. When located, the noise can often be reduced to levels that will not disrupt communications, by installation of noise-suppression filters at the noise source. Most receivers also contain filters which prevent noise from entering the equipment by means of the power lines.

When noise develops in a normally quiet receiver, the operator can often determine whether or not the noise is locally generated. The first step would be to disconnect the antenna. If the noise continues at the same level, some component of the receiver is bad. If the noise is not due to a faulty component in the receiver, other electrical equipments in the immediate area can be turned off, one at a time (with the antenna still connected). If the receiver suddenly becomes quiet when a particular piece of equipment is turned off, that piece of equipment is the most likely source of noise and may have to be repaired or modified by a technician.

SIGNAL-TO-NOISE RATIO

When a receiver picks up a signal from a remote station, the signal is generally very weak. It must be amplified many times before it can serve any useful purpose. If there is any noise picked up at the receiver input, it will also be amplified along with the signal. If the energy level of the noise is sufficiently high, it may prevent the receiver from producing the desired results.

It is possible to amplify very minute signals to almost any level, but it is impossible to detect and remove intelligence if the signal has no more energy than the noise about it. Therefore, the ratio of signal energy to noise energy at the input of a receiver is a most important consideration for communication receivers. For example, the SIGNAL-TO-NOISE RATIO for radiotelephone communications must be approximately 10 to 1 for reliable operation.

QUIZ

1. A carrier frequency of 15 mc is in the ________band. (e. g. LF, EHF.)
2. A carrier of 1500 mc is in the ________band.
3. Give the mathematical expression for the wavelength of an electromagnetic wave in free space in terms of the frequency and the speed of the wave. (Express wavelength in meters, and frequency in mc.)
4. What is the wavelength of a 300 mc wave? Of a 30 mc wave? Of a 30 kc wave?
5. The determination of whether a receiving antenna should be mounted in a vertical position or in a horizontal position is made according to the________of the wave to be received.
6. The amplitude of the voltage induced in a standard antenna at a given point in space is measured as an indication of the________ of a radio wave at that point.
7. The ground wave is considered to be comprised of a________wave and a ________ wave.
8. Most radio communications in the lower half of the MF band and below rely on the ________portion of the ground wave for propagation.
9. Most VHF and UHF communications rely on the ________portion of the ground wave for propagation.
10. Why do VHF and UHF transmitters usually transmit only small amounts of power?
11. Unusual distances of VHF and UHF propagation result from phenomena known as ________and________.
12. Give two reasons why few ions exist at altitudes below approximately 40 miles.
13. Why does the ionosphere not exist at altitudes above approximately 350 miles?
14. What is the layer designation of that portion of the ionosphere which exists at altitudes from approximately 40 to 50 miles and is present only during daylight?
15. At what time of day is the F layer of the ionosphere most likely to appear to be in two distinct layers?
16. Give the regular variations in the ionosphere.
17. Upon what three conditions does the ability of the ionosphere to return a radio wave to earth depend?
18. For a given frequency, the greatest angle of elevation from which a sky wave can leave the antenna, enter the ionosphere, and return to earth, is called the________ angle.
19. The highest frequency radio wave which can be transmitted vertically and to be returned to earth is called the________frequency.
20. The frequency from which most consistent sky-wave communication can be expected is called the________.
21. The distance between the transmitter and the nearest point where a usable refracted sky wave returns to earth is called the ________.
22. Space diversity reception is a technique used to overcome________.
23. How is man-made noise usually distinguished from natural static?

CHAPTER 6

ANTENNAS AND TRANSMISSION LINES

A CT of the T Branch may be required to perform a number of jobs involving use of frequencies in the r-f spectrum ranging from VLF through EHF. Since operation over the entire range of the r-f spectrum requires many types of antennas, transmission lines, and coupling devices, it is essential that the operator know something about the basic types, their characteristics, and uses.

Because the operator in most cases will have a choice of antennas, he must be able to select the one most suitable for the task at hand. In many cases, his ability to make connections or change connections can mean the difference between efficient and inefficient operation. In all cases he should be able to determine (1) whether or not his equipment is properly connected to the right antenna and (2) whether or not the antenna and connecting devices are operating properly. This chapter presents basic information which should be of assistance in making the most efficient use of antennas and associated equipment.

ANTENNAS

BASIC PRINCIPLES

An antenna is defined as a conductor or system of conductors which can be used to radiate or receive energy in the form of electromagnetic waves.

If an antenna is fed a radio frequency current from a transmitter, it will radiate electromagnetic waves into space. If an antenna is placed in the path of an electromagnetic wave traveling through space, a radio frequency current will be induced in the antenna. This induced current is used as the input to a receiver. Thus it can be seen that some type of antenna is necessary to either radiate or receive electromagnetic waves. However, before further discussion, it will be helpful to review and discuss four terms commonly associated with antennas.

Wavelength

The physical length of an antenna is often referred to in wavelengths. Such terms as quarter-wave, half-wave, and full-wave are used extensively. Wavelength (LAMBDA) is usually expressed in meters and is defined as the velocity of a radio wave in free space divided by the frequency of the wave. The symbol for LAMBDA is λ.

Since the velocity of an electromagnetic wave in free space is considered to be 300 million meters per second, the formula for computing wavelength is expressed as:

$$\text{Wavelength} = \frac{300,000,000}{\text{Frequency in cycles per second}}$$

or

$$\text{Wavelength} = \frac{300 \times 10^6}{f \text{ (cps)}}$$

If wavelength in meters is known, frequency in cycles per second can be determined by the following formula:

$$\text{Frequency in cycles per second} = \frac{300,000,000}{\text{Wavelength in meters}}$$

or

$$\text{Frequency in kilocycles per second} = \frac{300,000}{\text{Wavelength in meters}}$$

Polarization

Radio wave polarization is an important consideration with respect to antennas. In general, the following rules apply. Vertical radiating antennas radiate vertically polarized waves which are received best by vertical antennas.

Horizontal radiating antennas radiate horizontally polarized waves which are received best by horizontal antennas. Figure 6-1 shows both vertical and horizontal polarization of waves.

Directivity

All antennas are directional to some extent. This means that an antenna used for transmitting will radiate more energy in certain directions; an antenna used for receiving will receive signals better from certain directions. The directional characteristics of an antenna are determined to a great extent by its design and the position in which it is installed. Thus certain directional qualities are associated with each type of antenna. Special tests are usually conducted to determine the characteristics of an antenna when it is designed; then the characteristics are plotted on a chart. (See figure 6-2.) The information shown on the charts can be used to determine the best operational use for an antenna. An operator should be able to interpret and use these charts if they are available.

The directivity of an antenna is often referred to in terms of "beamwidth" which refers to the width of the directive lobes expressed in degrees of azimuth.

The following three terms are used to describe general directional qualities of an antenna:

Omnidirectional—Receives or radiates equally well in all directions

Bidirectional —Receives or radiates efficiently in two directions; for example, North and South or East and West

Unidirectional —Receives or radiates efficiently in only one direction

Frequency Coverage

Frequency coverage refers to the bandwidth in the r-f spectrum in which an antenna will receive or radiate efficiently. Because some

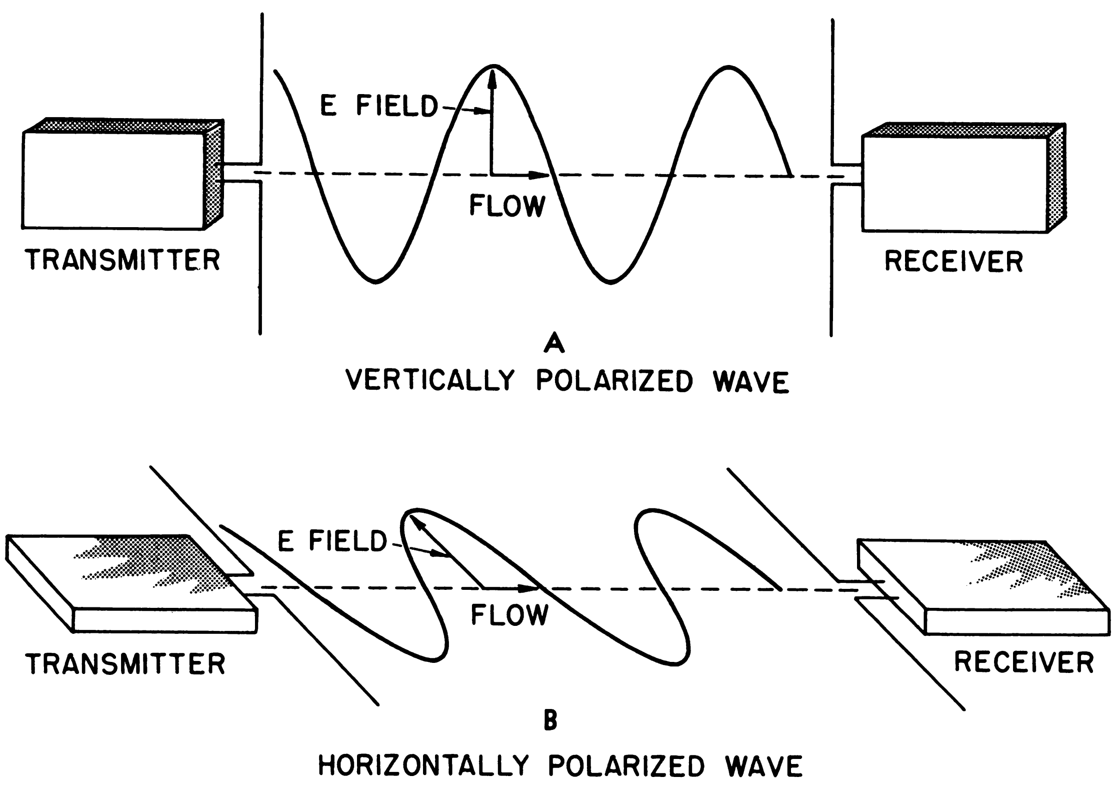

Figure 6-1.—Vertical and horizontal polarization.

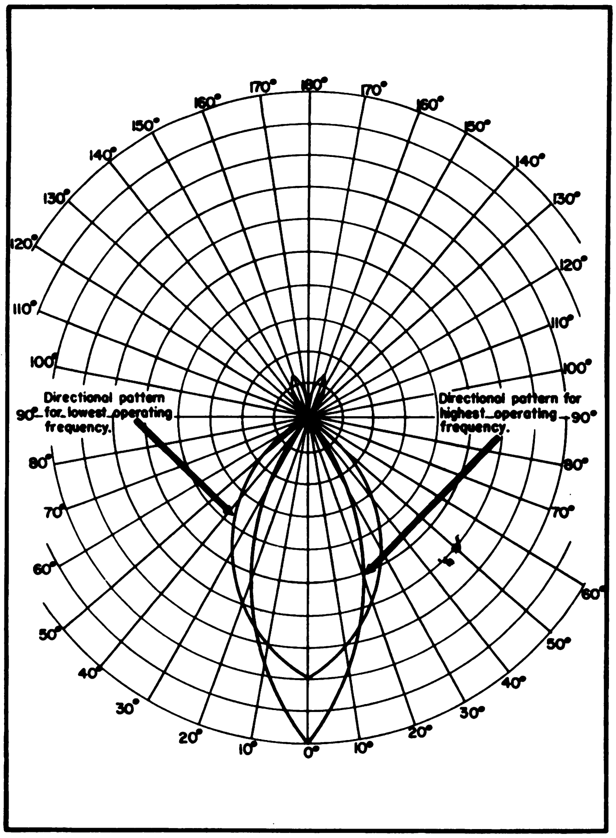

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Figure 6-2.—Plot of directional characteristics of an antenna.

antennas operate efficiently over a wide frequency range, they are referred to as "broadband" antennas. Others operate efficiently over a very narrow frequency band; the basic half-wave and quarter-wave antennas are example of this type.

BASIC TYPES OF ANTENNAS

Half-Wave

A basic form of antenna with a length of one-half wavelength or a multiple thereof is known as a dipole or Hertz antenna. (See figure 6-3.) This type of antenna will not function efficiently unless its length is one-half wavelength (or a multiple thereof) of the frequency to be radiated or received. Therefore, this antenna is not suitable when a wide range of

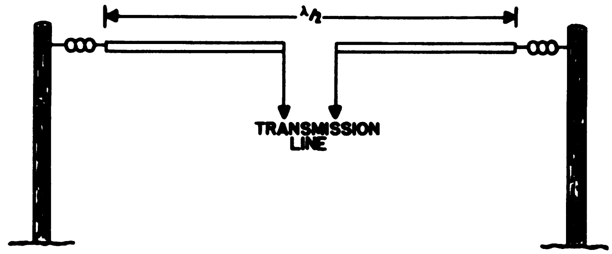

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Figure 6-3.—Half-wave (Hertz) antenna.

frequencies is to be used. A distinguishing feature of a dipole antenna is that it need not be connected to the ground as are other antennas which will be described later. At low frequencies half-wave antennas are rather long; therefore they are used primarily at shore installations where there is sufficient room for them. They can be connected to transmission lines either in the center or at the ends and can be installed in either a vertical or horizontal position. The half-wave antenna is sometimes referred to by other terms which indicate its shape or electrical characteristics, such as doublet, end-fed, center-fed, etc.

Quarter-Wave

A grounded antenna which is one-fourth wavelength or any odd multiple thereof of the frequency to be radiated or received is known as a Marconi antenna. (See figure 6-4.) Notice that the transmission lines are connected between the bottom of the antenna and the earth. Although the antenna itself is only a quarter wavelength, the earth acts as another quarter-wave antenna—the image antenna shown in figure 6-4. By aid of this image, half-wave operation is obtained. This type of antenna can be used on planes and ships where the plane's fuselage or the ship's hull provides the image antenna. It is often practical to use the quarter-wave antenna where space is a problem.

There are many variations of the quarter- and the half-wave antenna as well as many different types designed for special use throughout the range of the radio frequency spectrum. They are often used as components of more complex antennas. Combinations of elements, electrically connected and physically spaced

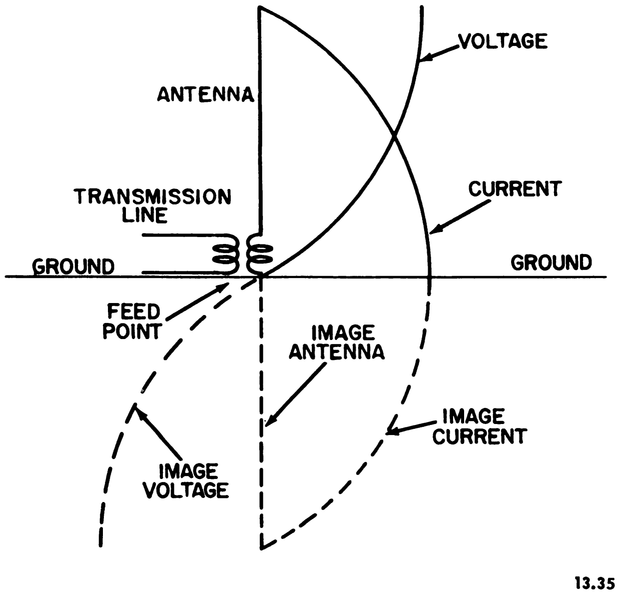

Figure 6-4.—Marconi antenna and waveforms of current and voltage.

in the proper manner, can be used to obtain many desirable features. Such a combination of elements is known as an ARRAY.

Long-Wire

For some applications, especially in VLF and LF transmissions, it is practical to use an antenna that is simply a long single wire connected at one end to the equipment. These long-wire antennas will usually be stretched between poles in such a manner that the wire is essentially parallel to the surface of the earth. (See figure 6-5.) Long single-wire antennas may be constructed of lengths from one to seven or eight wavelengths. This means that, in many cases, the wire may be several miles long. Long-wire antennas are somewhat directional in both the horizontal and vertical planes. They receive best those signals which arrive at a slight angle to the axis of the wire.

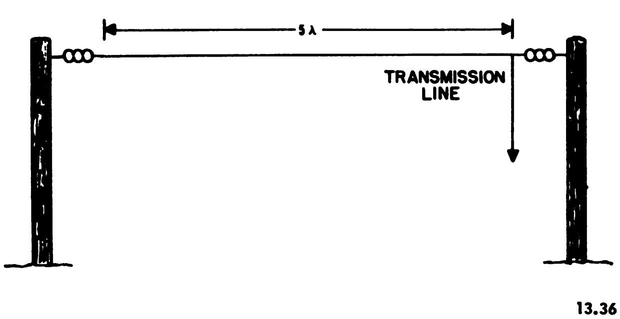

Figure 6-5.—Long-wire antenna.

One variation of the long-wire antenna, called the Wave or Beverage antenna, is composed of a single wire that is longer than one wavelength. However, it is constructed in such a manner that it is tilted from the horizontal (not parallel to the earth's surface) and is electrically terminated in such a way that it is essentially unidirectional along the axis of the wire in the direction of the tilt.

Rhombic

The rhombic antenna, which is used extensively at shore based activities, is actually an array, composed of a combination of basic long-wire antennas. The following are advantages which the rhombic offers over other types:

1. Broad frequency coverage.
2. Excellent directivity in both the horizontal and vertical plane.
3. When properly orientated, a good signal-to-noise ratio for receiving.
4. Relatively simple in design and construction.

These advantages depend upon certain design factors which are inter-related to some extent; therefore some compromise is necessary to obtain the best antenna for general use. For example, to design a rhombic for maximum directivity, some sacrifice of broad-band coverage may be necessary. Figure 6-6 shows a typical rhombic antenna.

The characteristics of a rhombic are determined by such factors as the length of the legs, the height of the antenna above the ground, and the angles between the legs. It is also possible to improve signal-to-noise ratio of receiving rhombics by using several wires instead of a single wire to form each leg. Such antennas are referred to as a multiple-wire or curtain rhombics.

The rhombic is either bidirectional or unidirectional, depending on the electrical termination at the ends of the antenna. If terminated as shown in figure 6-7, it is unidirectional in the direction of the terminating resistance. The rhombic antenna, when terminated at both

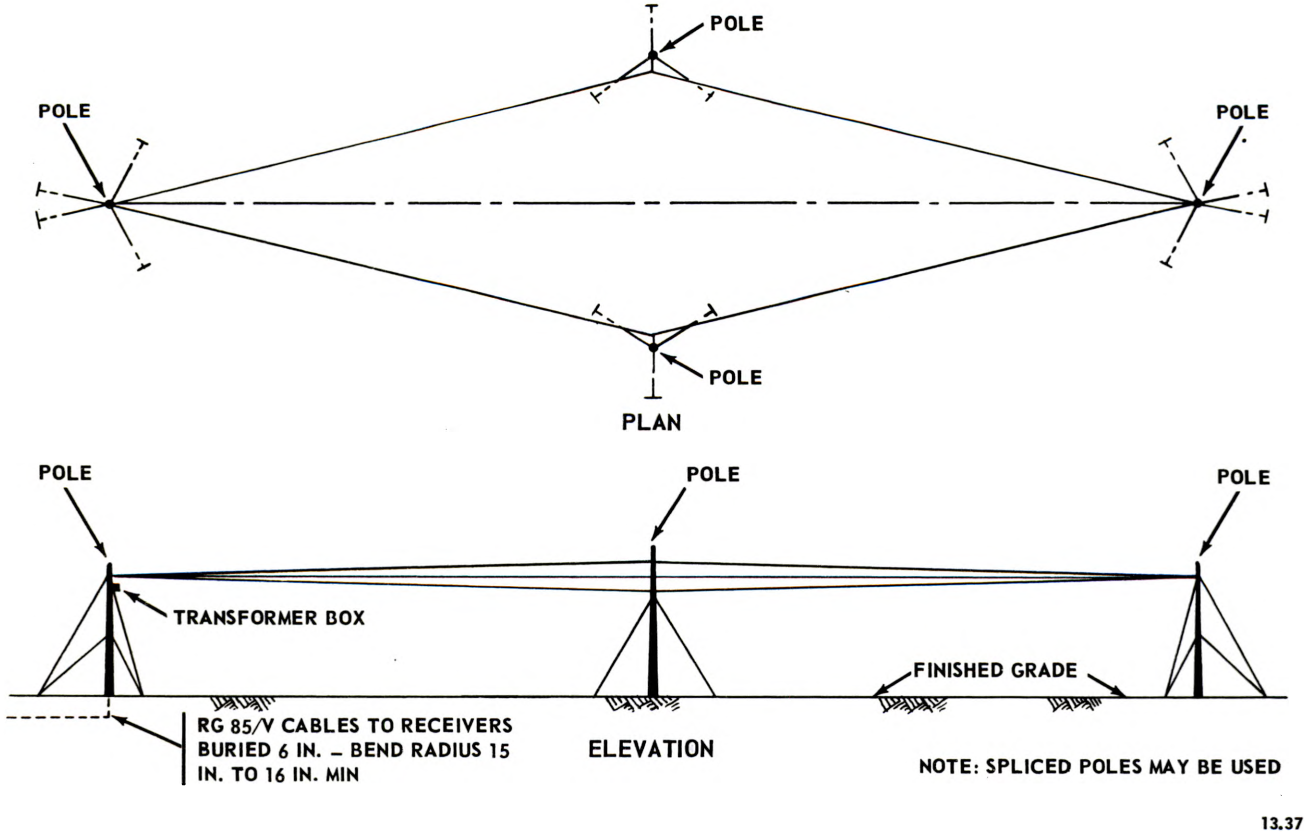

Figure 6-6.—Rhombic antenna-receiving.

ends and used simultaneously with two receivers, acts as unidirectional antennas in two directions separated in azimuth by 180 degrees. The rhombic is normally used for frequencies in the HF band and above.

Vee

The vee antenna, which is somewhat similar to the rhombic, is illustrated in figure 6-8. The vee, like the rhombic, is a broad-band antenna used for frequencies in the HF band and above. It can be bidirectional or unidirectional depending on its electrical termination.

Sleeve

Sleeve antennas are variations of either basic quarter- or half-wave antennas, depending upon the frequency range to be covered. They are normally used in the vertical position to provide omnidirectional coverage. One important advantage of the sleeve over basic Hertz or Marconi quarter- and half-wave antennas is that it operates efficiently over a much wider frequency range. For this reason it is often referred to as the broad-band sleeve antenna. Figure 6-9 shows a simplified sketch of a sleeve antenna.

Horn

Horn antennas are widely used in the frequency spectrum above 1000 mc because they are capable of high directivity. They are not used at lower frequencies because the physical dimensions become too large for practical application. Figure 6-10 illustrates three types of horn antennas.

Stub

One variation of a quarter-wave antenna is the stub antenna which is equipped with a ground

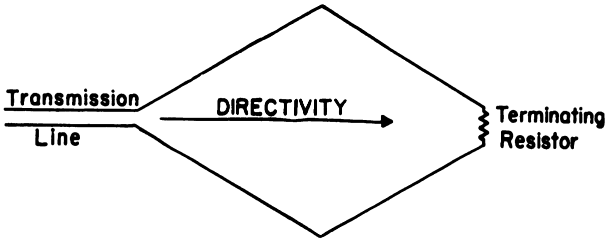

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Figure 6-7.—Directivity of a terminated rhombic.

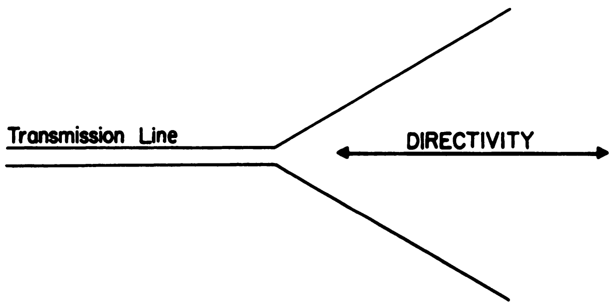

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Figure 6-8.—"V" antenna.

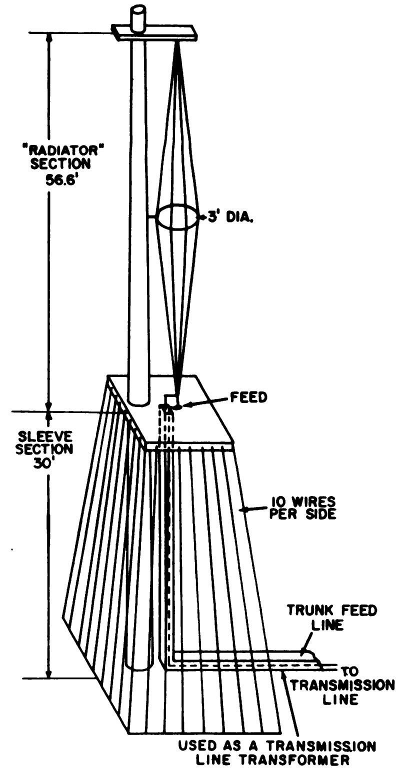

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Figure 6-9.—Simplified sketch of a sleeve antenna.

plane and is normally mounted at a 45-degree angle so that it is capable of receiving both horizontally and vertically polarized waves. Figure 6-11A shows a stub antenna with ground plane. The stub antenna is used primarily in the VHF and UHF bands.

Cone

Another variation of the quarter-wave antenna is the cone antenna. The name is derived from the physical construction which has the appearance of a cone. In many cases it is equipped with a disc at the apex of the cone to provide certain desired electrical characteristics. In such cases it is referred to as a discone antenna. A biconical antenna, in which two cone-shaped sections are joined at their tips, can also be used. Both the discone and biconical antennas operate more efficiently over a wider frequency band than the basic quarter-wave from which they are derived. Their most common applications are in the VHF and UHF bands. Figure 6-11B provides an example of a cone antenna.

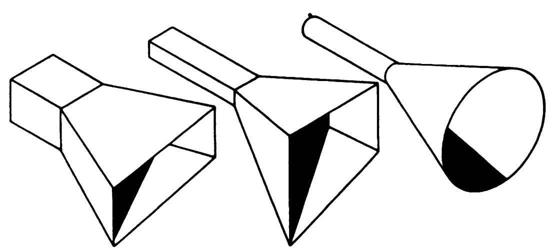

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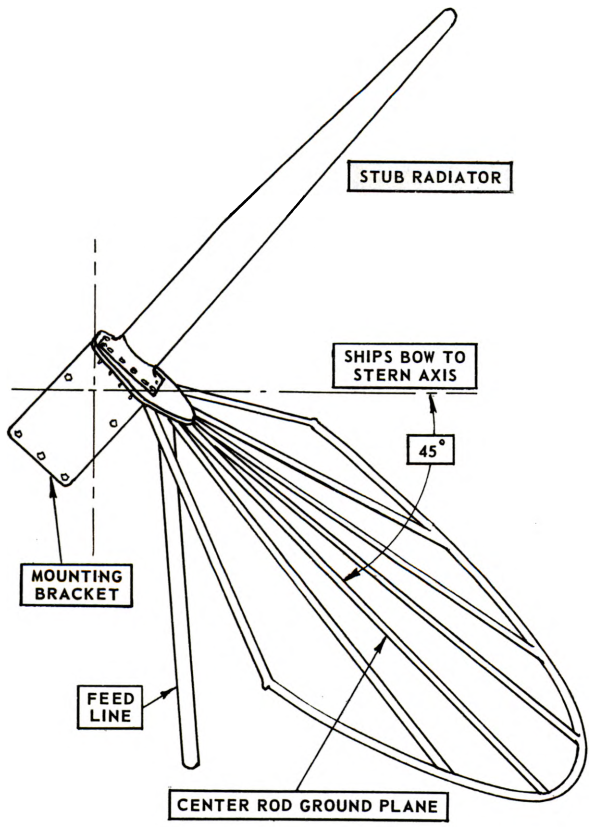
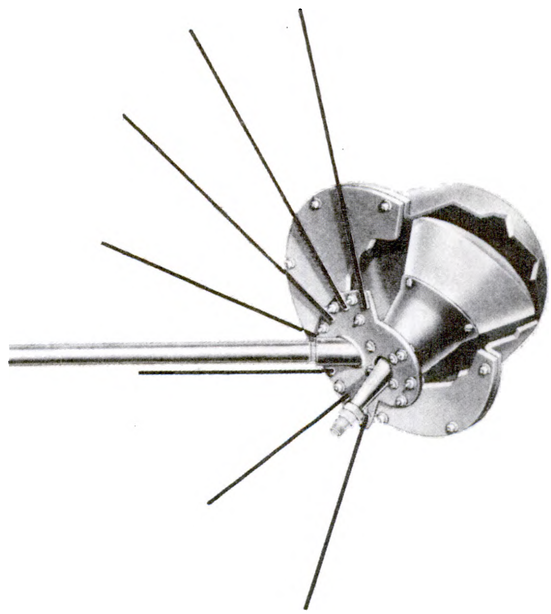
Figure 6-10.—Horn antennas.

Yagi

A yagi antenna, which is actually an array, is composed of a varying number of elements including radiators, reflectors, and directors. The directivity of the antenna depends upon the



A CAGW-66132 ANTENNA



B CAGW-66131 ANTENNA

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Figure 6-11.—Stub and cone antennas.

number of directors and reflectors. Figure 6-12 shows a four-element yagi. This type antenna is used primarily in the VHF range.

REFLECTORS

Reflectors are used to decrease the beamwidth of antennas. At frequencies below 1000 mc, the corner reflector is commonly used. A corner reflector antenna is shown in figure 6-13. At frequencies above 1000 mc, where it is easy to build antennas with beamwidths of many wavelengths, parabolic reflectors are used. Figure 6-14 shows one type of parabolic reflector.

TRANSMISSION LINES

Two basic elements in every receiving system are the antenna and the receiver. In most instances the two elements are physically separated from each other. A third element is required—a transmission line to carry the energy from the antenna to the receiver. Therefore, efficient coupling between the antenna and the receiver is a very important consideration. There are several types of transmission lines in general use, each type having certain advantages and disadvantages. For example, one type of line is suitable for use at low frequencies but may be very inefficient at high frequencies. See figure 6-15 for an illustration of the various types of transmission lines which are discussed in the following paragraphs.

TYPES OF TRANSMISSION LINES

Parallel Two-Wire Line

Two conductors, running side by side with insulating spacers to keep them separated and

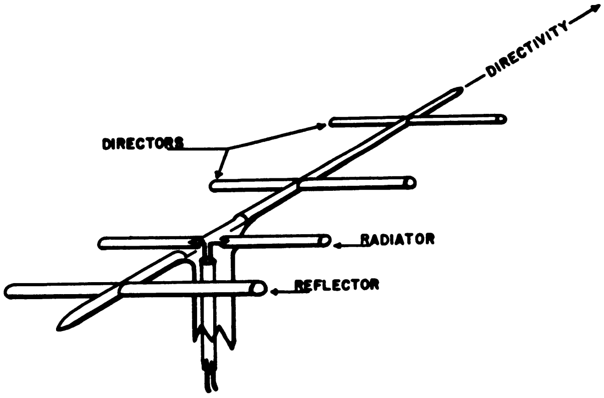

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Figure 6-12.—Yagi antenna.

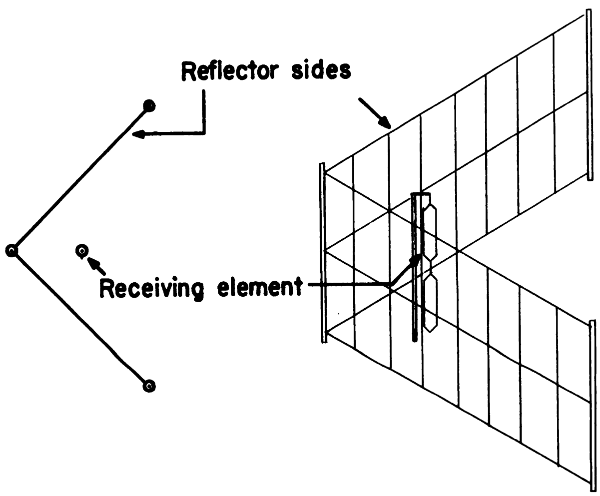

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Figure 6-13.—Corner reflector.

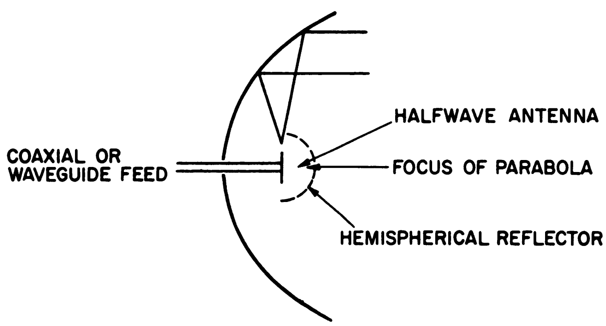

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Figure 6-14.—Cross-section view of a paraboloid.

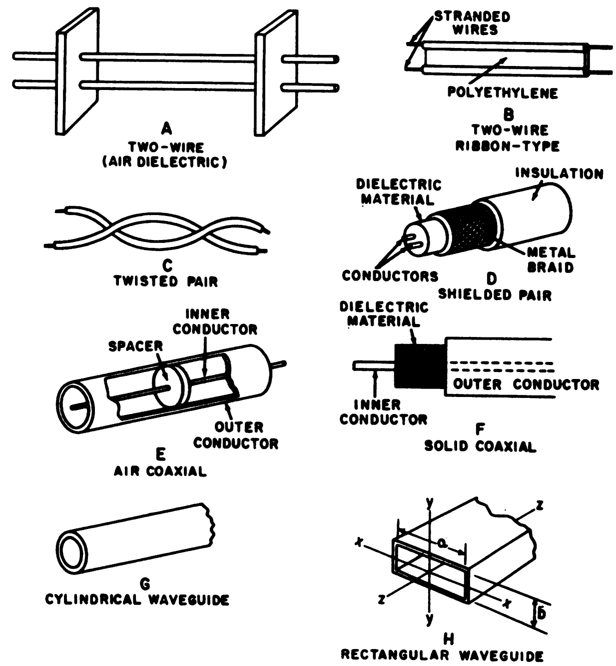

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Figure 6-15.—Types of transmission lines.

parallel form a parallel two-wire line. They are easy to construct, have good operating efficiency, and are economical. The principal disadvantage of this type of line is that it has high radiation losses and therefore cannot be used at the higher frequencies in the vicinity of metal objects. They are most often used in applications involving frequencies in the HF band and below. One notable exception is the two-wire ribbon-type line which has VHF applications. You will recognize this as the familiar antenna lead-in wire used for most television sets.

Twisted Pair

The twisted pair, as the name implies, consists of two insulated wires twisted to form a flexible line without the use of spacers. This type line is generally used for low-frequency applications over very short distances. It is not suitable for use at the higher frequencies because of the high losses incurred. Its chief advantages are that it is easy to construct, it is economical, and it may be used where more efficient lines would not be feasible because of mechanical considerations.

Shielded Pair

The shielded pair consists of two parallel conductors separated from each other and surrounded by an insulating dielectric material. The conductors are contained within a copper-braid tubing which acts as a shield for them. This type line is normally used for applications in the HF band and below. Its primary advantage is that the shield prevents radiation from the lines and prevents pick-up of undesired radiations.

Coaxial Lines

There are two general types of coaxial lines: one uses air as a dielectric between the two wires; the other uses a solid insulating dielectric. One conductor (usually the outer) is grounded to eliminate radiation. Coaxial lines operate efficiently for frequencies up to approximately 1500 mc.

AIR COAXIAL.—The air coaxial line has advantages that make it practical for operation in the UHF band and above. The disadvantages of such a line are: (1) it is expensive; (2) at extremely high frequencies, its practical length is limited because of the considerable loss that occurs; and (3) it must be kept dry in order to prevent excessive leakage between the conductors. To prevent condensation of moisture, the line may be filled with dry nitrogen gas at pressures ranging from 3 to 35 pounds per square inch.

SOLID COAXIAL.—The solid coaxial line is probably the most commonly used type of transmission line. It consists of a center conductor surrounded by a tubular outer conductor. A solid dielectric material insulates the two conductors from each other. This type of line is suitable for use up to frequencies in the lower portion of the UHF band. At higher frequencies they become less efficient due to high losses incurred in the insulating material.

Waveguides

The term "waveguide," as used in connection with transmission lines, refers to a hollow metal tube which may be either circular or rectangular in cross section. The waveguide is a very effective conductor at frequencies in the UHF band and above. Just as a speaking tube prevents voice waves from spreading and from becoming weaker, a waveguide channels the electromagnetic waves, reducing attenuation and preventing radiation until the waves are delivered to its end. Waveguides are widely used as transmission lines in modern radars. The physical dimensions of a waveguide are determined by the wavelength of the signal which is being conducted. Waveguides are not normally used for the lower frequencies because they would be too large for most practical applications.

TRANSMISSION LINE LOSSES

There are some losses associated with every type of transmission line. Any loss is undesirable because it tends to reduce the signal-to-noise ratio. Losses can be reduced to a certain extent by keeping the lines as short as possible; however, reducing the length of a transmission line does not minimize all losses. If there is a mismatch between the electrical characteristics of an antenna and a transmission line, a phenomenon called STANDING WAVES develops. Whenever there are standing waves on a transmission line, it does not serve as an efficient connection between the receiver and the antenna.

Standing waves can be minimized by the insertion of a device, either within the transmission line or at one end, which will change the electrical characteristics of the line to the desired value. Devices used for this purpose are called MATCHING DEVICES. Some matching devices provide external controls so that an operator can check the STANDING WAVE RATIO (SWR) or the VOLTAGE STANDING WAVE RATIO (VSWR). By adjusting external controls on the device, the operator can keep the standing wave ratio at a minimum value, thus providing maximum efficiency.

MULTICOUPLERS

Multicouplers are one type of antenna couplers which are used extensively at receiving sites to allow several receivers to operate simultaneously from one antenna. They are designed to provide the best possible coupling between antennas and receivers and at the same time isolate the receivers from each other. There is some loss of signal quality in multicouplers, and interference between receivers can not be completely overcome. ("Signal quality" is a term used to describe the overall usefulness of a signal and encompasses such properties as signal-to-noise ratio, distortion, etc.) In some cases it is necessary to bypass multicouplers and use only one receiver with an antenna. Such cases exist when there are several signals operating on or near the same frequency and when complex modulation systems are used. Multicouplers also are usually designed to operate sufficiently over a fixed frequency range and to have a relatively sharp cutoff above and below this range. Therefore it is important to know the operating frequency range of multicouplers in order to use them efficiently.

Multicouplers can be connected so that a large number of receivers can be fed from a single antenna. The two types of connections are known as TANDEM and CASCADE connections..

A TANDEM connection is one in which multicouplers are connected in series using a special connection provided for this purpose. Figure 6-16 shows a tandem connection.

A CASCADE connection is one in which a normal output of one multicoupler is used as the input to a second multicoupler. See figure 6-17 for an illustration of a cascade connection.

One important consideration regarding the use of tandem and cascade connections is that, as additional connections are added, there is a gradual decrease in the quality of the outputs. Because received signals are of various strengths and qualities, receiving facilities of higher capabilities are required for weak signals. Thus it is necessary to limit the number of receivers used with one antenna. If tandem or cascade multicoupler connections are properly made, a graduated quality of outputs can be obtained and used. Figure 6-18 shows an arrangement which might be used. Note that

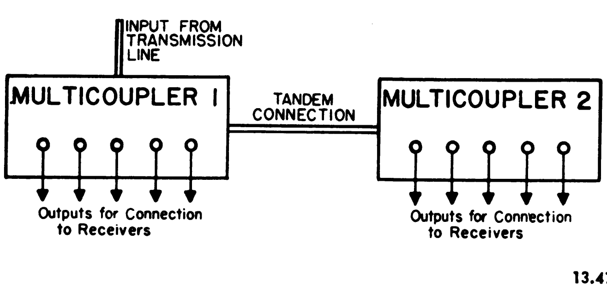


Figure 6-16.—Multicouplers connected in tandem.

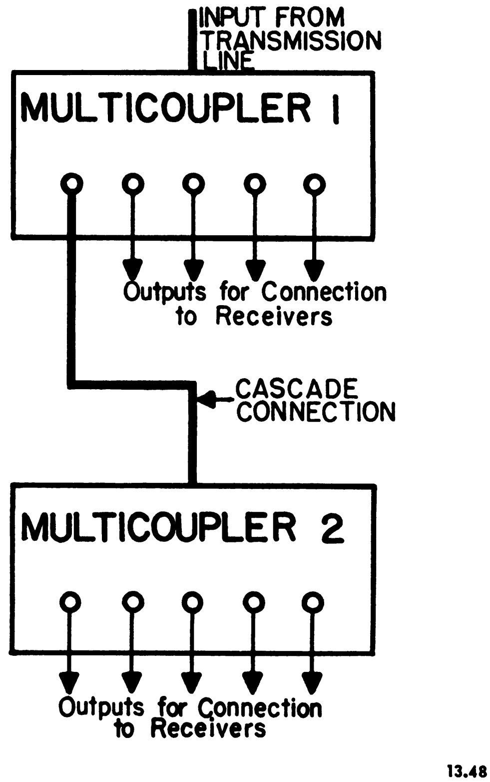


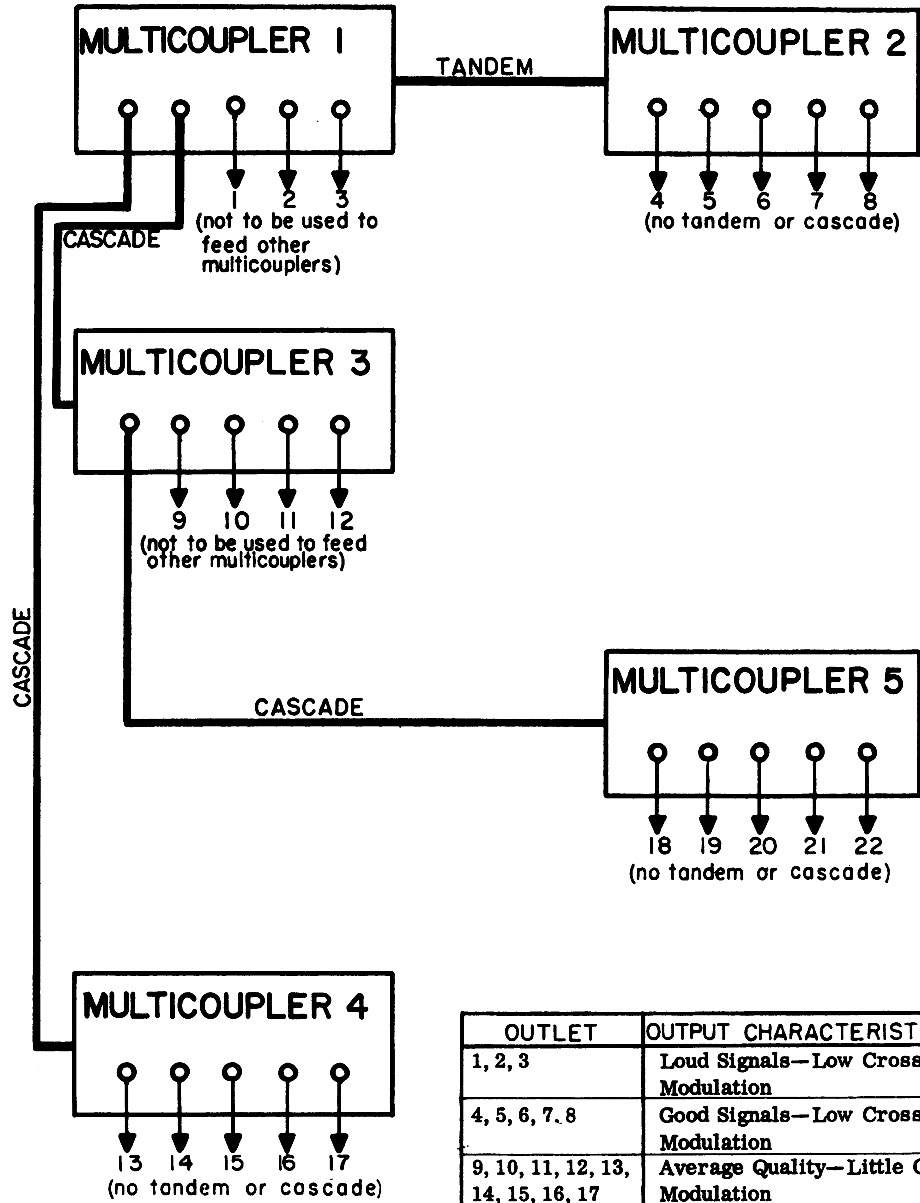
Figure 6-17.—Multicouplers connected in cascade.

multicoupler number 1 provides the highest quality outputs, with multicouplers 2, 3, 4, and 5 providing outputs of lowering quality as additional connections are added.

ANTENNA PATCH BOARDS

In addition to antennas, transmission lines, and coupling devices, an operator will also be concerned with antenna patch boards. This is the point at which the equipment is actually connected to the desired antenna. Because there are various types of patch boards in use, it is not possible to set forth detailed procedures to be used. It is well to remember that connections should be made with care and that connecting cords (usually solid coaxial lines) should be handled very carefully. Care should also be taken not to bend or break connecting plugs or damage the insulation on connecting cords.

In any case of poor communication signals, one of the first procedures should be to check the antenna patch board and all associated connections.



OUTLET	OUTPUT CHARACTERISTICS
1, 2, 3	Loud Signals—Low Cross Modulation
4, 5, 6, 7, 8	Good Signals—Low Cross Modulation
9, 10, 11, 12, 13, 14, 15, 16, 17	Average Quality—Little Cross Modulation
18, 19, 20, 21, 22	Compromised Quality but satisfactory for some signals

13.49

Figure 6-18.—Multicoupler connections showing graduated quality of outputs.

QUIZ

1. Give the definition of an antenna.
2. What is the length (expressed in meters) of a half-wave dipole designed to receive a 20-mc signal?
3. What is the frequency of a signal having a wavelength of 1000 meters?
4. Does the antenna pattern of figure 6-2 indicate that the antenna is more directive—has narrow beamwidth—at lower frequencies or at higher frequencies?
5. Which general description—omnidirectional, bidirectional, or unidirectional—would describe an antenna which has a pattern similar to that of figure 6-2?
6. What is the length (expressed in wavelengths) of the Hertz antenna? Of the Marconi antenna?
7. A system of basic antennas, connected to form a narrow directivity pattern, is known as a/an ________.
8. What is the length (expressed in meters) of an 8-wavelength long-wire antenna designed to receive 500 kc?
9. What are the general directional characteristics of a rhombic antenna?
10. What is the advantage of a sleeve antenna over the basic antenna from which it is derived?
11. Are reflectors used to make an antenna more directional or less directional?
12. What is the general directional characteristic of the Yagi antenna illustrated in figure 6-12?
13. With the exception of the ribbon-type line, parallel two-wire transmission line is limited in use to frequencies of ________ mc and below.
14. What is the advantage of the shielded pair over the parallel two-wire transmission line?
15. Which type of transmission line is most commonly used for ordinary HF communications purposes?
16. What causes standing waves and thus a loss of energy in transmission lines?
17. Which type of matching device permits more than one receiver to simultaneously use the same antenna?
18. When a normal (receiver) output of a multicoupler is connected to the input of another multicoupler, they are said to be connected in ________.

CHAPTER 7

MODULATION

INTRODUCTION

If the signal induced across the terminals of a receiving antenna is compared with the signals which energized the transmitting antenna, the received signal is found to have the characteristics of the transmitting signal. For example, if a pure sine wave of radio frequency excites a transmitting antenna, a receiving antenna placed in the path of the radiated wave will have a pure sine-wave signal induced across its terminals. The frequency of this induced signal will be exactly the same as the frequency of the signal exciting the transmitting antenna. If the frequency of the transmitting signal is increased or decreased, the frequency of the received signal will increase or decrease by a like amount. If the amplitude of the transmitted signal is increased or decreased, the amplitude of the received signal will increase or decrease by a proportional amount. This relationship of a transmitted signal to a received signal makes possible the transmission of information by radio waves. If the characteristics of the transmitting signal are altered in a manner to convey information, the variations of the signal can be interpreted at the receiver to recover the intelligence. This is the basis of the process known as modulation.

MODULATION is the process by which a characteristic, such as amplitude or frequency, of a signal is made to vary according to the voltage or current variations of another signal. The signal which is modulated is referred to as the CARRIER; its frequency, referred to as the CARRIER FREQUENCY, is ordinarily in the r-f spectrum. The modulating signal, which represents the information, is normally much lower in frequency than the carrier, usually in the audio frequency range. DEMODULATION is the process by which the information is recovered from the modulated carrier. Thus, modulation is a process associated with radio transmitters; demodulation is a process associated with radio receivers.

This chapter will be limited to an explanation of some of the common methods of modulation in use throughout the r-f spectrum. The theory will be explained in general terms rather than in technical detail since the purpose of the chapter is to provide the fundamentals only.

AMPLITUDE MODULATION

Amplitude modulation (am) may be defined as the variation of the strength of a radio-frequency wave for the purposes of conveying information. In other words, the r-f wave is made to decrease and increase in amplitude according to the modulating signal. The wave shown in figure 7-1 illustrates an amplitude-modulated signal.

In this illustration the carrier wave is made to increase and decrease in amplitude according to an audio-frequency signal. When the frequency of the audio signal is high, the radio-frequency carrier changes in amplitude more rapidly than when the frequency of the audio signal is low. When the amplitude variations of the audio signal are greatest, the amplitude of the carrier varies by a greater percentage than when the amplitude variations of the audio signal are low.

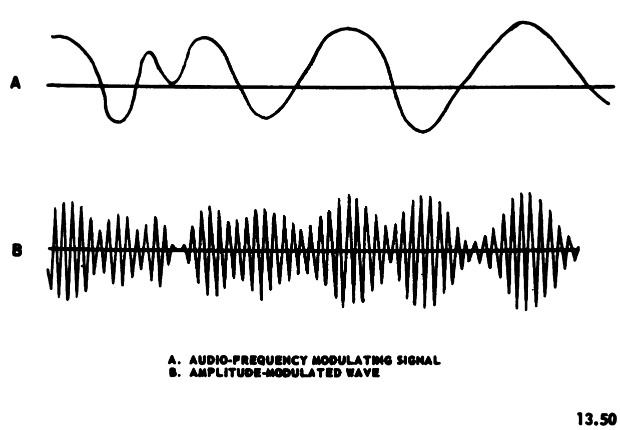


Figure 7-1.—Amplitude modulation.

The degree of modulation of an a-m wave is expressed as a percentage value. If, during the process of modulation, the amplitude of the wave is caused to go to zero, the percentage of modulation is said to be 100%. When using amplitude modulation to transmit audio information, if the r-f wave is caused to remain at zero amplitude during a portion of the audio signal, the percentage of modulation is in excess of 100%. This effect is illustrated in figure 7-2. Modulation of greater than 100% will result in distortion of the audio signal at the receiver. It is important that the amplitude of the carrier be varied as much as possible, because the output of a receiver varies with the amplitude variations of the received signal. Therefore, it is desirable that an a-m wave be modulated as near 100% as possible but not in excess of 100%.

Figure 7-3 shows the resultant wave produced

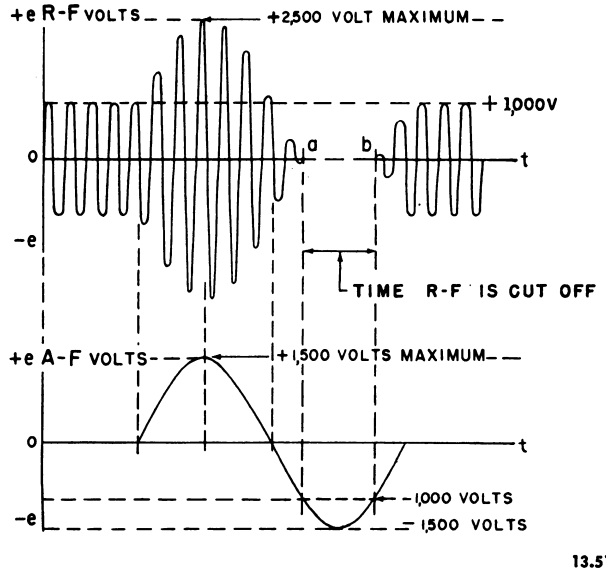


Figure 7-2.—Amplitude modulation in excess of 100 percent.

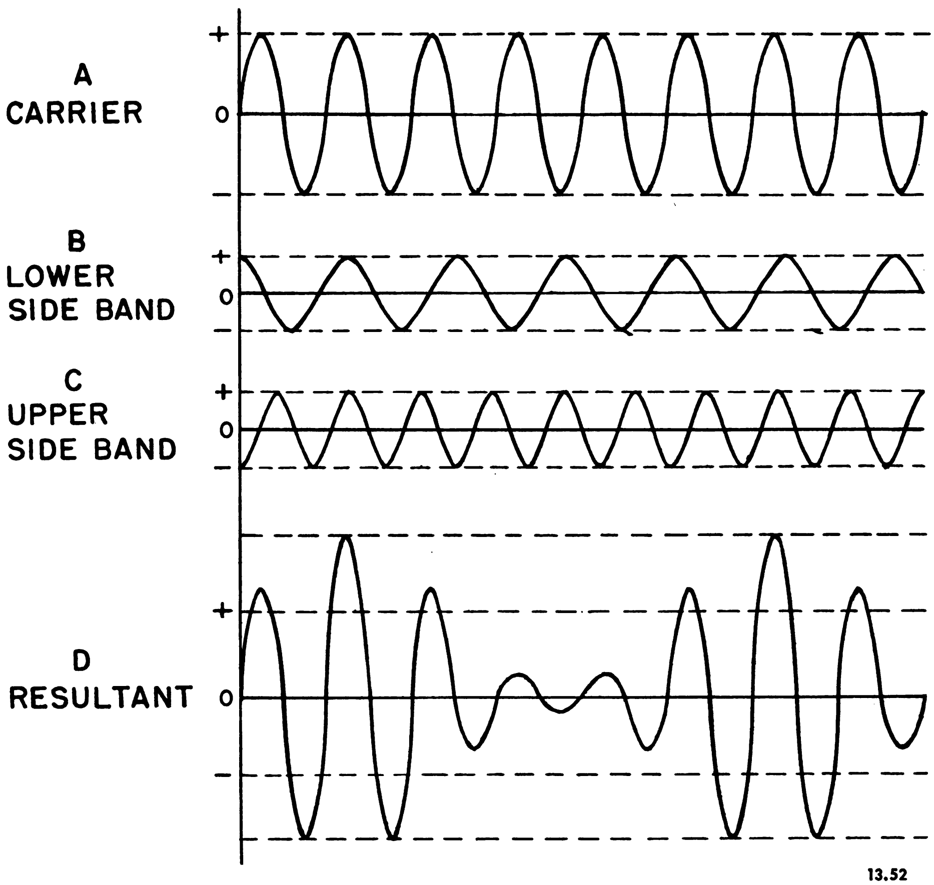


Figure 7-3.—Curves showing how the carrier and sidebands combine to produce an a-m wave with 100 percent modulation.

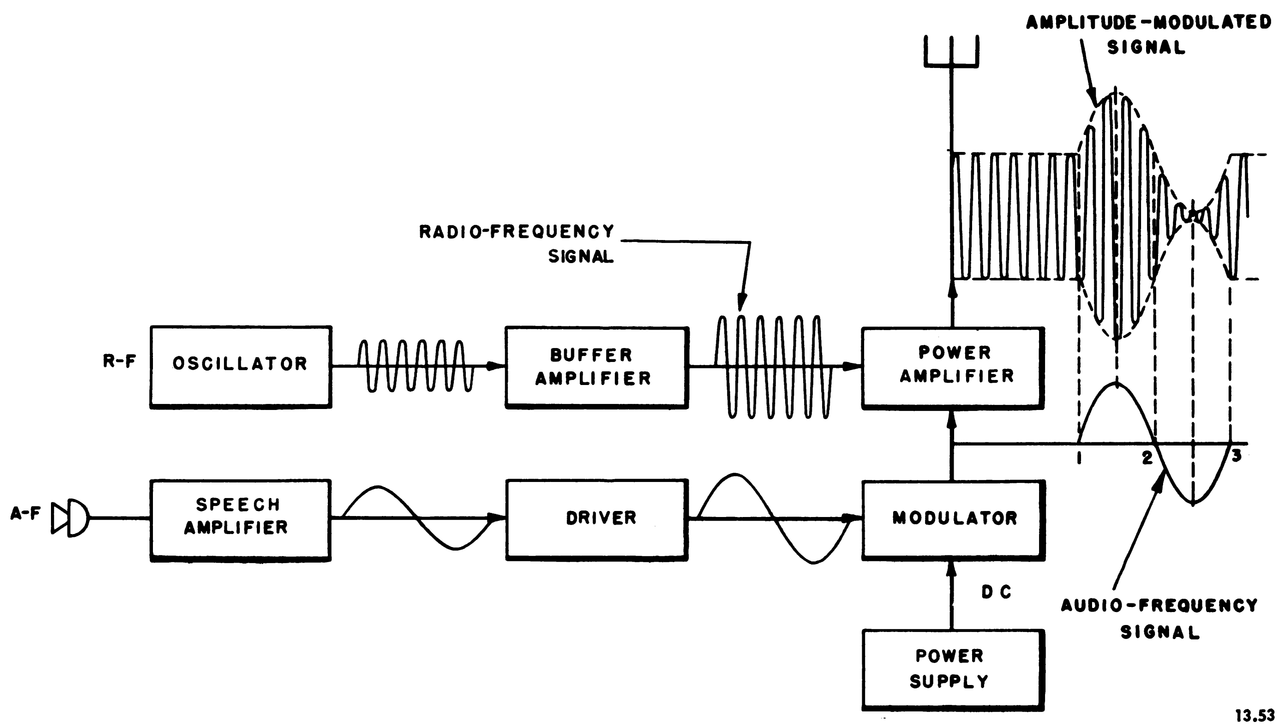


Figure 7-4.—A-m radiotelephone transmitter.

by amplitude modulating an r-f carrier with a single audio tone. Notice that the resultant wave consists of three separate waves. The three waves are the carrier (A), lower sideband (B), and upper sideband (C). The lower sideband has a frequency equal to the difference between the modulation and carrier frequencies. The upper sideband has a frequency equal to the sum of the carrier and modulation frequencies. The sum of the sideband signals and the carrier signal makes up the resultant wave.

The carrier and sidebands making up a modulated signal can be separated from each other, by means of filters, and used individually. In an a-m wave, only the sidebands contain information (the modulating frequencies). Thus, it is desirable that as much power as possible be put into the sidebands. The sidebands will contain the maximum amount of power when the degree of modulation is 100%. When this condition exists, the sidebands contain exactly one-half the amount of power contained in the carrier.

Because an a-m wave has sidebands on each side of the carrier, the transmission of information by amplitude modulation requires the use of a band of frequencies rather than a single frequency. The total bandwidth will equal twice the highest modulating frequency.

Figure 7-4 further illustrates amplitude modulation. This figure, a block diagram of an a-m radiotelephone transmitter, illustrates one of the common uses of amplitude modulation. The top row of blocks indicates the section of the transmitter which produces the radio-frequency carrier. The next row of blocks indicates the audio section of the transmitter. It receives an audio signal, produced by a voice microphone, and builds it up to the proper level by amplification to control the amplitude of the r-f signal produced at the final r-f amplifier. The output of the final r-f amplifier is fed to the antenna which then radiates a modulated r-f wave into space.

AMPLITUDE MODULATION METHODS

On-Off Keyed Carrier (OOK)

The simplest method of transmitting information by an r-f carrier is to turn the transmitter on and off according to a prearranged code. This system may be expressed as employing amplitude modulation in its simplest form; that is, the amplitude is changed from zero to 100 per cent. Figure 7-5 shows a radio wave after modulation by a telegraph code signal. The frequency of the carrier is unaffected by the modulation.

On-off keying has the overall advantage of simplicity, but has the disadvantage of inability to cope with variations in received amplitude. During the time the transmitter is turned off, the signal may be filled in with bursts of atmospheric noise, making it difficult for receiving equipment to discriminate between the signals and the noise. The most common use of OOK is for radiotelegraph Morse transmission. This method is often referred to as continuous wave (cw).

On-Off Keyed Modulation Carrier (MCW)

In the m-c-w method, the carrier is modulated by a tone of audio frequency before it is turned on and off (keyed) in accordance with a telegraph code. An m-c-w signal occupies a wider bandwidth in the r-f spectrum than a c-w signal. The m-c-w method is used primarily for emergency and distress communications.

Double Sideband (DSB)

Ordinary amplitude modulation systems, with both sidebands present, are referred to as double sideband systems. An r-f carrier with double sideband modulation was illustrated in figure 7-3, showing the information carried in the sideband frequencies generated by varying the amplitude of the r-f carrier. Voice-modulated radiotelephone and commercial radio broadcast transmissions are examples of DSB modulation.

Single Sideband (SSB)

As discussed earlier, an a-m wave consists of an r-f carrier with a pair of sidebands for each modulating frequency. Since it is the sideband frequencies (not the r-f carrier) which actually carry the desired information, it is obvious that only one sideband is required in order to transmit the information. Using only one sideband to transmit information is known as single sideband modulation (SSB), a method used in many present-day communication systems. The SSB system is essentially an ordinary a-m system in which only one of the side bands is transmitted. See figure 7-6. One sideband is eliminated by the use of filter circuits in the transmitter. If the carrier is reduced, the system is known as single sideband reduced carrier. When the carrier is completely eliminated and only one sideband is transmitted, the system is known as single sideband suppressed carrier.

Most transmitting stations are limited as to the total amount of power they are permitted to radiate. When SSB methods are used, the power that is used for transmitting the carrier and one sideband in ordinary a-m systems can be added to the single sideband which is transmitted in the SSB system. This means that an SSB system can transmit a higher quality signal under the same limitations of power as a comparable a-m system. Single sideband modulation is commonly used for radiotelephone, radioteletype, and other special-purpose transmissions.

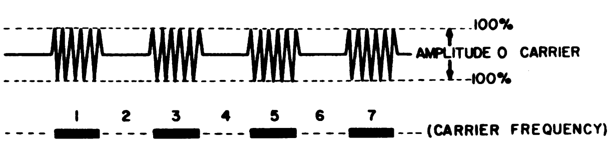


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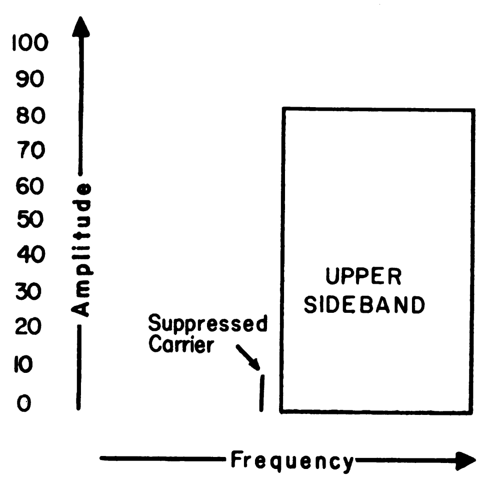
Figure 7-5.—On-off keyed carrier.



SSB Signal with carrier suppressed. Only the carrier and one sideband is transmitted.

13.55

Figure 7-6.—Single sideband suppressed carrier.

Double Single Sideband (DSSB)

Sideband systems transmitting two entirely independent canals of information, one on the lower sideband and one on the upper sideband are called double single sideband (DSSB) systems. See figure 7-7. Each sideband is independent from the other and is modulated separately to allow transmission of different types of signals. For example, the upper sideband could contain a voice transmission and the lower sideband a number of tone-modulated radioprinter signals. In order to do this, the information intended for upper and lower sidebands is passed through separate modulators and then both are radiated as sidebands of a common carrier frequency. As in single sideband modulation, the carrier may be reduced or suppressed to a very low value and the power, thus saved, added to the sidebands.

FREQUENCY MODULATION

In frequency modulation, the instantaneous frequency of a radio frequency carrier is varied in accordance with the information to be transmitted while keeping the amplitude of the wave constant. Note the comparison of the a-m wave (figure 7-8A) with the f-m wave for a single cycle of a modulating frequency. Figure 7-8B shows the frequency variations of an r-f carrier

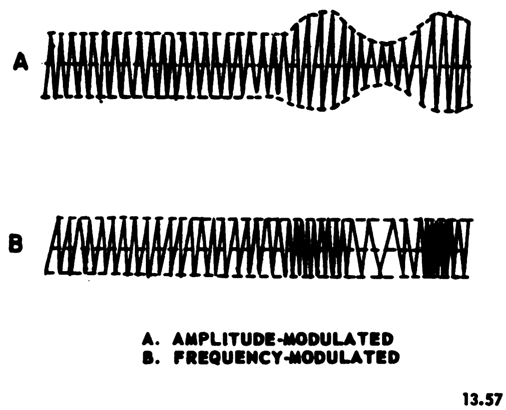


Figure 7-8.—Comparison of amplitude-modulated and frequency-modulated waves.

when frequency modulation is employed. Note that the amplitude of the carrier remains constant. The amount of frequency deviation of the carrier is proportional to the modulating signal. One of the common uses of frequency modulation is for commercial radio broadcast transmissions.

In analyzing a frequency-modulated wave for sidebands, as was done for an amplitude-modulated wave, it is found that an r-f carrier frequency modulated with a pure sine-wave audio tone has an infinite number of side-band pairs. This would indicate that an f-m signal requires an infinite bandwidth in the r-f frequency spectrum. Fortunately, only a limited number of the sideband pairs, close to the carrier frequency, contain sufficient energy to be of any consequence. However, in general, the bandwidth for most f-m systems is greater than that required for a comparable a-m system.

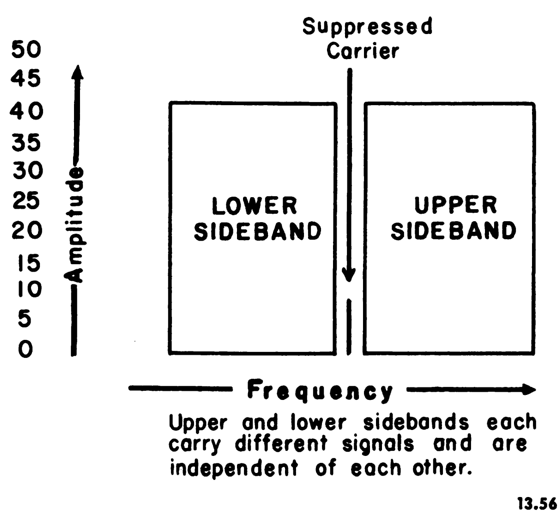


Figure 7-7.—Double single sideband suppressed carrier.

FREQUENCY MODULATION METHODS

Frequency Shift Keying (FSK)

Frequency shift keying (FSK) is a form of frequency modulation in which information is conveyed by shifting a constant amplitude carrier between two frequency limits representing mark and space conditions. FSK is commonly used in transmission of Morse code and radioteletype. In Morse code, the dots and dashes represent the marking conditions; the spaces between dots and dashes represent the spacing conditions. Teletype signals are composed of bands which have only two values, mark or space; therefore, these conditions can be represented by the two frequencies of an FSK transmission. Figure 7-9 is a diagram of frequency shift keying showing the mean carrier value and the upper (mark) and lower (space) frequency values.

Double Frequency Shift Keying (DFS)

When multiple frequency shift is used, one transmitter is capable of handling two high-speed telegraphic systems simultaneously without loss of power and within the bandwidth allocated to a single radiotelephone channel. The common name for this system is double frequency shift keying (DFS). In order to transmit two systems independently by the DFS method, four frequencies are necessary; the frequency of the carrier varies between the four values, each value indicating the combined states of the two systems. Figure 7-10 shows DFS keying of two teletype signals. If the four frequency values are represented by A, B, C, and D, the following indicates the function of each frequency:

Frequency	Function	
	System 1	System 2
A	Mark	Mark
B	Mark	Space
C	Space	Mark
D	Space	Space

For example, when the carrier is shifted to frequency A, there is a mark condition in both systems. When the carrier is shifted to frequency B, system 1 is mark and system 2 is space, and so forth. The spacing between the four frequencies may vary from a few hundred cps up to 1000 or more cps.

Carrier Frequency Stepping (CFS)

Carrier frequency stepping is a special kind of frequency modulation in which the carrier frequency is stepped to any one of a number of predetermined values. This system, although not as widely used as FSK and DFS, is sometimes used for teleprinter transmission. In such cases, because each frequency represents a character or teleprinter function, many frequency values are required; for example, 32 separate frequencies.

PHASE MODULATION

Phase modulation is defined as the variation of the instantaneous phase of a radio-frequency carrier (with respect to the phase of the carrier in the unmodulated state) by an electrical angle that is proportional to the variation of the modulating signal. When considering the waveform that results from pure phase modulation, it is found that changing the instantaneous phase is equivalent to changing the instantaneous frequency. Thus phase and frequency modulation are very similar. Pure phase modulation is not often used in practical systems; however, many systems use phase modulation methods to achieve frequency modulation of the r-f carriers.

PULSE MODULATION

In pulse modulation systems, information can be transmitted by the use of pulses of

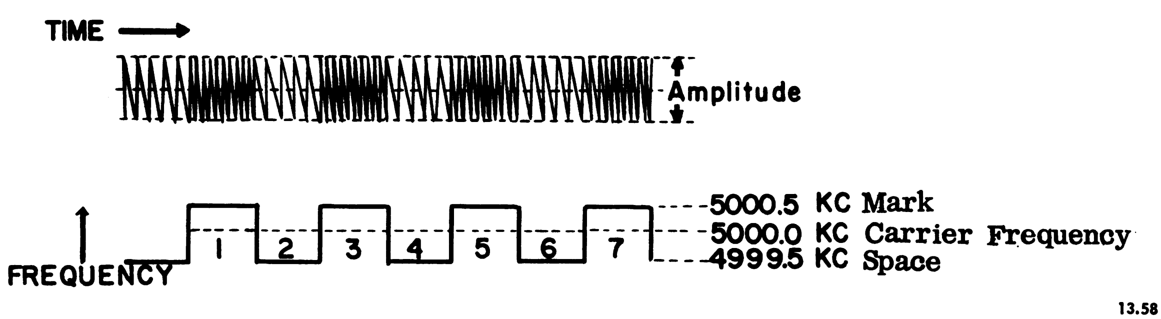


Figure 7-9.—Frequency shift keying.

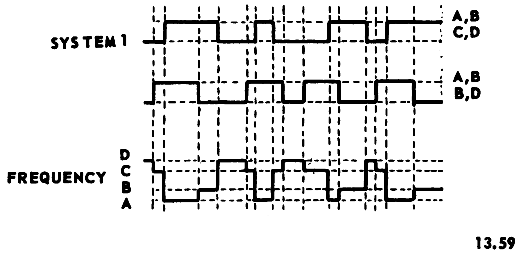


Figure 7-10.—Double frequency shift keying.

r-f energy. Pulses of r-f energy are formed by a method of quickly turning on and off a transmitter in order to form a series of pulses. In order to convey information, either the characteristics of the pulses or the sequence of pulses must be made to vary in accordance with the intended information. The process whereby the characteristics of pulses or pulse chains are caused to vary in such a manner is known as pulse modulation. There are several methods of accomplishing pulse modulation. Some of the most common methods are illustrated in figure 7-11.

Pulse modulation requires that the information occur at fixed intervals of time; or, if the information is of a continuous nature (a sine wave for example), it must be sampled at fixed intervals of time. Figure 7-11 assumed the use of a sine wave, as illustrated by the top line of the figure. In this instance, the sine wave has been sampled at evenly spaced instants in time. The value of the sine wave at these instants is represented by the pulses presented directly below. Each of the pulse modulation methods will be briefly described in the following paragraphs.

PULSE MODULATION METHODS

Pulse Amplitude Modulation (PAM)

Pulse amplitude modulation is accomplished by varying the amplitude of the pulses of a pulse train in accordance with the amplitude of the modulating signal.

Pulse Width (Duration) Modulation (PWM or PDM)

Pulse width modulation (also referred to as pulse duration modulation) is a process whereby the width of each pulse in a pulse train is caused to vary according to variations in the amplitude of the modulating signal.

Pulse Position (Phase) Modulation (PPM)

Pulse position modulation is a method whereby the position of the pulse along the time axis are caused to vary around their unmodulated position in accordance with the modulating signal. In the example shown, two pulses are transmitted for each information sample. The first pulse is a reference pulse and it does not vary in position. The second pulse varies in time position (time phase) with respect to the reference pulse in accordance with the amplitude of the modulating signal.

Pulse Frequency Modulation (PFM)

Pulse frequency modulation is a method whereby the repetition rate of the pulse train is caused to vary in accordance with the modulating signal. In the example shown in figure 7-11, the pulse repetition rate is greatest—the pulses of the pulse train are closest together—when the amplitude of the modulating signal is greatest.

Pulse Code Modulation (PCM)

Pulse code modulation signals are characterized by a coded train of pulses, each code representing an instantaneous condition (for example, amplitude) of the modulating signal; that is, the information to be transmitted does not actually modulate of modify the pulse train, but rather causes the formation of varying sequences of pulse groups. The pulse groups are caused to change in accordance with the modulating signal. In some systems, binary numbers are used as the basis for the symbols.

TONE MODULATION

Tone modulation methods may be considered as supplements to the basic carrier modulation methods already discussed. The tones used for this purpose are generally in the audio range and are commonly referred to as subcarriers. Because they are in the audio range, modulated tone signals may be transmitted over audio circuits such as telephone circuits or by radio. Modulation of r-f carriers with several tone signals is a system

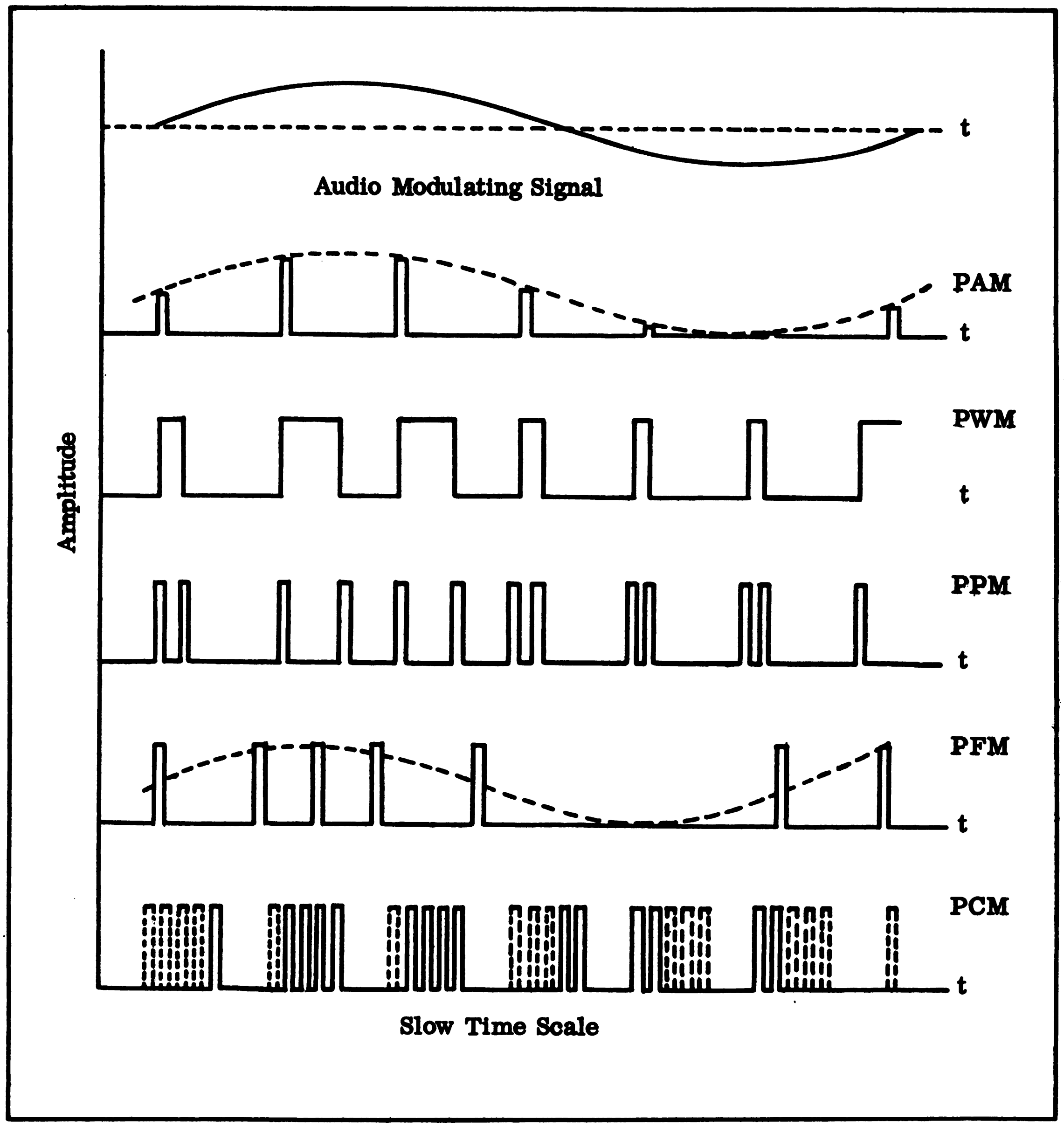


Figure 7-11.—Pulse modulation methods.

of frequency division multiplexing which will be discussed later in this chapter.

TONE MODULATION METHODS

On-Off Keyed Tone

This method is merely the keying on and off of one or more tones (each representing a different stream of information) within a transmission. In a single sideband transmission, a number of OOK tones can be used to send simultaneously several channels of traffic.

Tone Shift Keying

Tone shift keying applies the conventional frequency shift keying (FSK) method to an audio tone. The tone is shifted between two frequencies which represent marking and spacing conditions. This method is often used in single sideband systems carrying several channels of teleprinter or Morse information. Figure 7-12 illustrates a typical system with six teleprinter channels carried in a single sideband transmission by tone shift keying six separate tones.

MULTIPLEXING

Radio stations of the world are prevented from interfering with each other primarily by being assigned to different carrier frequencies and by being limited to prescribed bandwidths about these carrier frequencies. This assignment of the available frequency spectrum allows a maximum number of stations to use a common propagating medium with a minimum of interference between transmissions. The term multiplexing describes methods which allow two or more channels or canals of information to be transmitted on one carrier, thereby permitting each station to transmit more information within its allotted portion of the r-f spectrum. The two general methods of multiplexing are FREQUENCY DIVISION and TIME DIVISION. Multiplexing is a technique of combining several channels of information for transmission on a common carrier; therefore, it is not actually a form of modulation. It is, however, discussed here to help you understand how simple signals can be combined to form complex signals for transmission.

MULTIPLEXING METHODS

Frequency Division Multiplexing

The principle of frequency division is applied to allow a maximum number of stations to use the entire radio frequency spectrum. Similarly, the bandwidth allowed to each r-f carrier can be subdivided into smaller bands separated by frequency division, thus permitting the transmission of more than one channel of information on a single carrier. In frequency division multiplexing, each channel of information is caused to modulate a different frequency, which is called a subcarrier because it must be much lower in frequency than the common r-f carrier. The individual subcarriers may be amplitude-, frequency-, or pulse-modulated. The only requirement is that the subcarriers be separated in frequency by a sufficient amount to prevent interference between channels. After the individual subcarriers have been modulated, they are combined to form a complex wave which modulates the common carrier by one of the ordinary methods of modulation.

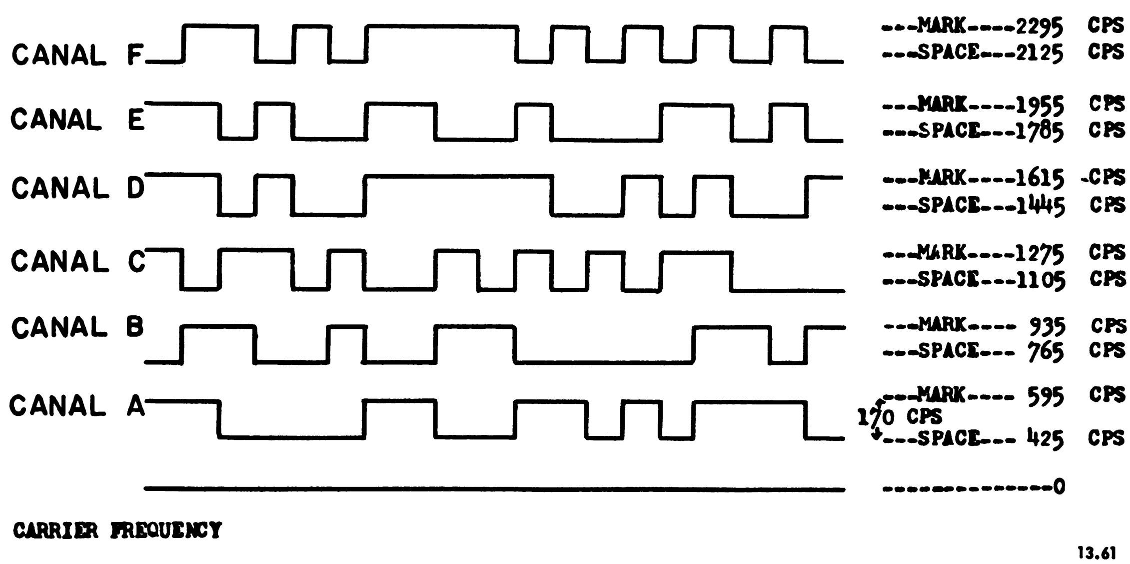


Figure 7-12.—Transmission using tone shift keying.

One example of frequency division multiplexing is a system used to transmit several channels of voice on one carrier. Each voice signal causes amplitude modulation of a subcarrier which is separated from other subcarriers by a definite frequency interval. These individually modulated subcarriers are then combined to form one complex wave which modulates the r-f carrier. Of course, the requirement that all subcarriers be sufficiently separated to prevent mutual interference requires that a wide bandwidth be used for transmission. For example, a single carrier modulated by four voice channels could require a bandwidth of as much as 12 KC. (See figure 7-13.)

Another example of frequency division is the multiplexing of a number of teleprinter channels on one carrier frequency. In this case, the subcarriers are usually tone modulated by one of the methods previously described (OOK or FSK). Refer to figure 7-12 in which six teletype signals are being transmitted on an SSB system using FSK tone modulation.

Telemetry signals from test aircraft and space vehicles are often multiplexed by the frequency division method. Because it is desirable in most telemetering systems to transmit a large number of channels of information, a wide bandwidth is required. For this reason most telemetering signals are transmitted on frequencies in the VHF band and above where wide bands of frequencies can be allocated. When frequency division multiplexing is employed, one subcarrier is used for each channel of information. The subcarriers can be modulated by any of the ordinary methods before they are combined for transmission by the common carrier.

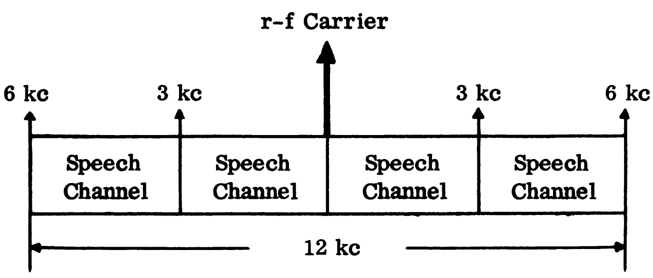


Figure 7-13.—DSSB signal with 12-KC bandwidth.

Methods used for microwave relay links provide another example of frequency division multiplexing. A system might contain two or more canals of frequency division multiplexed information modulating an r-f carrier in the VHF band. The first of the canals might carry amplitude-modulated telephone traffic, the second might carry high speed FSK teletype, and a third canal might be further subdivided by frequency division to carry several channels of teletype and Morse information by tone modulation methods. In addition to being frequency division multiplexed, any of the individual channels may be time division multiplexed. (Time division multiplex will be discussed in the next section of this chapter.) The foregoing example illustrates the possible complexity of a signal generated by multiplexing methods. It also illustrates the possibility of simultaneous transmission of not only a large number of channels of information but also information of different types.

Time Division Multiplexing

Time division multiplexing is the process of dividing the time available in a transmission among two or more channels of information to be transmitted on a single carrier. It is particularly adaptable for use with baud-based systems (such as radioprinter) and pulse-type systems. In time division multiplexing all channels to be transmitted are "sandwiched" together by a timing device (the multiplexer) which samples the intelligence signal of each channel in turn and allots a specific and equal portion of the available time to each channel. A similar device (the demultiplexer) at the receiving end separates the individual channels. Obviously, in this type system the multiplexing and demultiplexing devices must be synchronized (maintained in proper time relationship).

In most time division multiplexing systems, synchronization is accomplished by inserting a reference or timing element at the same time instant during each multiplexing cycle. This timing element is usually referred to as the "sync" element and can be made distinguishable from information elements by retaining exactly the same characteristics for every cycle. The timing elements of a time division multiplexing system serve the same purpose as subcarrier frequencies in frequency division multiplexing systems in that they provide points of reference to locate individual channels of the system.

There are two basic methods of time division multiplexing, SEQUENTIAL and INTERLACED. A sequential system is defined as one in which the elements (normally bauds or pulses) of each channel are adjacent to each other. When all elements of one channel have been sent, those of the succeeding channel are sent, and so on until all channels of the system have been transmitted. Consider a four-channel, five-baud printer signal. If the individual bauds of each channel are represented by the numbers 1 through 5, and there are four channels, identified by the letter A through D, the order of transmission of one complete cycle would be as follows: A1, A2, A3, A4, A5; B1, B2, B3, B4, B5; C1, C2, C3, C4, C5; D1, D2, D3, D4, D5—and then the cycle repeats.

An interlaced system is defined as one in which one element is sent from each channel in turn, followed by the next element from each channel in turn. For example, if we again assume a four-channel, five-baud printer system, the order of transmission for one complete cycle using an interlaced arrangement would be as follows: A1, B1, C1, D1; A2, B2, C2, D2; A3, B3, C3, D3; A4, B4, C4, D4; A5, B5, C5, D5—and then the cycle repeats.

In many situations it is desirable to use time division multiplexing for continuously varying information. Telemetry systems are examples of the application of time division multiplexing of several channels of continuously varying information. Many of these systems use pulse modulation to represent the information of the individual channels, and then transmit a number of channels (for example 64) of information on one carrier using time division multiplexing. Figure 7-14 illustrates several possible methods of time division multiplexing of three channels of pulse modulation information.

During a given interval of a time division multiplex transmission, the time duration available to each channel of the system is inversely dependent on the total number of channels in the system—the larger the number of channels, the shorter the time duration allotted each channel. The practical limit on the number of channels of information which can be transmitted on one such system is determined by the shortest time duration which can be used to transmit the information from each channel and still retain reliable operation.

For example, consider a multichannel printer system in which each channel transmits information at the rate of ten characters per second (100 milliseconds/character). If the system contains five channels, 20 milliseconds are available for transmission of a character in each channel. If five bauds are required to represent each character, the resulting baud lengths are four milliseconds. If more than five channels are used, the resultant baud length will be shorter. When bauds are short, a slight amount of distortion, occurring at some point in the transmission process, results in errors at the receiver. Because of this limitation on minimum baud length, most printer systems for high frequency radio transmissions normally do not use baud lengths shorter than approximately 3.55 milliseconds.

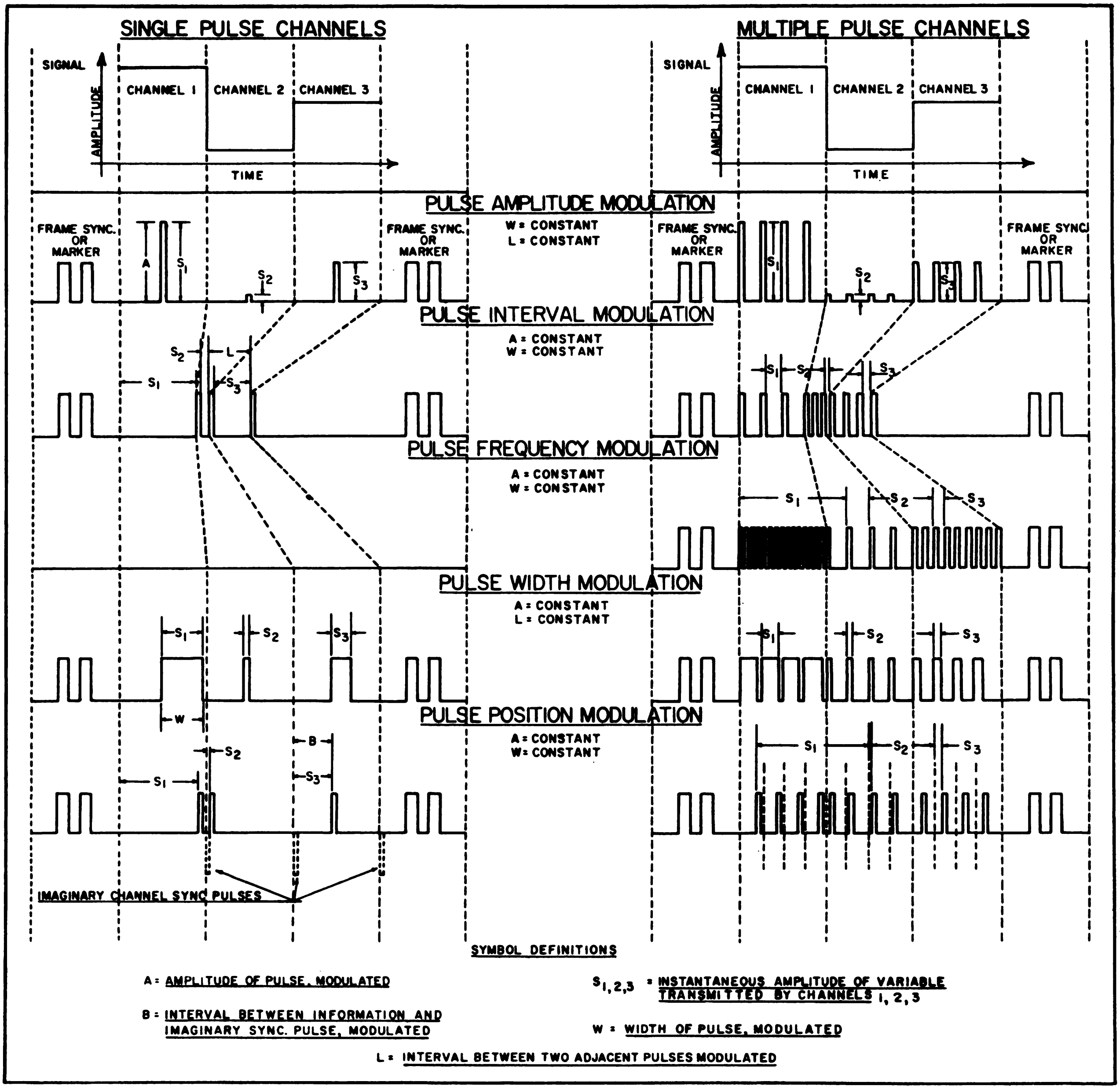


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Figure 7-14.—Methods of time division multiplex for a 3-channel system.

QUIZ

1. If the frequency of the signal fed to a transmitting antenna is increased by 1%, what change in frequency would result in the signal induced in another antenna which is receiving the radio wave?
2. Varying the characteristics of a signal according to changes in another signal is called__________.
3. The r-f signal which has its characteristics varied according to the information to be transmitted is called the__________.
4. Varying the intensity (strength) of an r-f wave according to the variations of an information signal is called__________ modulation.
5. The maximum amount of power which can possibly be placed in the sidebands of an ordinary a-m wave occurs when the percentage of modulation is__________%.
6. For ordinary a-m radio transmission, the total bandwidth required in the r-f spectrum equals__________times the highest modulating frequency.
7. Transmitting information by means of an on-off keyed carrier wave is also known as__________transmission.
8. The designation "double sideband system" is given to systems which use ordinary __________modulation.
9. For a given limit of maximum power on which a station is permitted to transmit, which system, DSB or SSB, would ordinarily provide the highest quality signal to a distant receiver?
10. To transmit comparable information, which type of modulation, a-m or f-m, ordinarily requires the greatest bandwidth in the r-f spectrum?
11. The method of frequency modulation whereby a constant amplitude r-f signal is shifted to either of two fixed frequencies is called__________.
12. How many carrier frequencies are required to transmit two printer systems by the DFS method?
13. Pulse modulation may be accomplished by varying either the__________of the individual pulses or by varying__________.
14. Describe pulse code modulated signals.
15. The tones employed in tone modulation are normally in the audio range and are referred to as__________.
16. What are the two basic methods of multiplexing?
17. Subdividing the normally allotted bandwidth in order to transmit simultaneously several channels of information on a single carrier is known as__________.
18. How is synchronization maintained in most time division multiplex systems?
19. The two basic methods of time division multiplexing are__________ and__________.
20. During a given interval of a time division multiplex transmission, the duration available to each channel is__________dependent on the number of channels in the system.
21. Printer systems for high frequency radio transmissions do not normally use baud lengths shorter than approximately__________ ms.

CHAPTER 8

INTRODUCTION TO RECEIVERS

The T Branch CT will generally work with receivers and associated terminal equipment. Navy transmitters are usually remotely located from the receiving equipment and are maintained and operated by other specially trained personnel. The purpose of this chapter is to discuss the basic theory and operation of some general-purpose receivers. In addition to the receivers discussed here, there are other special-purpose receivers and many types of terminal and associated equipment used with receivers.

RECEIVER THEORY

THE TUNED-RADIO-FREQUENCY RECEIVER

Certain features and characteristics are common to all radio receivers. This discussion of receivers, therefore, will begin with an explanation of the principles of the simplest basic receiver, the tuned-radio-frequency receiver, generally referred to as the t-r-f receiver. A block diagram of a t-r-f receiver is given in figure 8-1. The waveforms which appear in the respective sections of the receiver are shown below the block diagram. (The waveforms represent reception of an amplitude-modulated signal.)

The symbol at the left hand side of the block diagram represents an antenna. The signal induced in the antenna first passes through an r-f amplifier section, sometimes referred to as the preselector. The r-f amplifier contains (1) one or more stages of amplification and (2) tuned circuits which pass only a band of frequencies centered on the carrier frequency to which the circuits are tuned. With respect to the band of frequencies passed, it is appropriate to define SELECTIVITY as it is used to describe a receiver. Selectivity is the ability of a receiver to select and amplify the desired signal and to reject all others. The overall selectivity of the t-r-f receiver is determined by the circuitry in the r-f amplifier portion.

SENSITIVITY is another term often used to describe a receiver. Sensitivity is the ability of a receiver to pick up and amplify weak signals. The overall sensitivity of a t-r-f receiver is determined by the amount of amplification which occurs in the r-f amplifier portion of the receiver. Greater sensitivity is obtained as more stages of r-f amplification are added.

The output of the r-f amplifier is fed to a detector which demodulates the signal; that is, it recovers, from the r-f signal, the modulation components which represent the transmitted information. The output of the detector is then fed to an audio-frequency amplifier which produces an output of sufficient strength to operate terminal equipment, such as the headphones indicated in figure 8-1. The power supply block indicates the circuitry necessary to provide power at the proper voltages for the various circuits of the receiver.

One example of a t-r-f receiver is the Navy RBA receiver, which is designed primarily for reception of m-c-w and c-w signals in the VLF and LF bands. A block diagram of this receiver is given in figure 8-2. The RBA receiver has three stages of r-f amplification as shown. The output of the detector circuit is fed through filter circuits to the audio-amplifier section, which also includes three stages of amplification. The output of the audio section of the receiver is fed to some form of reproducer (indicated by the block labeled 30-600-ohm load) and to a metering device. The metering device provides a meter measurement of the amplitude of the output signal. This meter is valuable in tuning the receiver to achieve the strongest signal output because the meter can detect changes in amplitude which are too small to be noticeable in headphones or other audio reproducers.

The block labeled OSCILLATOR represents the circuit which enables the receiver to detect c-w signals. The r-f signal received by means

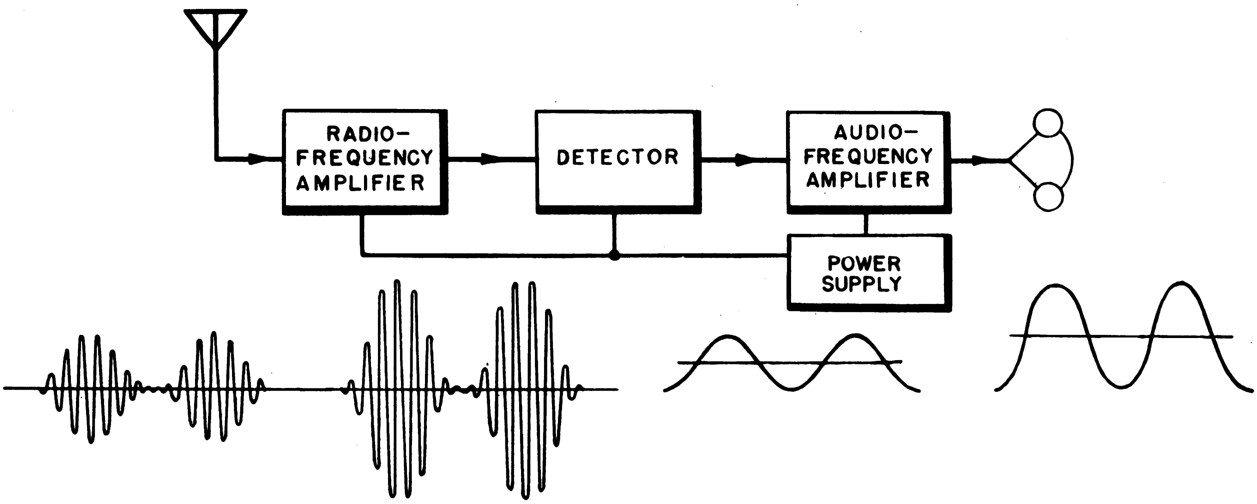

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Figure 8-1.—Block diagram of a t-r-f receiver and waveforms.

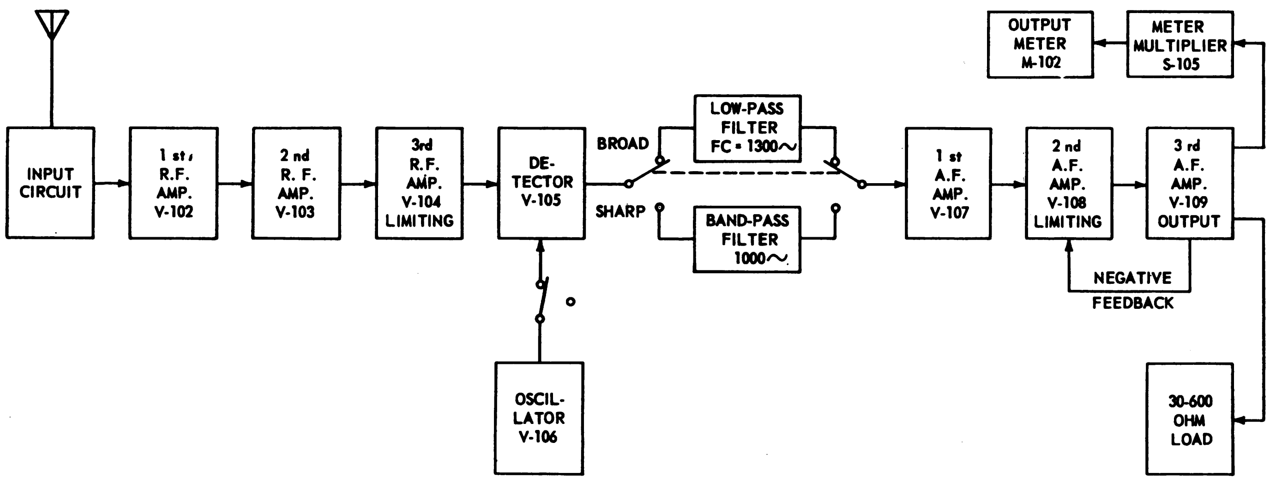

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Figure 8-2.—Block diagram of the RBA receiver.

of c-w transmission has no audio-frequency modulation components. Therefore, the detector will not produce an output signal. For this reason, a BEAT FREQUENCY OSCILLATOR is installed in the detector circuit in such a manner that, when activated, the signal produced by the beat frequency oscillator (BFO) heterodynes with the r-f signal, producing a signal of a different frequency which is within the audio range. (Heterodyning will be discussed later in this chapter in connection with the superheterodyne receiver.) The oscillator of the RBA is so designed that when the receiver is tuned to the frequency of the carrier, the frequency of the signal produced by the beat frequency oscillator is simultaneously tuned, and an audio tone of 1000 cps results whenever an r-f signal appears at the input of the receiver.

The RBA operates in the VLF and LF bands where static interference produces much undesirable noise. Therefore, the last r-f amplifier stage provides amplitude limiting, which prevents strong signals, such as noise bursts, from overdriving the circuitry in later stages of the receiver. The audio amplifier circuitry also has provision for limiting to prevent the output level from exceeding a desired amplitude.

In addition to the amplitude limiting provisions included in the RBA receiver, filter circuits are included between the detector and the audio-amplifier circuits to prevent undesired noise and interference frequencies from appearing in the output. The front panel controls required to operate a t-r-f receiver, such as the RBA, are essentially the same as those required for the operation of a superheterodyne receiver.

THE SUPERHETERODYNE RECEIVER

At high frequencies, it is difficult to achieve desired selectivity and sensitivity in a t-r-f receiver. Therefore, a slightly more complex receiver, called the superheterodyne receiver, is used. Most receivers which the CT will operate are of the superheterodyne type.

A block diagram of a basic a-m superheterodyne receiver is shown in figure 8-3. As in the t-r-f receiver, the signal induced in the antenna first passes through an r-f amplifier. The overall selectivity of the superheterodyne receiver, however, is determined only in part by the r-f amplifier. Most of the selectivity is usually determined by the i-f amplifier, which will be discussed later. The overall sensitivity of the superheterodyne receiver is therefore determined by both the r-f and i-f amplifier portions of the receiver.

The amplified r-f signal from the preselector is fed to one input of a MIXER stage. The second input of the mixer receives a signal from a LOCAL OSCILLATOR. The local oscillator is often referred to by other names—High Frequency Oscillator (HFO), Variable Frequency Oscillator (VFO), or as the Tuning Oscillator. The combination of the local oscillator and the mixer sections is sometimes referred to as the First Detector of the receiver. In a previous chapter on basic electronics, you learned that the function of a mixer is to combine signals of two frequencies in such a manner that sum and difference frequencies are produced. The process of beating (mixing) two frequencies together is called HETERODYNING; hence, the name SUPERHETERODYNE RECEIVER.

Superheterodyne receivers are so designed that, when the preselector stage is tuned to select the desired incoming signal, the local oscillator is tuned simultaneously to track at a constant frequency interval either above or below the frequency of the signal tuned by the

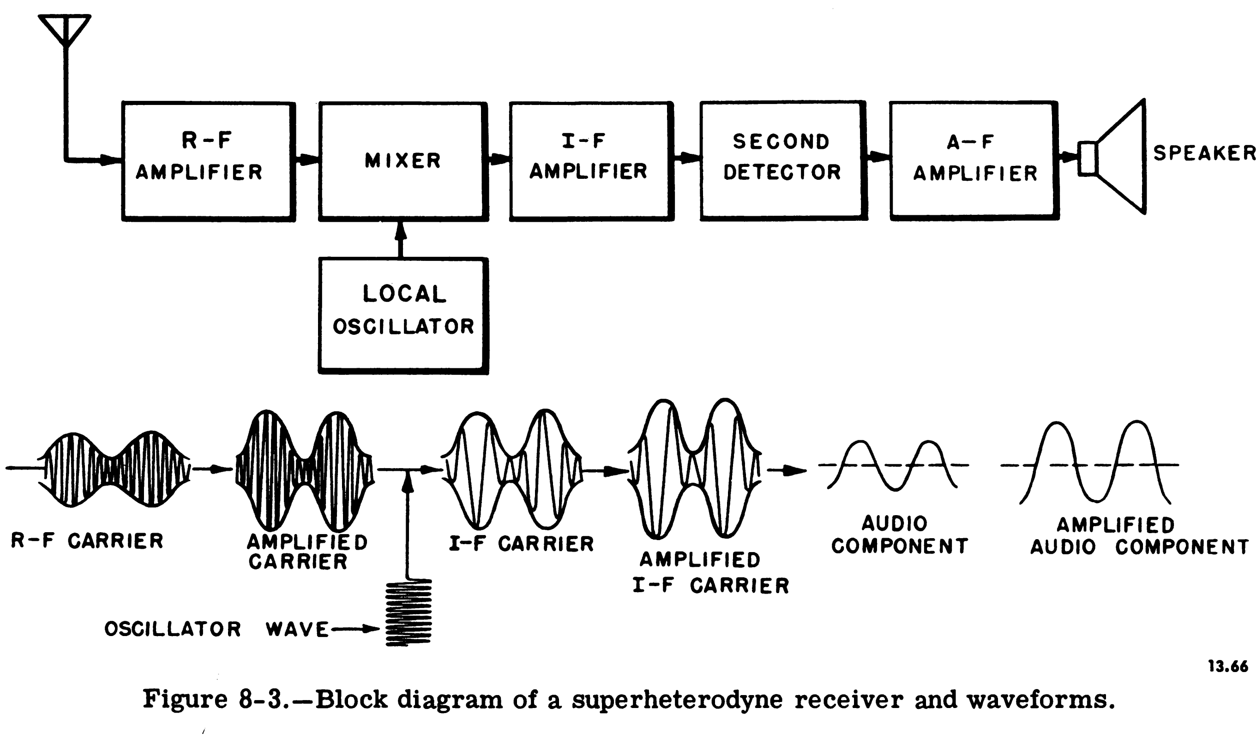

Figure 8-3.—Block diagram of a superheterodyne receiver and waveforms.

preselector. Whether the local oscillator tracks above or below the incoming frequency depends on the design of the particular receiver. The ability of a receiver to remain on the tuned station is called the STABILITY of the receiver, and is normally determined by the ability of the local oscillator to maintain a stable frequency throughout its tuning range.

The output of the mixer stage is called the INTERMEDIATE FREQUENCY, or simply the i-f signal, and has the same modulation characteristics as the original r-f signal. As discussed earlier, the local oscillator tracks at a fixed frequency interval from the tuning of the r-f stages. As a result, the i-f signal has a constant center frequency. The i-f signal is fed to a high-gain amplifier, referred to as the i-f amplifier. Because the i-f frequency is a fixed frequency, the i-f amplifier can be permanently tuned to provide optimum desired characteristics. The i-f amplifier portion of the receiver usually provides rejection of all signals outside the prescribed pass band of the receiver. Thus, the i-f amplifier, to a large extent, determines the selectivity of the receiver.

The output of the i-f amplifier is fed to the SECOND DETECTOR which demodulates the signal; that is, it recovers, from the i-f signal, the modulation components which represent the transmitted information. The output of the detector is then fed to an a-f amplifier which produces an output signal of sufficient strength to operate headphones, speakers, or other terminal equipment necessary to reproduce the desired information.

The discussion thus far has been concerned with a typical superheterodyne receiver designed to receive a-m signals. In order to receive f-m signals, there must be a change in the demodulation section of the receiver. In f-m receiver design, a common procedure is to feed the output of the last i-f amplifier to an amplitude limiter, which eliminates any amplitude variations of the signal. As you recall, from the preceding chapter, frequency modulation is the variation of the instantaneous frequency of an r-f carrier while the amplitude is maintained constant. The output of the limiter is fed to an f-m demodulator stage, referred to as a DISCRIMINATOR. For comparison, figure 8-4 shows block diagrams of basic a-m and f-m commercial broadcast receivers. Some receivers are designed to receive either a-m or f-m signals. In such cases, a front panel switch is provided for switching internal circuits of the receiver to the desired function.

RECEIVER CONTROLS

In order to efficiently operate a receiver, an operator must be able to make certain required adjustments, which are normally made by means of front panel controls. The front panel of an R-390 receiver is shown in figure 8-5. The R-390 receiver is a widely-used, general-purpose communications receiver of the superheterodyne type which provides reception of radioteletype, voice, and other signals within the frequency range of 0.5 to 32 mc. Although controls on other receivers may vary somewhat in their placement, appearance, and perhaps in their nomenclature, their basic functions will be the same as those on the R-390.

FUNCTION SWITCH

The FUNCTION SWITCH, which serves several purposes, has a number of positions, each of which will be discussed. The OFF position, which is self-explanatory, simply turns off power to the receiver.

Stand By

When the function switch is in the STAND BY position, the filament supply voltages are energized, but the plate supply voltages are not applied to the tubes. This condition readies the receiver for instant use without a long warm-up time.

AGC and MGC

The abbreviation AGC stands for Automatic Gain Control. When the function switch is placed in the AGC position, the circuitry which automatically adjusts the r-f and i-f amplifier gain to compensate for variations in the level of the incoming signal is activated. In connection with the AGC function, notice the AGC switch at the top of the panel which has three positions marked SLOW, MEDIUM, and FAST. This AGC switch adjusts the rate at which the AGC circuitry responds to a change in the signal level.

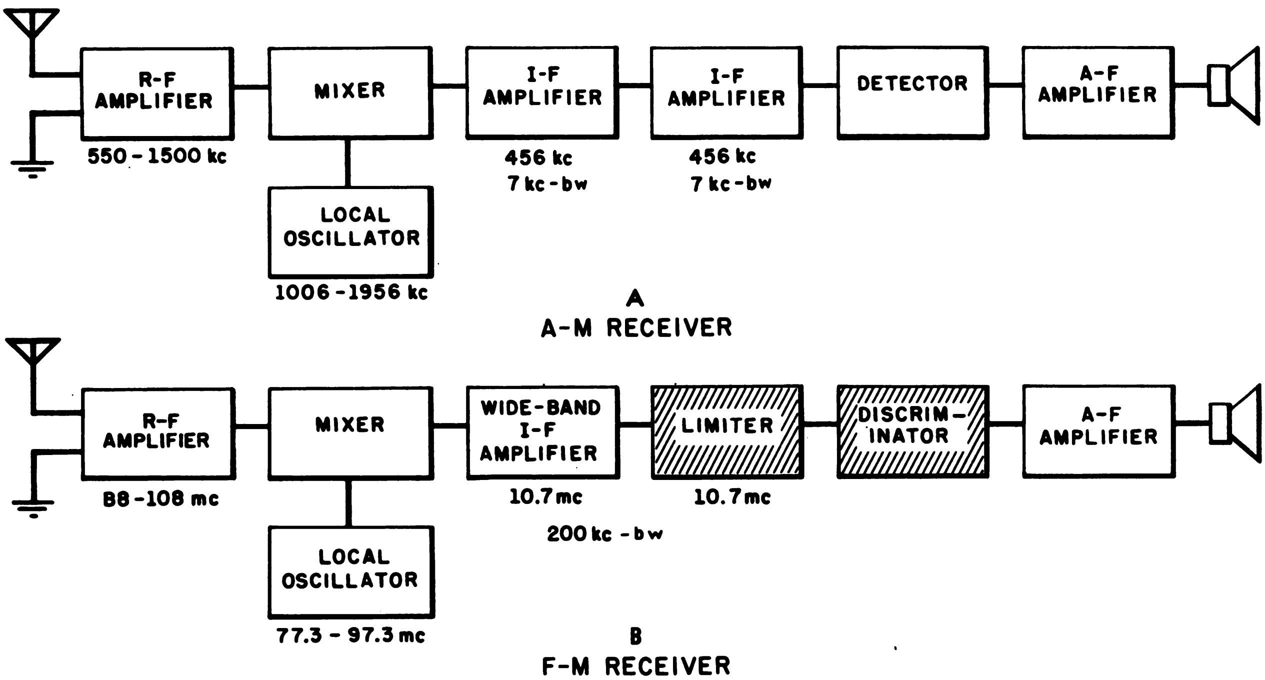

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Figure 8-4.—Receiver block diagrams.

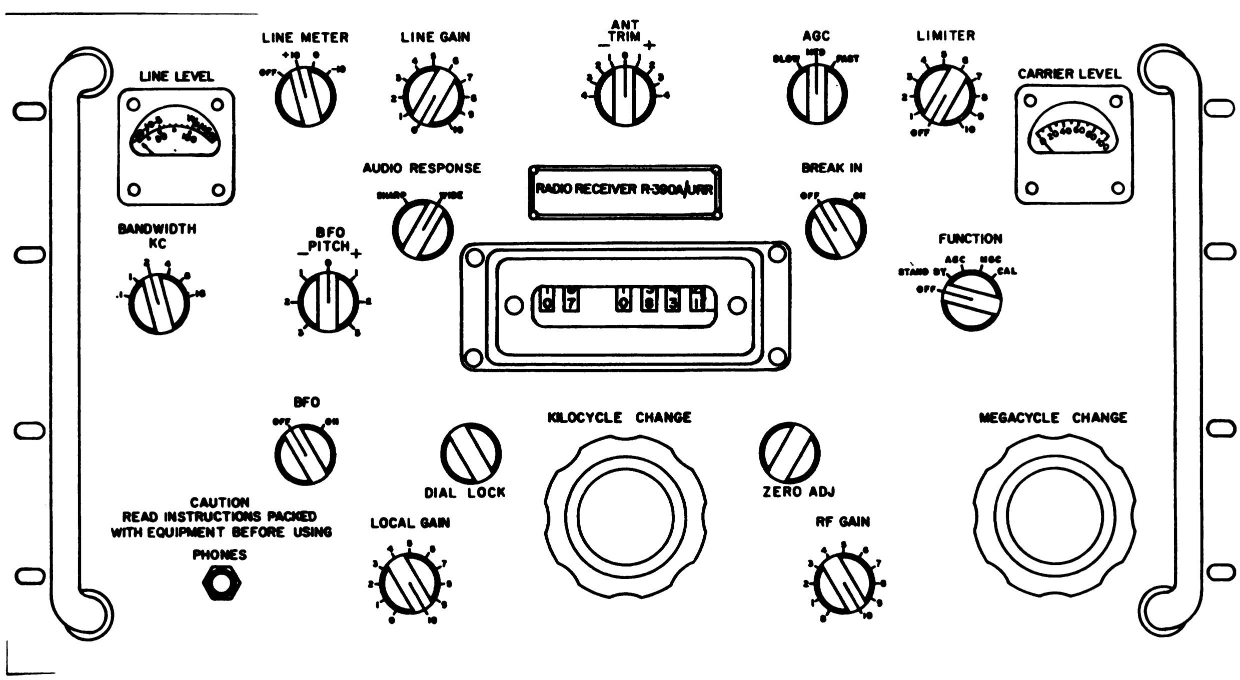

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Figure 8-5.—Front panel of the R-390 receiver.

The correct position of the AGC switch depends on the type of signal being received.

The abbreviation MGC, which identifies the next position of the function switch, stands for Manual Gain Control. When the function switch is in the MGC position, the AGC circuitry is not activated, and the gain is controlled manually by means of the RF GAIN switch.

CAL

When the function switch is in the CAL (calibrate) position, a stable crystal oscillator introduces a signal at the input circuitry of the receiver. This signal allows the operator to calibrate his receiver; that is, to ascertain that the reading of the tuning dial corresponds to the frequency being received. The calibration circuitry of the R-390 permits the operator to calibrate the receiver at each 100-kc point throughout the tuning range of the receiver. In connection with calibration, notice the ZERO ADJ knob near the frequency dial. When turned clockwise, this knob disengages the frequency indicator from the tuning control (KILOCYCLE CHANGE). The calibration procedure consists essentially of the following steps:

1. Tune the receiver to a point where the frequency indicator dial shows an exact multiple of 100 kc.
2. Turn the ZERO ADJ knob clockwise to disengage the tuning controls from the frequency indicator.
3. With the function switch in the CAL position, turn the KILOCYCLE CHANGE control to give the maximum response to the calibration signal.
4. Turn the ZERO ADJ knob counterclockwise to reengage the tuning control to the frequency indicator.

Squelch

When the function switch is placed in the SQUELCH position, a circuit is activated which silences the audio portion of the receiver unless the incoming signal is of a predetermined level. One use of this circuit is to relieve the operator, who is monitoring an intermittent but normally strong transmission, from listening to the static and interference in his headphones unless the transmitting station is actually on the air.

TUNING CONTROLS

Two front panel knobs provide the tuning control of the R-390, the MEGACYCLE CHANGE knob and the KILOCYCLE CHANGE knob. The MEGACYCLE CHANGE knob selects any 1-mc bandwidth of the tuning range. Turning this knob affects the reading of the first two digits of the frequency indicator. The KILOCYCLE CHANGE knob tunes the receiver to any desired frequency within the megacycle band selected by the MEGACYCLE CHANGE control. The last three digits of the frequency indicator dial provide the kilocycle reading. The tuning controls actually adjust the tuned circuits in the r-f stages and in the local oscillator in order to select the desired station frequency and to provide simultaneously the desired i-f signal to the i-f portion of the receiver. The DIAL LOCK knob is associated with the tuning controls. This knob locks the KILOCYCLE CHANGE control so that the frequency setting will not be accidentally changed.

BANDWIDTH CONTROL

Some transmissions use narrower bandwidths in the r-f spectrum than others. Therefore, receivers are provided with a control which allows the operator to adjust the pass band of the receiver so that only the desired bandwidth is received. On the R-390 receiver, this control is achieved by the BANDWIDTH KC switch, which adjusts the tuned circuits of the i-f portion of the receiver, thereby controlling receiver selectivity. Proper adjustment of this control helps to eliminate noise and interfering signals. Of course, if the bandwidth is set too narrow, part of the incoming signal will be lost.

BEAT FREQUENCY OSCILLATOR

Some radio transmissions, such as Morse telegraphy and FSK teletype, contain no audio-frequency information when they are received. If it is necessary or desirable to produce an audio output, some method must be provided to convert the incoming r-f signal to an audio-frequency signal. This requirement is fulfilled by the beat frequency oscillator (BFO). In a superheterodyne receiver, the BFO is installed in such a manner that, when activated, the signal produced by the BFO heterodynes with the i-f signal, producing an audio-frequency output signal. On the R-390, the BFO is activated by the BFO ON-OFF switch, and the pitch of the audio output can be adjusted by the BFO PITCH knob.

GAIN CONTROLS

The R-390 has three front panel gain controls. The RF GAIN control, which was mentioned earlier, permits manual adjustment of the gain of the r-f and i-f portions of the receiver. The LOCAL GAIN and LINE GAIN knobs control the gain of the audio circuitry. The LOCAL GAIN control adjusts the level of the output to the phone jack. The LINE GAIN controls the level of the audio output used to operate terminal equipment.

ANTENNA TRIMMER

The front panel control labeled ANT TRIM adjusts the input circuit in such a manner that optimum coupling from the antenna to the receiver can be achieved at each frequency.

AUDIO RESPONSE

The AUDIO RESPONSE control, which adjusts the bandwidth of the audio circuits, has three settings, SHARP, MED, and WIDE. The setting of this control will depend on the type of signal being received.

LIMITER

When the control labeled LIMITER is activated, the operator can control the amplitude of the audio output circuits to predetermined limits. The setting of the limiter control is dependent upon the type of signals being received; for example, a low setting of the control may be desirable to prevent loud crashes of static in the output when monitoring voice signals. Or, if the received signal is FSK-modulated, it may be desirable to remove all amplitude variations by using a high setting on the LIMITER control. However, for many types of reception, the LIMITER should not be activated.

BREAK IN

The ON-OFF switch labeled BREAK IN is used when a receiver and transmitter are used together as a radio set. When in the ON position, circuits are activated which will remove the antenna from the receiver and ground the antenna and receiver audio circuits whenever the transmitter is energized.

INDICATORS

The R-390 has three indicators on the front panel. The frequency indicator dial indicates the frequency to which the receiver is tuned. This dial is of the digital-counter type which permits the frequency to be read directly with little chance of misreading.

The CARRIER LEVEL indicator is a meter which measures the level of the r-f signal appearing at the input of the receiver. The operator will find this meter valuable in tuning to the exact frequency which will give the strongest signal. It is also used to indicate proper adjustment of the antenna trimmer.

The indicator labeled LINE LEVEL is a meter which may be used to monitor the level of the local line audio output used to drive terminal equipment. This meter is placed across the output circuit by the LINE METER switch. The three available values of meter sensitivity (voltage required for full-scale deflection) are determined by the setting of the LINE METER switch.

RECEIVER OUTPUTS

Receivers usually have several output terminals in order to provide connections to various types of terminal equipment. On the R-390, the signal from the audio amplifier is connected to a phone jack on the front panel and is used for plugging in either headphones or a speaker. The audio output is also connected to local line output terminals on the back of the receiver in order to provide connections to other terminal equipment as required. The output of the i-f section of the receiver is often brought to a connector on the back of the receiver because the i-f signal is required for operating some types of terminal equipment. In other receivers, specially designed for the reception of wide-band signals, output terminals, called video outputs, are provided. The video output is a wideband signal including all audio frequencies and extending considerably above the audio band. For example, it is necessary to have video output capabilities for reception of certain types of multichannel or pulse transmissions.

Although the controls and outputs discussed were those of a general-purpose communications receiver, the R-390, they are typical of nearly all receivers. In your work you may encounter special-purpose receivers which require different controls in order to accomplish the purpose for which they are designed.

QUIZ

1. In the t-r-f receiver, the overall selectivity of the receiver is determined by the______.
2. In the t-r-f receiver, the overall sensitivity is determined by the__________.
3. Which section of the t-r-f receiver recovers the desired information from the modulated r-f signal?
4. What is the purpose of the oscillator in the RBA receiver?
5. The oscillator referred to in question 4 is often referred to as the_________.
6. The limiting circuits in the RBA receiver serve what functions?
7. A superheterodyne receiver contains two basic circuits which are not included in the t-r-f receiver. What are they?
8. The selectivity of a superheterodyne receiver is determined primarily by the _________ and in part by the_________.
9. The sensitivity of a superheterodyne receiver is determined by__________.
10. The process of beating two frequencies together to obtain their sum and difference frequencies is known as_________.
11. How is the i-f signal of a superheterodyne receiver maintained at a constant center frequency?
12. The demodulator portion of an f-m receiver is referred to as a_________.
13. What is the frequency range of the R-390 receiver?
14. What is the purpose of AGC?
15. (a) What is the function of the ZERO ADJ knob on the front panel of the R-390?
    (b) When is it used?
16. What is actually accomplished within the receiver when the BANDWIDTH KC control is adjusted?
17. What does the LINE GAIN control on the R-390 accomplish?
18. Which front panel control is used to obtain optimum coupling from the antenna input terminals to the r-f stages of the receiver?
19. The level of the r-f signal at the input to the receiver is indicated on the_________.
20. Name three types of outputs commonly found on receivers.

CHAPTER 9

TRANSMISSION SYSTEMS

As a Communications Technician of the T Branch, you will be concerned with the operation of a variety of communications and other related electronic equipments. The purpose of this chapter is to provide background information on some of the many forms of radio transmission systems which are in use in the Navy today. An understanding and appreciation of their basic principles will be of considerable value in mastering the specific tasks to which you may be assigned.

TELETYPEWRITER

SINGLE CHANNEL TELETYPEWRITER

Teletypewriter, both landline and radio, is a major means of present-day communications throughout the world. As a CT T Branch operator you will become thoroughly familiar with teletypewriter signals and operation. The following section presents the basic theory of operation of a teletypewriter transmitting one channel of information.

As mentioned in an earlier chapter, teletype information is transmitted by means of signals having only two conditions, MARK and SPACE. To see how a teletype signal is sent, let us first consider a simpler device, the manual telegraph circuit. The circuit shown in figure 9-1 includes a telegraph key, a source of power (battery), a sounder, and a movable sounder armature. If the key is closed, current flows through the circuit and the armature is attracted to the sounder by magnetism. When the key is opened, the armature is retracted by a spring. With these two electrical conditions of the circuit, closed and open, it is possible to transmit information according to a predetermined code. When the circuit is closed and a current flows, the circuit is said to be marking; when the circuit is open and no current flows, the circuit is said to be spacing. Thus we have the MARK and SPACE conditions necessary for operation.

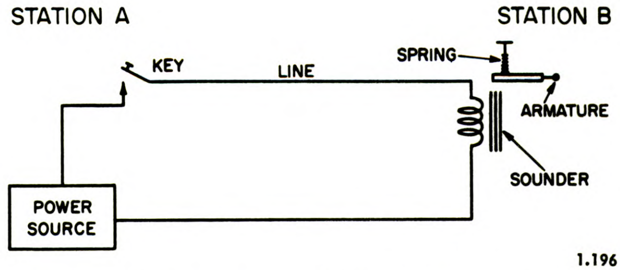


Figure 9-1.—A manual telegraph circuit.

In order to achieve teletypewriter operation, it is necessary to transmit a unique signal for each key on the teletyewriter keyboard. Mechanical considerations require that the signal for each character be of uniform time duration. (Note: The word "character" as used here means a letter, number, or machine function as found on the teletypewriter keyboard.) Figure 9-2 illustrates the mark and space conditions in the teletypewriter character R.

To adapt teletype signals for radio transmission, it is only necessary to have the signals, which are produced by a teletypewriter keyboard, control the modulation of a radio transmitter. At the receiving station, a radio receiver, together with the required terminal equipment, changes the modulated r-f signal back into keyed d-c impulses which are fed to a receiving teletypewriter for producing copy.

For purpose of illustration we will discuss a single-channel, start-stop system, the type used on many military and commercial circuits. In the single-channel, start-stop system, the signal transmitted for each character is divided

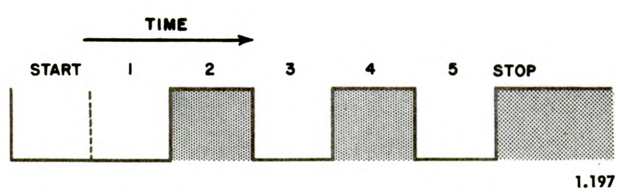
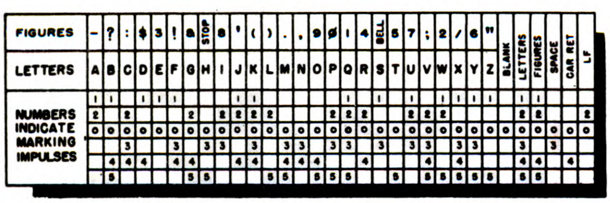


Figure 9-2.—Mark and space signals in the teletypewriter character R.

into five elements or units of equal time duration. These units, which are known as BAUDS, were named for the French inventor BAUDOT, who produced one of the first practical teletypewriter codes. A particular mark and space combination of the five bauds makes up the code for each keyboard character. See figure 9-3. The five bauds representing each character are known collectively as the INTELLIGENCE BAUDS of the signal.

In addition to the intelligence bauds, the system utilizes two additional bauds, one preceding and one following the five intelligence bauds of each character. These two additional bauds, commonly called SYNC bauds, synchronize the operation of the transmitting and receiving equipments. In other words, the sync bauds prevent garbles by keeping the transmitting and receiving equipments in proper time relationship. The baud which precedes the five intelligence bauds acts as a release signal to start the receiving equipment; it is referred to as the START or RELEASE baud. The baud which follows the intelligence bauds causes the printing or receiving equipment to stop; it is referred to as the STOP or LATCH baud. Thus it can be seen why this system is called a start-stop system. One important fact to remember is that in the signal under discussion, the sync bauds will be of constant condition for every character signal; that is, the start baud will always be a space baud and the stop baud will always be a mark baud.

To understand the composition of the teletype signal, refer again to figure 9-2. Notice the sync bauds which are labeled START and STOP. Notice that intelligence bauds 2 and 4 are in the mark condition. This is the teletype code for the letter R: bauds 2 and 4 marking; bauds 1, 3, and 5 spacing.

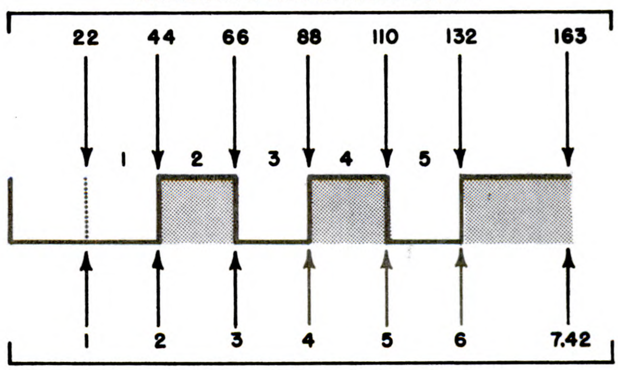


1.198

Figure 9-3.—Mark and space combinations for characters on the teletypewriter keyboard.

Next consider the combination of all seven bauds which represents one CYCLE of operation. A cycle is the time interval from the beginning of the start baud to the end of the stop baud of a signal representing one character. Cycle time is normally expressed in milliseconds. The signal illustrated in figure 9-4 is a theoretical, or perfect, signal because the quality (amplitude and duration) of each baud remains constant during the transmission. The shift from marking to spacing, and vice versa, is instantaneous. These changes are called transitions. Notice that the first six bauds of the signal shown are the same length, but the seventh (stop) baud is longer. In this case the first six bauds each require 22 milliseconds for transmission. The stop baud requires 31 milliseconds. If a value of 1 unit is assigned to each of the first six bauds, the stop unit has a value of 1.42 units. Thus the total number of units in the signal for a single character is 7.42. (In some situations, the length of the shortest signal unit used is given a value of "One baud." Cycle length can then be expressed in terms of bauds. In our example, cycle length would then be expressed as 7.42 bauds.) The total time required to send one character in the system being described is 7.42 X 22 milliseconds, or 163 milliseconds. This means that the cycle time of the system is 163 milliseconds.

Figure 9-3 shows the characters of a standard teletypewriter keyboard with the corresponding mark and space baud arrangements which make up each character. This particular code is known as INTERNATIONAL TELETYPE



1.199

Figure 9-4.—Each teletypewriter signal has 7.42 units.

CODE #2. It is used by many countries throughout the world. A total of 32 different combinations is possible using five intelligence bauds. But, by using both upper and lower case, the number of characters obtainable is almost doubled. Double use can not be made of all 32 possible combinations. Six are utilized for machine functions consisting of carriage return, line feed, figures shift (upper case), letters shift (lower case), space, and a blank key which can be used for other purposes if required. This leaves 26 of the 32 combinations which are employed for both upper and lower case operations. Adding the six special functions to the 26 "double-use" combinations gives a total of 58 characters and functions which can be sent from this keyboard.

The signals discussed thus far have been theoretically perfect signals. In actual practice, it is not possible to obtain such signals. In the process of transmission, either over landline or by radio, the mark and space bauds have a tendency to become shortened or lengthend, depending upon circuit conditions. This shortening and lengthing is called DISTORTION of the signal. A receiving teletypewriter must use the signal as it is received in order to accomplish a selection of the proper key or machine function. (See figure 9-5 and 9-6.) If the signal is distorted, there will be errors in the copy. To help overcome the effects of distortion, each teletypewriter has an external adjustment called the ORIENTATION RANGEFINDER which allows the machine to be adjusted for best reception. The rangefinder is a device normally consisting of a scale and a finder arm. The finder and scale are illustrated in figure 9-7.

The orientation rangefinder adjusts the time of positioning of the swords, which are mechanical linkages that determine which keyboard function will be printed or accomplished. Control of the selection interval is shown at the

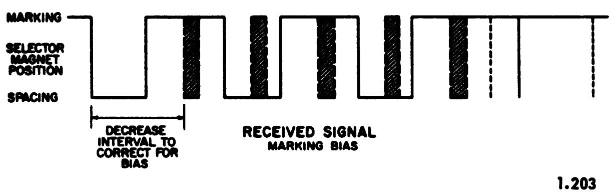


Figure 9-5.—Received signal with marking bias.

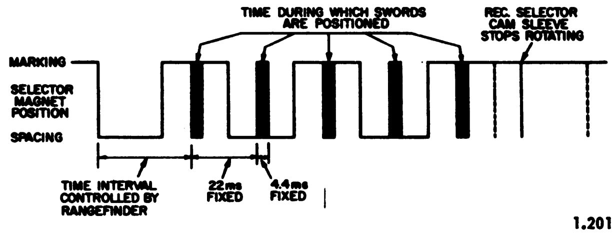


Figure 9-6.—Selecting intervals for letter Y.

bottom of figure 9-6. When you change the finder arm, you shift the selection point (time during which swords are positioned) within the intelligence units. Each unit on the rangefinder scale represents a percentage of one intelligence unit. Because the scale goes up to 120 percent of one unit, you can shift far enough so that the selection point is entirely off the proper intelligence unit. Thus, even with a perfect signal, it is possible to shift the finder far enough to produce errors. The chance for errors should be minimized by placing the finder in a position midway between the rangefinder settings which begin to produce errors. The

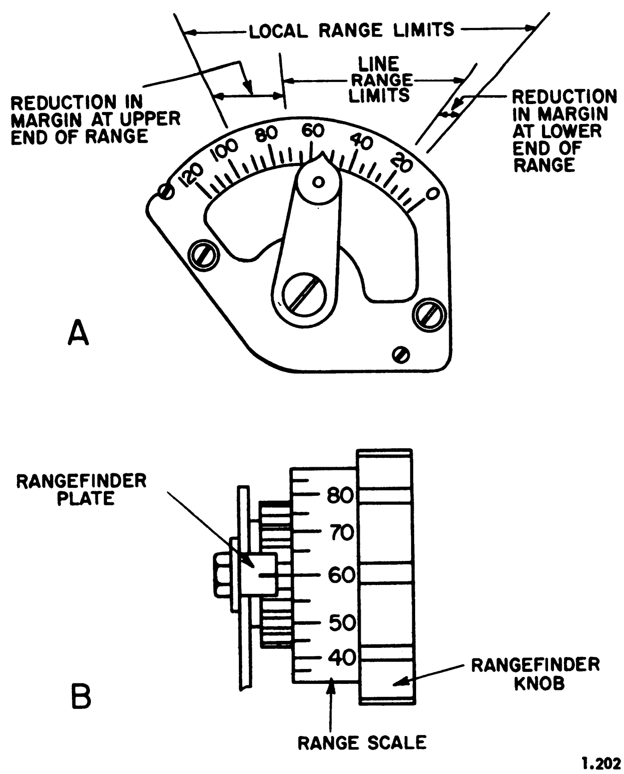


Figure 9-7.—The orientation rangefinder.

procedure for establishing range limits is to observe the typed record produced by the machine as the rangefinder is adjusted. The upper range limit and lower range limit are the scale readings at the rangefinder settings which produce about one error per line of copy (72 characters).

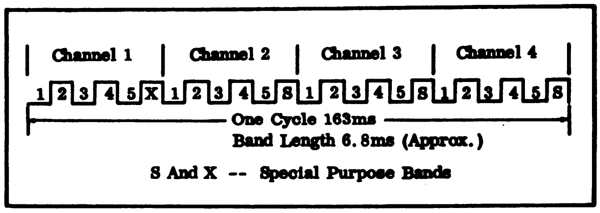
Actually, the orientation range is determined twice: First the range of the machine itself (local range) is determined. Then the range is determined when the machine is connected to the line (line range). The orientation range limits for practically perfect signals will be determined by the local range limits. For a machine in good condition, local range limits would be approximately 15 and 95. These limits would indicate that the rangefinder should be set at 55 (the midpoint). The orientation range determined by the line range limit will be smaller. Values of 20 and 70 are illustrated in figure 9-7. The setting of the finder arm, if considering only the line range limits, would be at a value of 45. The final setting of the rangefinder arm should be the average of the values determined by the local range test and the line range test. In our example the cirrect setting would be midway between 55 and 45, or 50.

MULTIPLEXED TELETYPEWRITER

One means of transmitting several teletypewriter channels simultaneously on a single r-f carrier is to use time division multiplexing. We will consider a system capable of handling four separate channels of information. For such a system, special sending and receiving terminal equipments are required in addition to the radio transmitter and receiver.

The sending equipment accepts four standard, single-channel teletypewriter signals and changes the length of the bauds to allow the four channels to be transmitted in approximately the same length of time ordinarily required for ONE channel. The four signals are combined (multiplexed) by time division to form a signal such as that illustrated in figure 9-8. Notice that the sync (start-stop) bauds of the individual channels are omitted, but there are four special bauds which are used for synchronization and separation of channels.

The multiplexed signal is used to modulate an r-f carrier for radio transmission. Frequency shift keying is a modulation method com-



13.69

Figure 9-8.—A four-channel multiplex signal.

monly used for this purpose. The receiving terminal equipment accepts the multiplex signal from the output of a receiver, demultiplexes it (separates and reconstructs the signals of the four channels), and provides d-c keying signals to four separate teletypewriters.

This example has illustrated only some of the basic principles involved in multiplexed teletypewriter operation. Many other factors are involved, and there are many variations which may be employed in the composition of the multiplex signal. For example, nothing has been said about the polarity of the bauds, either of individual channel bauds or of special-purpose bauds. Polarity is the term used to indicate which circuit condition represents marking signals and which circuit condition represents spacing signals. It is possible to use different polarity for different channels within a single system, and it is even possible to use different polarity for bauds within a single channel. Therefore, because of the many possible variations, this example represents no one particular system but has been given to represent the basic principles involved in multiplexing.

FACSIMILE

Facsimile is a method of electrical communication which conveys information in graphic (written, diagrammed, or pictorial) form. This method is used by the Navy to send photographs, weather charts, and other types of graphic information. In addition to military applications, facsimile is widely used by news agencies for sending news pictures to their stations and subscribers around the world.

The term "radiophoto" is often used to denote facsimile transmitted by radio; the term "wirephoto" is often used to denote facsimile transmitted by wire. The word "facsimile" is the general term used to denote this entire field of communications.

Facsimile is useful for sending messages written in languages such as Japanese which cannot readily be sent by other methods. Other commercial applications include such uses as rapid verification of signatures in banking and transmission of layouts and proofs in advertising. Tape facsimile, or "Hellschreiber," is a type of facsimile system used, especially in continental Europe, for disseminating news to subscribing agencies.

PRINCIPLES OF FACSIMILE

Although there are several types of equipment used for facsimile, they all operate on the same basic principles. This basic operation is described in the following paragraphs.

To illustrate facsimile operation, consider the objective to be the transmission, to a remote station, of a photograph by means of wire or radio. The information contained in a photograph is based on variations in the intensity of shading (that is, variations in "blackness") of the area which makes up the photo. In order to send a photograph by wire or radio, the variations in shading must be converted into electrical signals. It is not possible to instantaneously sense the variations in shading of the entire photo and form an electrical signal which can completely represent the desired information. Instead, the area of the photo must be sensed, in a systematic manner, a small portion at a time. The intensity of shading of each small portion can then be converted into an electrical signal having a corresponding amplitude. As the sensing device moves from each small portion of the area to another portion, the resulting electrical signal instantaneously varies in amplitude according to the intensity of the shading at that instant of sensing.

Because there must be some systematic method of sensing, a logical choice is to begin by sensing a small area at the upper-left-hand corner of the photograph, and move to the right across the photo. Thus, the sensing device first senses the intensity of the shading in a small strip at the top of the photo, finally reaching the right-hand edge of the page. The sensing device then moves back to the left-hand edge of the page and begins sensing a strip just below the area previously covered. This procedure, when continued, finally senses the entire area of the photo. The output of the sensing device is an electrical signal which has a series of amplitude variations corresponding exactly to the shading of the original photograph.

Some sort of reproducer is necessary at the receiving station. The input to the reproducer is the electrical signal which has amplitude variations representing the variations of intensity in the original photograph. This is accomplished by having a printing device which scans back and forth across the page in exactly the same manner as the sensing device scanned the original photo at the transmitting station. The printing device, like the sensing device, must start at the upper-left-hand corner of the page. Then, if the printing device darkens the page in proportion to the variations in amplitude of the electrical signal, the original photograph is reproduced.

In order to reproduce accurately the original photograph, it is obvious that some method of synchronization is necessary. The reproducer must begin printing at the upper-left-hand corner of the page at the exact time when the electrical signal corresponding to the upper-left-hand corner of the original photo is received. Similarly, the printing device of the reproducer must be at the left-hand edge of the page at the time when the electrical signal representing the intensity of an area at the left-hand edge of the page is received.

Of course, it is necessary that the printing device move down the same distance on the page as the senser moves down. This is, however, a relatively simple problem. It is only necessary to mechanically design the reproducer so that it moves down the page the correct distance whenever the printing device moves to the left-hand edge of the page.

In order to achieve synchronization of facsimile transmitting and receiving devices, the usual method is to transmit a unique "sync" signal which corresponds to the start of a scan. It is possible to make the sync signal unique by transmitting a pulse which is greater in amplitude than the signal which corresponds to the blackest shading ever encountered in the sensing procedure.

TYPES OF FACSIMILE EQUIPMENT

The type of equipment described in the explanation of facsimile principles is called PAGE TYPE. Page type equipment operates on the principle of left-to-right, top-to-bottom scanning procedures, analogous to the manner in which a person normally reads a printed page. The most common type of equipment used in the military services, however, is the ROTATING CYLINDER type. In this type of equipment, the material to be transmitted is wrapped around a cylinder in the transmitting machine. (See figure 9-9.) The cylinder rotates at a constant speed, and, at the same time, moves horizontally along a shaft. The material on the cylinder is illuminated by a small beam of light focused through a lens. As the beam passes over each small area of the material, a portion of the light is reflected. The amount of light reflected depends on the intensity of the shading of the material in the small area on which the beam is focused. The variations of the reflected light are sensed by a photo-electric tube. The amount of light which is sensed by the photoelectric tube controls the amplitude of the voltage in the phototube output circuit. Thus, variations of shading in the original information are converted into variations in the amplitude of the output voltage, which can be transmitted directly over wires, or may be used to modulate the r-f carrier of a transmitter for radio transmission.

At the receiving end of a facsimile transmission, a rotating cylinder reproducer may be used. In order to maintain synchronization, the cylinder of the reproducer must be rotating at exactly the same speed as the transmitting cylinder. To accomplish this synchronization, a sync pulse is ordinarily sent at fixed time intervals—such as at the start of each rotation of the transmitting cylinder. Prior to transmission of information, a transmitting station normally sends, for a few minutes, only sync pulses in order to enable the receiving station to adjust the speed of rotation of the reproducer cylinder so that it is "in sync" with the cylinder at the transmitter. Commonly used cylinder speeds are 60, 90, or 120 revolutions per minute (rpm).

In reproducing facsimile information, the most common printing method employs a specially treated (sensitized) paper on which the information is printed by a burning process. In such a system, the reproducing (printing) head is a stylus, which is connected to the output

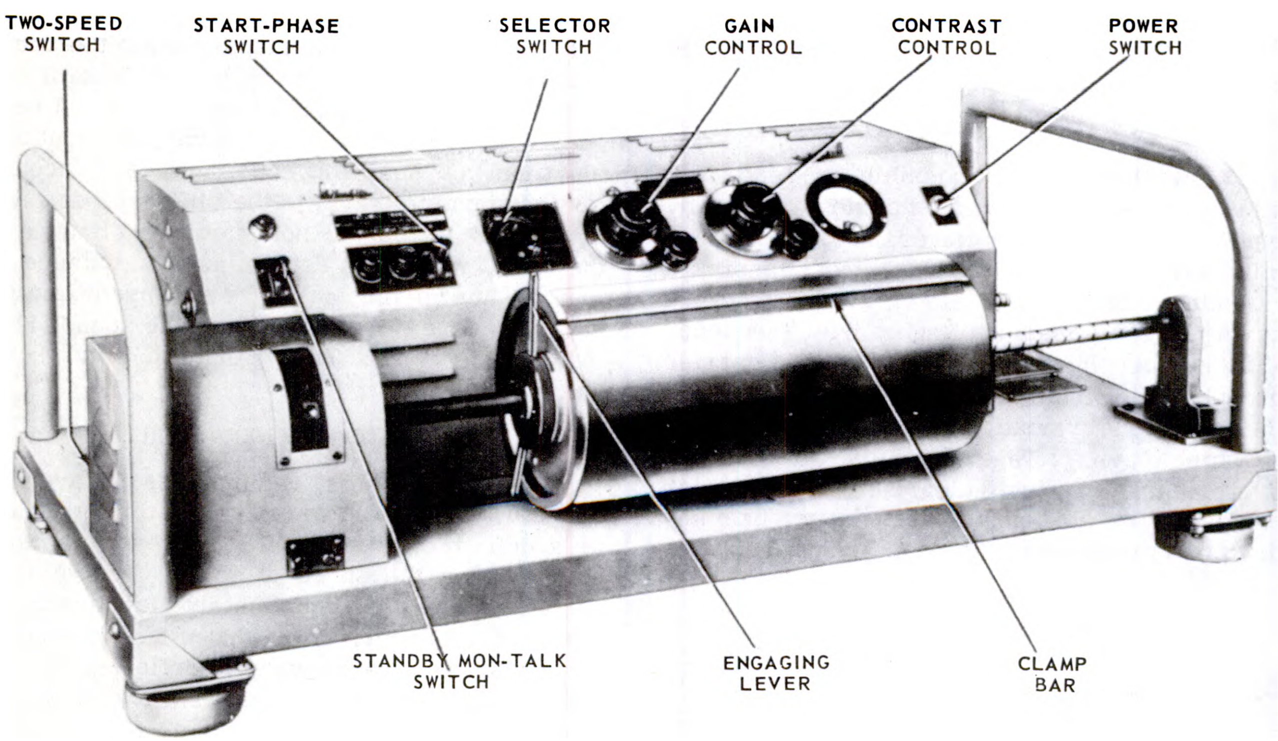


Figure 9-9.—FAX transceiver.

circuit of the receiving equipment in such a manner that a high voltage is placed on the stylus. This voltage varies in amplitude according to the received signal. The voltage on the stylus causes a white surface coating on the sensitized paper to be burned away, revealing a black under-coating. The intensity of the voltage determines how much of the white coating is burned away. Thus the variations in the received signal causes variations in the blackness (shading) of the sensitized paper, thereby reproducing the original information.

The operation of tape facsimile equipment is very similar to that of page type equipment. However, the information is transmitted from a long continuous tape, similar to teletypewriter tape. At the transmitting station, a scanning device senses the information on the tape by traversing the width of the tape as the tape moves beneath the device. At the receiving station, as a tape moves through the reproducer, the reproducing head traverses the width of the tape, thereby reproducing the information. When tape systems are used solely for the transmission of printed information, there is no need for degrees of shading. Only two shading conditions are present—black and white—thus allowing the use of a current-no current or marking-spacing type of transmission similar to that used in radioteletype operations.

FACSIMILE SIGNALS

It is theoretically possible to send facsimile by radio-wave transmissions using any type of modulation. However, because of certain technical considerations, most facsimile transmissions employ either frequency shift keying or some method of subcarrier frequency shift keying. In such systems, the r-f carrier or subcarrier shifts in frequency according to the amplitude variations in the output of the scanning device. The sync pulse is produced by regularly causing the carrier or subcarrier to deviate by an amount much larger than any deviation produced by the sensing of information.

PULSE SYSTEMS

RADAR

Radar Principles

Radar is based on principles very similar to the principles of sound reflection. You have probably experienced the phenomenon of your voice echoing back when you shout in the direction of the cliff. What actually takes place is that the sound waves, generated when you shout, travel through the air until they strike the cliff. A portion of the waves are reflected or "bounced off," and return to the originating spot, where you hear the echo. Since sound waves travel through the air at only 1100 feet per second, a definite amount of time elapses while the sound makes the round trip from you to the cliff and back. If the cliff is 2200 feet from you, 4 seconds will elapse between the time you shout and the time you hear the echo; that is 2 seconds for the sound to travel to the cliff and 2 seconds to return. If you did not know the distance to the cliff, you could determine the distance in feet by multiplying half of the elapsed time (in seconds) times the velocity of the sound (1100 feet per second). This calculation is shown below.

$$1/2 \times 4 \times 1100 = 2200$$

In many respects, radio waves behave like sound waves. Radio waves travel through space at a definite velocity, which, however, is much greater than the speed of sound. The velocity of radio waves is approximately the same as the speed of light which is 186,000 miles per second. A portion of a radio wave is reflected when it strikes an object in its path such as a ship, a plane, or a hill.

Let us assume the following situation, comparing it with the phenomenon of a voice echo.

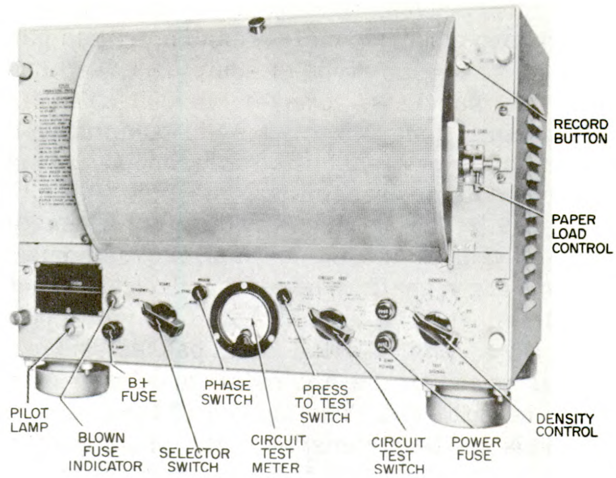


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Figure 9-10.—FAX recorder.

A burst of r-f energy (an r-f wave) is generates by a radio transmitter and transmitted in a given direction. As the r-f wave travels through space, it strikes an airplane; some of the wave is reflected back toward the location of the transmitter. A radio receiver, which is located at the site of the transmitter, detects the portion of the r-f wave that returns. A measurement is made of the time interval elapsing between the generation of the burst of energy and the return of a portion of the r-f wave.

Comparing the situation just described to that of a voice echo, we see that the two situations are alike in the following manner. The radio transmitter is analogous to your voice; the r-f wave is analogous to the sound wave. Both waves were transmitted in a particular direction—toward the cliff in the case of the sound wave. Both types of waves traveled through space at a definite speed. However, the r-f wave traveled much faster. Both types of waves were, in part, reflected back toward their source when they struck an object in their paths. The airplane, like the cliff, acted as a reflector. The receiver detecting the returning portion of the r-f wave corresponds to your ears detecting the returning portion of the sound wave.

Radar is based on the fact that the amount of time elapsing between generation of a wave and its return from a reflecting object to the point of generation is directly proportional to the round trip distance. Since the velocity of radio waves is so great, elapsed time is usually measured in microseconds (10^{-6} seconds) rather than in seconds. The velocity of radio waves can be expressed as 328 yards per microsecond, which is a practical expression for radar computations. The distance in yards from a radar location to its target can then be expressed as half the elapsed time, from transmission to reception of the "echo," multiplied by the velocity of the r-f wave (328 yards per microsecond). For example, to determine the distance to the airplane in the previously described situation, if 20 microseconds elapsed between transmission of the r-f wave and the return of the echo, the following calculation would be made: 1/2 X 20 X 328 = 3280 yards.

Radar Methods

One radar method, used for moving targets, makes use of a phenomenon known as Doppler effect. The frequency of a reflected radio wave is changed when the object which reflects the wave is moving toward or away from the radio transmitter. This change in frequency is known as the Doppler effect. This effect is often experienced when listening to audio frequency signals. For example, the sound from the whistle of an approaching train appears to increase in pitch. The opposite effect occurs when the train is moving away from the listener. The radar application of this effect, known as the continuous-wave method, detects the presence and speed of a moving target by measuring the difference between the frequency of the transmitted wave and the echo wave. Practical use of this method is limited to rapidly moving targets.

The frequency-modulation method is a method used for stationary targets. In this method, the transmitted energy is continuously varied over a specified band of frequencies. Because of the time interval required for a wave to reach a target and return, the instantaneous frequency of the energy being transmitted will be different from the instantaneous frequency of the echo from a target. Because the difference in frequency is proportional to the distance from the target, a means is provided for measuring the range to the target. This method is limited to stationary targets because moving targets would introduce an additional change in frequency due to Doppler effect. The frequency change due to Doppler effect can either increase or decrease the frequency of the echo wave, depending on the direction of relative motion between transmitter and target. The amount of change will depend on the relative speed between the transmitter and the target. Therefore, it is not possible to make an accurate determination of the range to a moving target by the frequency-modulation method.

The most commonly used radar method employs pulse emmission. In this method, the radar transmitter is basically a high-power radio transmitter which is quickly switched on and off to form pulses of r-f energy. The transmitter is turned on and then is turned off before any echoes can return from targets. The transmitter is not turned on again until all possible echoes have returned. While the transmitter is off, a receiver detects any echo signals. The receiver output is connected to an indicator which measures the time interval between the transmission of energy and its return from the target, thereby providing a measurement of range to the target. To provide a continuing succession of measurements of range to the target, this process is repeated continuously: pulse, listen, pulse, listen, etc. Because this method does not depend on a relationship of the frequency of the returned signal to the frequency of the transmitting signal, or on the motion of the target, it overcomes many of the difficulties inherent in the continuous-wave and frequency-modulation methods.

Determination of Direction

This discussion of radar methods has dealt only with the determination of target range or speed. Radar systems also determine the direction to the target, and all radar systems commonly use the same method for this determination. The method by which radar systems determine direction can be easily understood by referring again to your voice and its echo.

Assume that it is dark. You are standing in a field that is open in every direction except one. In that direction is an obstruction, a high mountain with steep sides. You face one direction and shout. No echo returns. You face another direction and shout. No echo returns. You continue this process until you hear an echo. When an echo returns, you note that, by careful adjustment of the direction in which you shout, the echo is loudest from one particular direction. When this condition exists, you know that you are facing directly toward the mountain, even though it is dark and you can not see it.

Radar systems determine direction in a similar manner. Radio-frequency energy is transmitted by means of a highly directional antenna, which must be unidirectional. If any energy returns as an echo, the direction of the object returning the echo is determined simply by noting the direction in which the energy was transmitted.

To determine direction and to concentrate the transmitted energy so that the greatest portion of it is useful, antennas used for radar should be very directional. As higher carrier frequencies are employed, smaller antenna arrays are required for a given sharpness of radiation pattern. Therefore, most radars use carrier frequencies in the upper portion of the VHF band and higher.

Pulse Characteristics

Figure 9-11, 9-12, and 9-13 illustrate pulse characteristics. Figure 9-11 is a presentation of a single pulse of ideal pulse shape as it would appear on an oscilloscope display. However, actual pulses will not have instantaneous changes in amplitude as indicated in figure 9-11, but will have sloped leading and trailing edges as shown in figure 9-12. The rise time is usually expressed as the time required for the pulse to increase, on the leading edge from 10% to 90% of maximum amplitude. The decay time, or fall time, is similarly expressed as the time required for the pulse to decrease, on the trailing edge, from 10% down to 90%.

The measurement of pulse width, or pulse duration, is an important measurement that can be used to evaluate the purpose of a pulse emission system when its transmission is received. Pulse width is preferably measured from a point 90% up on the leading edge to a point 10% down on the trailing edge of the pulse. Another method of expressing pulse width is to measure the width from a point 70% up on the leading edge to a point 30% down on the trailing edge. This is known as the pulse width between the half power points.

For radar systems, the pulse width is important for two reasons. First, the minimum range at which a target can be detected depends on how narrow a pulse is used. If the pulse is too wide the transmitter would still be transmitting when echoes from close targets are returned. Associated with minimum range capabilities is a factor called range resolution. Range resolution is the minimum range

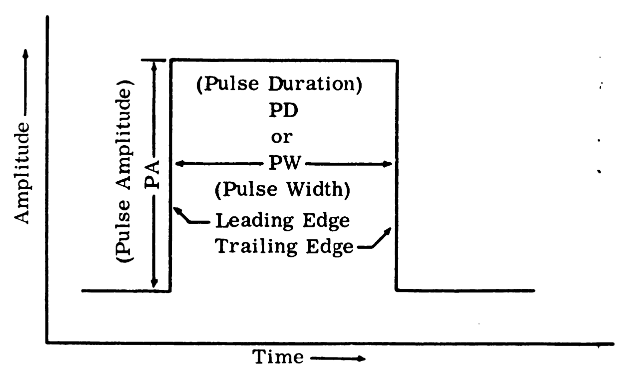

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Figure 9-11.—Pulse characteristics.

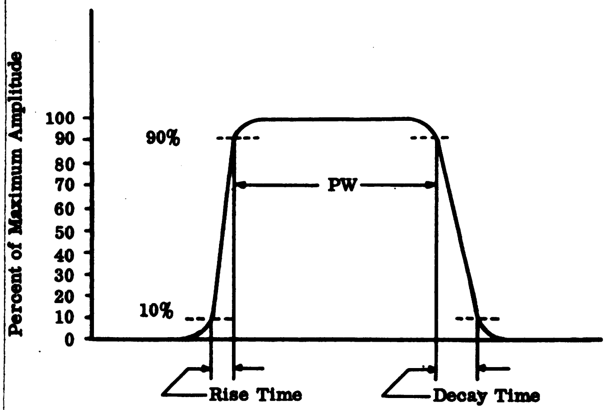


Figure 9-12.—Characteristics of a typical radar pulse.

difference between two targets, on the same bearing, which can be detected by a radar system. If the pulse is too wide, targets which are close together return echoes that merge together, and therefore appear as only one target to the radar system. A typical pulse width for radar systems used for close range or accurate range measurements is 0.1 microsecond.

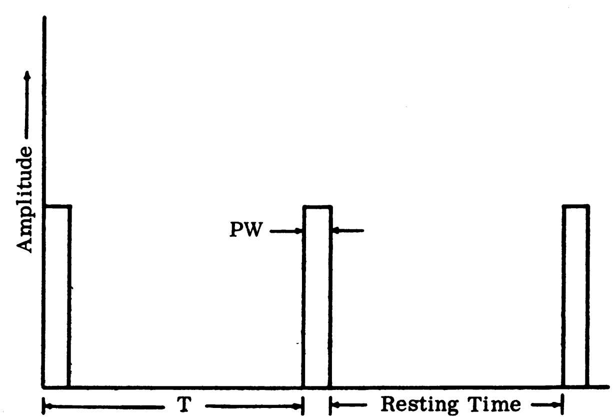
Second, pulse width is important for radar systems because, the wider the pulse, the more power that is transmitted in the pulse. Thus, if the radar is to be used for detecting targets at long ranges, it will be necessary to use wide pulses. For long-range radar systems, pulse widths normally range from 1 microsecond to 5 microseconds long.

Most radar systems transmit pulses at a constant rate; that is, the radar transmitter sends out pulses of r-f energy at evenly spaced intervals in time. The time interval from the leading edge of one pulse to the leading edge of the next pulse is called a period or pulse period, which is noted by the symbol T in figure 9-13. In the study of radar systems, the time interval known as resting time is equal to the difference of one pulse period minus a pulse width. The resting time, assuming that adequate power has been transmitted, determines the maximum useful range of a radar system. The resting time must be sufficiently long in order that an echo of a given pulse, reflected by the most distant detectable target, will return before another pulse is transmitted.

Instead of pulse period, pulse repetition rate is more commonly used in describing radar systems. Pulse repetition rate (PRR), the inverse of pulse period (1/T), is generally expressed in pulses per second (pps). Radar repetition rates range from approximately 40 pps to 5000 pps, depending upon the purpose for which the system is designed. A low PRR means that the system will have a long resting time. Therefore, low PRR is required for long-range systems and high PRR is used for short-range systems.

Scanning

Radar systems transmit energy in a narrow beam extending into space from the transmitter antenna. This beam is then moved around in space in a manner similar to searching with a searchlight beam. The process of moving the beam around in space for the purpose of searching is called scanning. There are many types of scan that can be utilized. The type of scan is usually determined by the purpose for which the radar is used. For example, a radar utilizing circular scan covering the entire horizon would most likely be used as a search radar looking for targets or for navigation purposes. Some other types of scan are sector, conical, helical, and spiral.



T = Period

$\frac{1}{T}$ = Pulse Repetition Rate (PRR) or Pulse Repetition Frequency (PRF)

13.74

Figure 9-13.—Pulse train characteristics.

Uses of Radar

Radar was first developed for long-range search purposes. This type of radar is still important for air defense and navigation. However, many additional uses for radar have been developed. During World War II, the use of radar was adapted to fire control. Fire control radars not only detect targets, but by means of servomechanisms, actually control weapons used to render the targets useless.

Because radar enabled weapons to destroy targets before they were visibly sighted, it became necessary to develop a method of ascertaining whether a target was an enemy or a friend. As far as an ordinary radar is concerned, targets of the same type (e.g., aircraft) look alike, whether friend or foe.

For purposes of identifying aircraft and other targets which are part of one's own forces, a system known as Identification Friend or Foe (IFF) was developed. This system uses a special radar transmitter, called an interrogator, which accompanies the ordinary search radar, plus a special radar transmitter-receiver, called a transponder, which is placed in friendly targets that could be mistaken for an enemy. The transponder is not an ordinary radar in that it does not transmit signals and then receive the echoes. Instead, it is designed to transmit pulses when it receives pulse signals from another radar. To prevent the transponder from responding to every radar pulse it receives, the interrogator and transponder are equipped with coding circuits so that only a received radar signal with the correct carrier frequency, pulse length, and spacing (the combination making up the "code") will trigger the transponder. The transponder in turn, sends out a coded reply (a series of pulses with the proper carrier frequency, pulse width, etc.) which can be interpreted by the search radar to identify the target.

To illustrate IFF, consider an air search radar that has just picked up an unidentified aircraft. The radar operator presses a button which activates the IFF interrogator. If the target is friendly, pulses transmitted by its transponder in response to the interrogation pulses cause an identifying signal to be displayed on the search radar indicator, and the operator knows the target is friendly.

A more recent development in the use of radar is for missile guidance systems. The problem of missile guidance can be subdivided into three functional areas: locating the target, tracking the position of the missile, and controlling the missile. A missile guidance system may use a separate radar system to achieve each function. It may use two radars, one for tracking the missile and controlling it and the other for tracking the target. It may also employ one radar system to provide all three functions. In order to carry intelligence to the missile for control purposes, some type of pulse modulation must be used. In addition, a type of scan known as lobe switching (also used in many fire control systems) is most often used. There are other types of missile guidance systems which utilize other radar techniques such as Doppler effect or frequency modulation.

RADIO NAVIGATION AIDS

Racon

Closely related to radar systems are the navigation aids systems. Many of them are actually special-purpose radar systems. Two familiar examples are the radar altimeter and the radar beacon (known as racon). The radar altimeter uses f-m radar to determine the altitude of aircraft. Racon is a system employing transponders, similar to IFF transponders, located at fixed geographical locations. When the racon interrogator aboard an aircraft is energized, the station transponder transmits a coded series of pulses which enables the aircraft (1) to identify the racon station (according to the coded reply), (2) to determine the range to the station (by the time interval from interrogation to reply), and (3) to determine the direction of the station from the aircraft (the direction in which interrogation pulses were sent and a reply received). Thus the aircraft can obtain a fix using only one racon location.

Loran

Loran is another system of position finding by reception of pulsed radio signals from fixed transmitters of known location. The basic unit of the Loran system is a pair of pulse transmitters operating on the same carrier frequency and having the same repetition rate. One of the transmitters, the master station, determines the repetition rate. The other transmitter, the slave, is synchronized to the master transmitter in such a manner that it emits a pulse at a specified time following each master pulse. A vehicle navigating by Loran carries special receiving equipment which measures the time interval between the reception of the master and the slave pulses. This time interval gives the navigator a hyperbolic line of position on which he is located. If he can obtain another line of position from another pair of Loran stations, the intersection of the two lines gives a fix of his position. See figure 9-14. The standard Loran system is in practically world-wide use by both air and naval navigators. The standard carrier frequency range is 1700 kc to 2000 kc; the two basic pulse rates in use are 25 pps and 33 1/3 pps.

In addition to the aids already discussed, many other types of radio navigation aids are in current use. There are navigation aids systems operating in prescribed portions of all the communication bands (LF through UHF). The following paragraphs contain brief summaries of some of the systems.

Instrument Landing System (ILS)

ILS provides a glide path for "blind-landing" aircraft. The glide path is formed by using two transmitting systems. The first system determines the path of descent. This system transmits two beams, one above the other. Both beams have the same carrier frequency, which is usually in the UHF band around 333 mc, but are modulated by different audio-frequency signals. The proper path of descent is defined by the equal-signal-strength path of intersection of the two beams. If the aircraft is too high, one audio signal will be stronger; if too low, the other audio signal will be stronger.

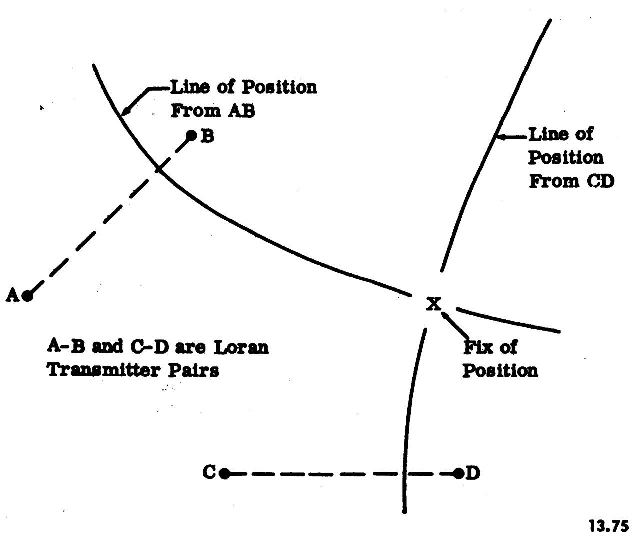


Figure 9-14.—A fix by Loran

The second transmitting system, which uses a different carrier frequency, generally in the VHF band around 110 mc, defines the proper course of approach. Two beams of the same carrier frequency, but modulated by different audio frequencies, are transmitted in such a manner that the beams provide an equal-signal path over the runway. If the aircraft is to the right of course, one audio signal will be much stronger than the other; if the craft is to the left of course, the other audio signal will be stronger. The equal-signal path defining the proper path of descent is known as the glide-path beam; the equal-signal path defining the proper course is known as the localizer beam. In addition to the glide-path and localizer beams, an instrument landing system generally has several VHF marker-beacon transmitters, operating at approximately 75 mc. These transmitters provide vertical, fan-shaped beams which indicate the position of the aircraft with respect to the runway.

Four-Course Radio Range

Low-frequency (LF and MF band) radio range stations provide four aircraft course legs through the overlapping (equisignal zones) of two figure-8 radiation patterns. The pattern is obtained by using four vertical radio towers. To provide information as to the sector in which the navigating craft is located, one radiation pattern is keyed with the Morse signal for the letter N and the other pattern is keyed with the Morse signal for the letter A. When the navigating craft is on one of the course legs, the signals for the two patterns run together to form a continuous signal.

Visual Omnirange (VOR)

VOR is a system which provides an unlimited number of course legs for an aircraft pilot to fly. The basis of the VOR system is a VHF transmitting system that provides both a radiation pattern which rotates through 360° at a rate of 30 rps and a fixed omnidirectional radiation pattern which is modulated by a 30-cps signal. The VOR receiving equipment in the navigating craft compares the phase of the signal due to the rotating pattern with the phase of the modulation signal of the omnidirectional pattern. The phase relationship provides a line of bearing to the VOR station which is translated by receiver indicators to provide compass headings of the aircraft with respect to the range station.

Since VOR gives the aircraft pilot a bearing to a fixed location but does not give him the distance, he does not obtain a fix. Therefore, VOR systems have been supplemented with distance measuring equipment (DME). The distance measuring equipment used for VOR-DME systems operates in the UHF band at about 1000 mc. The DME equipment is essentially a racon system.

Tacan

TACAN, another recent development, combines the advantages of continuous bearing information and continuous distance measuring information thereby providing a continuous fix of position. It operates on principles similar to a VOR-DME system, but operates completely in the UHF band, on channels ranging from 962 to 1213 mc.

When navigation aids signals are received on ordinary receivers, the signals of all systems (except transponder type systems) have one common characteristic—great regularity. The transmissions from most radio-navigation systems are either continuous, or last at least for several minutes. During the period of transmission, the characteristics of the signal such as the modulation, carrier frequency, etc., are not likely to change.

TELEMETERING

Telemetering, which means "measuring from afar," involves obtaining measurements from instruments located in equipments or vehicles where physical access to the instruments is not possible. Instead, a system is required which will automatically transmit the instrument readings from the point of measurement to a monitoring point where the information may be read and analyzed. Situations which require telemetering include the following: testing of prototype models of planes and missiles; testing of equipment under extreme conditions of heat, cold, or atomic radiation; testing of equipment and machines to the point of failure and physical destruction; measurements of conditions in the extreme upper atmosphere, or the extreme depths of oceans.

It is impossible to describe all types of telemetering systems because of their wide range of application. Therefore, telemetering will be discussed only in terms of general operation. The following sequence of operations is required in any telemetering system:

1. Picking up and converting the desired information into electrical signals.
2. Combining the electrical signals into one composite signal.
3. Transmitting the composite signal to a remote location.
4. Separating the composite signal into its individual signal components.
5. Recording the information contained in the individual signal components.

PICKING UP AND CONVERTING INFORMATION

Two major types of devices are employed to pick up desired information; (1) TRANSDUCERS, which convert into electrical energy some other form of energy being measured (heat, light, or motion and (2) MODIFIERS, which simply modify electrical energy but do not actually convert from one form of energy to another. The transducer or modifier (or perhaps a separate CONVERTER) takes the signal as received from the pick-up and converts it into a proportional electrical signal which varies in amplitude, frequency, or interval.

COMBINING SIGNALS INTO A COMPOSITE SIGNAL

Most telemetering systems are designed to measure and transmit several items or "channels" of information. In order to accomplish this, each item is picked up and converted into an electrical signal which must be combined, with the signals from all other items, in such a manner that all of the information may be transmitted on a single carrier frequency. Combination of signals is accomplished by one of the schemes of multiplexing, either frequency-division or time-division, or a combination of both.

TRANSMITTING THE COMPOSITE SIGNAL

When all of the information has been combined into a single signal, that signal is used to modulate an r-f signal which is transmitted to the receiving station. Many telemetering systems employ pulse modulation.

SEPARATING AND RECORDING THE SIGNALS

At the receiving station, the r-f signal is demodulated to recover the composite signal. This signal is then separated into its individual channels (demultiplexed), each of which represents an item of information from a separate "meter." The separated signals are then displayed or recorded in a manner which permits the information from each meter to be read and analyzed.

QUIZ

1. In a single-channel, start-stop teletype system,
   (a) How many bauds are transmitted for each keyboard character or function?
   (b) How many of these bauds actually represent the character or function?
   (c) What is the purpose of the remaining bauds?
2. The time required to transmit the signal for one keyboard character or function is called one_________ time.
3. What is the transmission time required for each signal unit in the stop-start system described in this chapter?
4. The teletype code illustrated in figure 9-3 is known as_________.
5. Considering the number of intelligence units actually employed in the commonly used teletype code, 32 unique characters are possible. However, a total of 58 characters and functions are actually available. How is this accomplished?
6. Which character code has all intelligence units in the marking condition?
7. The effect of shortening or lengthening the mark or space bauds of a teletype signal during the process of transmission is called_________.
8. What adjustment is performed by positioning the arm of the orientation rangefinder on a teletypewriter?
9. What is the general purpose of the orientation rangefinder?
10. How many errors occur in the copy when the settings of the rangefinder are at the orientation range limits?
11. Determine the correct rangefinder settings if the local range limits are 20 and 90, and the line range limits are 28 and 70.
12. Briefly describe the action of the multiplexing equipment which is required to time-division multiplex four standard teletype signals.
13. Facsimile transmission requires the use of a sensing device which provides an electrical output signal which varies in proportion to _________.
14. By what general method is a unique sync signal provided in most facsimile transmissions?
15. What cylinder speeds are commonly used in rotating-cylinder types of facsimile equipment?
16. Facsimile transmissions by radio most often use which kind of modulation?
17. If a radar echo pulse returns 16 microseconds after the pulse was originally transmitted, what is the distance in yards to the object which reflected the pulse?
18. (a) What are three general methods which may be employed in radar systems?
    (b) Which method relies on Doppler effect?
    (c) Which method is most commonly used?
    (d) In which method is Doppler effect an undesirable occurrence?
19. In order to determine direction to targets, radar systems require antennas having what directional characteristic?

20. Most radar systems employ carrier frequencies in which portion of the r-f spectrum?
21. Should pulses be wide or narrow in order to obtain a high degree of range resolution?
22. Long-range radar systems ordinarily use which type of pulses, wide or narrow?
23. Do long-range search radars require the use of low or high pulse repetition rates?
24. The IFF transmitter-receiver installed in friendly targets is called a__________.
25. (a) When the racon system is used, at how many geographical locations must equipment be installed to provide a continuous fix of position for navigating craft?
    (b) How many locations are required to provide the same information by the Loran system?
26. The equisignal path of an ILS system which defines the proper path of descent is known as the __________beam; the equisignal path which defines the proper course is known as the__________beam.
27. What is the advantage of the TACAN navigation aid system over the VOR system?
28. A pick-up device which measures some form of energy—such as light, heat, or motion—and provides an electrical signal output is called a__________.
29. What device is used in telemetering to convert the electrical signal from a pick-up device into a proportional electrical signal suitable for multiplexing?
30. List three processes which must be accomplished at a receiving location in order to convert an r-f telemetering signal, as it is received, into information which can be analyzed.

APPENDIX I

ANSWERS TO QUIZZES

Chapter 1

THE COMMUNICATIONS TECHNICIAN, TECHNICAL BRANCH

1. The Naval Security Group.
2. Fulfill your military requirements by completing the correspondence course based on Military Requirements for Petty Officer 3 & 2, NavPers 10056.
3. Before becoming a petty officer, your duties are primarily the performance of certain standard Navy tasks. As a petty officer, although you retain some similar duties, the emphasis is changed to direction and supervision of operations performed by others.
4. Cryptology.
5. Military bearing.
6. CTs of the T Branch handle classified equipment and information.
7. Quals Manual NSGINST P02573.3 (effective edition).
8. Study List, NSGINST 02573.2 (effective edition).

Chapter 2

SECURITY

1. Top Secret, Secret, and Confidential including Confidential-Modified Handling Authorized.
2. The design, manufacture, or utilization of atomic weapons; the production of special nuclear material; the use of special nuclear material in the production of energy.
3. National Agency Check and Background Investigation.
4. Commanding Officer.
5. "Need-to-know" basis.
6. Cryptographic Security is that component of communication security which is achieved by the correct use of technically sound cryptosystems.
   Transmission Security is that component of communication security which results from all measures designed to protect transmissions from interception, traffic analysis, and imitative deception.
7. It is the Armed Forces Courier Service which is responsible for the safe transmittal of highly classified matter to military addressees and certain agencies throughout the world.
8. Secret.
9. An approved circuit is one designated by appropriate authority as suitable for transmission in the clear of messages classified no higher than Secret.
10. Radio.
11. Radio silence is placed in effect when it is reasonable to assume that the enemy is ignorant of the location or impending movements of a ship or force.
12. One of the best defenses against imitative deception by the enemy is proper authentication.
13. Such a message should be delivered promptly to the addressee with the operator's notation that it was not properly authenticated.

Chapter 3

ORGANIZATION OF NAVAL COMMUNICATIONS

1. Naval Communication System.
2. Reliability, security, speed.
3. Security.
4. Reliability.
5. Assistant Chief of Naval Operations (Communications)/Director, Naval Communications.
6. Deputy DNC for NAVSECGRU.
7. NAVSECGRU.
8. Naval communication stations, activities, detachments.
9. Message center, cryptocenter.
10. Naval communication stations, naval radio stations, naval communication units.
11. To minimize the possibility of the transmitters interfering with the naval communication station radio receiving function.
12. Officer in charge.
13. Security Group Department.
14. Defense Communications System (DCS).
15. Naval Communication System Headquarters Activity.

Chapter 4

INTRODUCTION TO ELECTRONICS

1. Electrons, protons, neutrons.
2. Conductors.
3. Ampere.
4. Volt.
5. Increase.
6. 2 ohms.
7. 2.4 amps.
8. 12.5 volts.
9. Series
10. Counterclockwise, 4 amps.
11. 4 volts, the top end—the end closest to the positive battery terminal.
12. Parallel.
13. 0.9 amp.
14. 0.6 amp.
15. 33.3 ohms.
16. 121 watts.
17. 60 cycles per second.
18. $T = 1/f = 1/400 = 2.5 \times 10^{-3}$ seconds = 2.5 milliseconds.
19. The dielectric between the plates is a good insulator.
20. Self-inductance.
21. Impedance.
22. Resonant frequency.
23. Parallel-tuned, or tank.
24. Thermionic.
25. Cathode, grid, plate.
26. Rectifier.
27. Oscillator.
28. Band-elimination filter, or wave trap.
29. A burned-out fuse often is a sign of a faulty circuit.
30. CO_2 (carbon dioxide).
31. Be sure the victim is free from the electrical circuit; if not free, be careful in freeing him so as not to endanger yourself.

Chapter 5

RADIO WAVE PROPAGATION

1. HF.
2. UHF.
3. $\lambda = 300/f$; where λ is wavelength in meters, f is frequency in mc.
4. 1 meter, 10 meters, 10,000 meters.
5. Polarization.
6. Field strength.
7. Surface, space.
8. Surface.
9. Space.
10. Distance under normal propagation conditions is usually limited to line-of-sight distances; therefore, it is of no advantage to use large amounts of power.
11. Ducting, sporadic-E.
12. (1) The rate of recombination is high
    (2) The ultra-violet rays which cause ionization are absorbed in the upper layers of the ionosphere and do not reach below approximately 40 miles altitude.
13. Too few particles of air and gas exist at the higher altitudes to permit large scale ion formation.
14. D.
15. During daylight, especially when the sun is high—local noon.
16. Daylight, seasonal, 11-year sunspot cycle.
17. (1) The angle at which the sky wave strikes the ionosphere.
    (2) The frequency of the radio wave.
    (3) The density of the ionosphere.
18. Critical.
19. Critical.
20. Optimum Frequency for Transmission (FOT), or Optimum Working Frequency (OWF).
21. Skip distance.
22. Fading.
23. Natural static occurs at random time intervals; man-made noise is usually periodic.

Chapter 6

ANTENNAS AND TRANSMISSION LINES

1. An antenna is defined as a conductor or system of conductors which can be used to radiate or receive energy in the form of electromagnetic waves.
2. 7.5 meters.
3. 300 kc.
4. Higher.
5. Unidirectional.
6. 1/2, 1/4.
7. Array.
8. 4800.
9. It may be unidirectional, bidirectional, or simultaneously unidirectional in two directions, depending on how it is terminated.
10. It is efficient over a broader band of frequencies.
11. More.
12. Unidirectional.
13. 250.
14. The shield prevents radiation from the transmission lines.
15. Solid coaxial.
16. A mismatch between antenna and transmission line.
17. Multicoupler.
18. Cascade.

Chapter 7

MODULATION

1. The received signal frequency increases by 1% also.
2. Modulation.
3. Carrier.
4. Amplitude.
5. 100.
6. Two.
7. C-w.
8. Amplitude.
9. SSB.
10. F-m.
11. Frequency shift keying.
12. Four.
13. Characteristics, the sequence of the pulse train.
14. They are coded pulse trains, each code representing an instantaneous amplitude of the modulating signal.
15. Subcarriers.
16. Time division and frequency division.
17. Frequency division multiplexing.
18. By inserting a reference timing element at the same time instant in each multiplex cycle.
19. Sequential and interlaced.
20. Inversely.
21. 3.55.

Chapter 8

INTRODUCTION TO RECEIVERS

1. R-f amplifier.
2. R-f amplifier.
3. Detector.
4. To detect c-w signals.
5. Beat frequency oscillator.
6. Prevent strong signals overdriving later stages and prevent the output from exceeding the desired output level.
7. Mixer and i-f amplifier circuits.
8. I-f amplifier, r-f amplifier.
9. I-f and r-f amplifiers.
10. Heterodyning.
11. By having the local oscillator track at a fixed frequency interval from the tuning of the r-f stage.
12. Discriminator.
13. 0.5 to 32 mc.
14. Automatically adjusts the r-f and i-f gain to compensate for variations in the level of the incoming signal.
15. (a) Disengage the tuning controls from the frequency indicator.

    (b) When calibrating the receiver.
16. Adjusts the tuned circuits of the i-f portion of the receiver, thereby controlling selectivity.
17. Controls the level of the audio output which is used to operate terminal equipment.
18. ANT TRIM.
19. Carrier level meter.
20. Phone jack, local line, and i-f.

Chapter 9

TRANSMISSION SYSTEMS

1. (a) Seven.
   (b) Five.
   (c) Synchronization of the transmitting and receiving equipments.
2. Cycle.
3. The start and intelligence bauds each require 22 milliseconds. The stop baud requires 31 milliseconds.
4. International Teletype Code #2.
5. By the use of upper and lower case for each intelligence combination, the number of characters and functions which may be transmitted is nearly doubled.
6. The LETTERS shift function is the only code which has all five intelligence units in the marking condition.
7. Distortion.
8. It adjusts the time, within the intelligence units of the received teletype signal, at which the swords, which select the character to be printed or the function to be accomplished, are positioned.
9. To overcome the effects of distortion.
10. One error per line of copy; that is, one error per 72 characters.
11. 52.
12. (a) The multiplexer accepts the four channel signals and modifies the lengths of the bauds in individual channels to permit all four channels to be sent in the time ordinarily required for one channel.
    (b) The modified signals are combined, by means of time division, into a single signal which can be used to modulate an r-f carrier.
13. The intensity of the shading of the information being sensed.
14. The sync signal is caused to have greater deviation than any deviation caused by the sensing of information.
15. 60, 90, and 120 rpm.
16. Carrier FSK or subcarrier FSK.
17. 2624 yards.
18. (a) Continuous-wave, frequency-modulation, and pulse emission.
    (b) Continuous-wave.
    (c) Pulse emission.
    (d) Frequency-modulation.
19. Unidirectional.
20. The upper portion of the VHF band and above.
21. Narrow.
22. Wide.
23. Low.
24. Transponder.
25. (a) One.
    (b) Four.
26. Glide-path; localizer.
27. TACAN provides a continuous fix of position; VOR provides only continuous compass headings.
28. Transducer.
29. Converter.
30. (a) Demodulate the r-f wave to recover the multiplexed (composite) signal.
    (b) Demultiplex the composite signal to recover the individual channel signals.
    (c) Record or display the individual channel signals.

APPENDIX II

INTERNATIONAL MORSE CODE

As a T Branch CT you are required to copy Morse code. If you are a service school graduate, you have been taught the Morse code. However, you will be able to learn code by using the following information which is provided primarily for personnel who have not completed service school. If you are a school graduate and need refresher training in copying Morse code, you may also effectively use this information. Most of the Morse code you will copy will be hand sent at slow speeds; therefore you will be required to demonstrate copying speeds of approximately 12 1/2 words per minute.

To learn the code you must concentrate and practice and, above all, not become discouraged. With enough effort, you will soon be copying code much faster than you thought possible. The international Morse code is a dit and dah system. The code is pronounced "dit" and "dah"— not "dot" and "dash." Forget about dots and dashes and think only in terms of dits and dahs. The groups of dits and dahs which represent each letter must be made as one unit, with a clear break between each dit and each dah, and a much more distinct break between characters. A dit is one-third the length of a dah.

You must never try to count the dits and dahs. Don't let yourself get in the habit of doing so. It's a temptation at first, but you won't be able to count fast enough when the code speed picks up. Instead, learn SOUND PATTERNS. To understand what this means rap out the pattern beginning "Shave and a haircut." You recognize this from its characteristic rhythm, not from the fact it has a certain number of beats in it. You must learn the code the same way. There are 36 Morse sound patterns representing the letters and numbers, plus a few others representing prosigns and punctuation marks. With study and drill you will learn to recognize each as fast as you now recognize "Shave and a haircut." The accent always falls on dahs, and you should pronounce each rhythmical combination with that in mind. Go through the alphabet several times getting the sound pattern of the dit and dah combination.

Morse Signal	Roman Alphabet	Phonetic Alphabet	Code Pronunciation
. -	A	ALPHA	di-DAH
- . . .	B	BRAVO	DAH-di-di-dit
- . - .	C	CHARLIE	DAH-di-DAH-dit
- . .	D	DELTA	DAH-di-dit
.	E	ECHO	dit
. . - .	F	FOXTROT	di-di-DAH-dit
- - .	G	GOLF	DAH-DAH-dit
. . . .	H	HOTEL	di-di-di-dit
. .	I	INDIA	di-dit
. - - -	J	JULIETT	di-DAH-DAH-DAH

Morse Signal	Roman Alphabet	Phonetic Alphabet	Code Pronunciation
- . -	K	KILO	DAH-di-DAH
. - . .	L	LIMA	di-DAH-di-dit
- -	M	MIKE	DAH-DAH
- .	N	NOVEMBER	DAH-dit
- - -	O	OSCAR	DAH-DAH-DAH
. - - .	P	PAPA	di-DAH-DAH-dit
- - . -	Q	QUEBEC	DAH-DAH-di-DAH
. - .	R	ROMEO	di-DAH-dit
. . .	S	SIERRA	di-di-dit
-	T	TANGO	DAH
. . -	U	UNIFORM	di-di-DAH
. . . -	V	VICTOR	di-di-di-DAH
. - -	W	WHISKEY	di-DAH-DAH
- . . -	X	XRAY	DAH-di-di-DAH
- . - -	Y	YANKEE	DAH-di-DAH-DAH
- - . .	Z	ZULU	DAH-DAH-di-dit

Morse Signals	Numerals	Code Pronunciation
. - - - -	1	di-DAH-DAH-DAH-DAH
. . - - -	2	di-di-DAH-DAH-DAH
. . . - -	3	di-di-di-DAH-DAH
. . . . -	4	di-di-di-di-DAH
. . . . .	5	di-di-di-di-dit
-	6	DAH-di-di-di-dit
- - . . .	7	DAH-DAH-di-di-dit
- - - . .	8	DAH-DAH-DAH-di-dit
- - - - .	9	DAH-DAH-DAH-DAH-dit
- - - - -	Ø	DAH-DAH-DAH-DÀH-DAH

Morse Signal	Punctuation Mark	Code Pronunciation
- . . . . -	Dash	DAH-di-di-di-di-DAH
- . - - . -	Parenthesis	DAH-di-DAH-DAH-di-DAH
. - . - . -	Period or decimal point	di-DAH-di-DAH-di-DAH
- . . - .	Slant	DAH-di-di-DAH-dit
. - - - - .	Apostrophe	di-DAH-DAH-DAH-DAH-dit
- - - . . .	Colon	DAH-DAH-DAH-di-di-dit
- - . . - -	Comma	DAH-DAH-di-di-DAH-DAH
. . - - . .	Question Mark	di-di-DAH-DAH-di-dit

Hints on Studying Code

If you have trouble learning the code, the following hints may be helpful. Go through the three groupings of short, medium, and long sounds with their accompanying practice words. Make up words of your own if you wish to give yourself further practice. Speak the practice words in code. Say "TEE: DAH dit dit," "MINE: DAH-DAH di-dit DAH-dit dit."

If you can speak words in code rapidly and distinctly, you will have an easier time learning to receive code. The sounds are very similar.

Short Sounds	Practice Words
E dit	TEE ATE EAT TEA MEAT MEET
T DAH	MINE TIME MAINE TEAM
A di-DAH	AIM NITE TAME TEA MATE
I di-dit	TAME NAME MITE MIAMI
M DAH-DAH	MAMA MEAN MAN MAT EMIT
N DAH-dit	MINT MANE TAN ITEM TINT

Medium Length Sounds	Practice Words
D DAH-di-dit	MUST SAME MAMA SUIT AUTO
G DAH-DAH-dit	MUSS OUST MUSE MUTE ATOM
K DAH-di-DAH	TAUT MAST MASS SUET SAM WIND
O DAH-DAH-DAH	SEA TUM SAW OAT SUE SAT WED
R di-DAH-dit	SUM MUD IOU USE SEAM WOOD DARK
S di-di-dit	GEORGE DOWN KIND SORT DOOR MASK
U di-di-DAH	WORK GROW WOMAN EDGE GAGE
W di-DAH-DAH	WIGS WORM WAGER WAKE KEG

Long Sounds	Practice Words
B DAH-di-di-dit	VAT VET VIM HAM SIX SIX
C DAH-di-DAH-dit	HAS HAT EVE CUT CAM VEST
F di-di-DAH-dit	HEAT HAVE MUCH THAT EACH
H di-di-di-dit	COAT ACHE SAVE HUSH ACME
J di-DAH-DAH-DAH	CUTE BAKER CHARLIE FIVE
L di-DAH-di-dit	HOW JIMMY LIKE PAPA QUICK
P di-DAH-DAH-dit	QUILL VICTORY XRAY YOUNG
Q DAH-DAH-di-DAH	ZERO BUZZ GARGLE FIZZLE
V di-di-di-DAH	LYNX OXYGEN WAX QUAY
X DAH-di-di-DAH	JERKY WHIP QUEBEC
Y DAH-di-DAH-DAH	
Z DAH-DAH-di-dit	

Figure Sounds

1. di-DAH-DAH-DAH-DAH
2. di-di-DAH-DAH-DAH
3. di-di-di-DAH-DAH
4. di-di-di-di-DAH
5. di-di-di-di-dit
6. DAH-di-di-di-dit
7. DAH-DAH-di-di-dit
8. DAH-DAH-DAH-di-dit
9. DAH-DAH-DAH-DAH-dit

Ø. DAH-DAH-DAH-DAH-DAH

Receiving

If you have carried out the recommendations made up to this point, you are ready to receive code transmitted to you from an oscillator, records, or tapes. The station to which you are attached will almost certainly have practice oscillators and tapes or records for code practice. No doubt there will be an experienced operator who will key code groups to you for training.

The sound produced by an oscillator closely resembles the sound of code from a radio receiver. When using an oscillator for practice, the operator keying to you for practice should transmit each character at a steady rate of speed with fairly long intervals between characters. As you progress, you gain speed by shortening spaces BETWEEN characters. If you learn the fundamentals well, it will be fairly easy for you to increase your speed. Do not seek speed before accuracy. When copying code, if you miss a character, don't stop to worry about it; get the next character and let that missed one go by. Note that in the code, the time of a dit is the basic unit. There is one unit between each element of a character, three units between each character, three units in each dah, and seven units between each group or word.

As your speed and accuracy increase as a result of practice in copying from oscillators, tapes, or records, you will be ready for practice on a live circuit. It is then that you will receive your most valuable training under actual operating conditions.

APPENDIX III

TIME ZONES AND TIME CALCULATIONS

In 1884, an international conference of astronomers in Washington, D. C., decided that the Greenwich Observatory at Greenwich, England, should mark the prime, or first, meridian of longitude of the earth because it was the oldest observatory in constant use. Although the Greenwich Observatory was later moved southeast to Sussex, zero degrees longitude remains at its original location at Greenwich.

A system of standard time has been adopted throughout most of the world. Nearly all world time calculations are now based on the meridian which passes through Greenwich, England. Though no formal agreement took place, the world was divided into 24 equal zones, each 15 degrees in longitude, because, as the earth rotates, the sun's rays travel 15 degrees over the earth's surface in an hour. Each of the 24 time zones uses the SUN TIME of its central or standard meridian. Maps of most countries were changed to show the longitude marked east and west of Greenwich.

The zero zone designated by the letter "Z" extends 7 1/2 degrees on either side of the prime meridian and is called the zero zone because the difference between the standard time in this zone and Greenwich Time is zero. Greenwich Time is referred to as GREENWICH MEAN TIME (GMT), GREENWICH CIVIL TIME (GCT), and is also called UNIVERSAL TIME (U.T.).

The number used to designate each of the other zones represents the difference in hours between the local standard or SUN TIME in that particular zone and the Greenwich Mean Time (GMT). The zones lying east of Greenwich are designated minus zones; those lying west of Greenwich, plus zones. In addition, each zone is also given a letter designation. A through M (J omitted) indicate minus zones; N through Y, plus zones.

At sea, each zone is cut exactly in half by its standard meridian. The zone extends 7 1/2 degrees east and the same distance west of each standard meridian. But on land, the zone boundaries are often irregular. For example, if part of a city, county, state, or country lies within two different time zones, the zone boundaries are sometimes altered so that the same time may be used in the geographical entity.

Time Zones of the United States

The United States now has seven time zones which are given in the following table, together with the standard meridian from which each is measured, the zone number, and letter designator.

Designation	Standard Meridian	Zone Number	Zone Letter
Eastern	75th	+5	R
Central	90th	+6	S
Mountain	105th	+7	T
Pacific	120th	+8	U
Juneau	135th	+9	V
Central Alaska (Hawaiian)	150th	+10	W
Nome	165th	+11	X

For boundaries of the listed zones, see the time zone chart of the world, figure III-1.

Daylight Saving Time

For various reasons, time which is one or more hours in advance of standard time is frequently used. In the United States, such time is referred to as DAYLIGHT SAVING TIME. As will be noted on the time map of the world, figure III-1, the U.S.S.R. advances time one hour throughout the entire country and uses this as their standard time. This places the northeastern corner of Siberia on -13 time. The letter used to designate the -13 zone thus created is the same letter which is used to indicate the +1 zone, namely "N."

International Date Line

The 180th meridian, exactly halfway around the world from Greenwich, England, has been established, through general practice of the large nations of the world, as the location of the International Date Line. In certain places, the date line deviates from the 180th meridian in order to avoid differences in date within countries or between island groups. For example, if the line adhered exactly to the 180th meridian, the northeastern corner of Siberia would have a different date from the rest of Asia. Therefore, the date line was moved to run east of Siberia. Part of the Aleutian Islands extend west of the 180th meridian. However, the date line has been curved so that all of the Aleutians remain east of it. The date line jogs again at the Fiji Islands. It was moved at this point to keep all the islands on one side of the date line.

For each 15 degrees of longitude east of Greenwich, the time is advanced one hour. For each 15 degrees of longitude west of Greenwich, the time is set back one hour. At longitude 180 degrees east, the time is 12 hours ahead of Greenwich time. At longitude 180 degrees west, the time is 12 hours behind Greenwich time. Therefore, there is a 24-hour difference between the two sides of the date line, or 180th meridian. If a ship crosses the date line going in a westerly direction, it loses a day; if it crosses the date line going in an easterly direction, it gains a day.

A new date first begins on the western side of the date line. As the earth rotates on its axis, this new date sweeps westward around the world. The date covers the earth in 24 hours. As a result, people in New Zealand, on the western side of the line begin their new day 22 hours ahead of the people in Hawaii, which lies on the eastern side of the line.

Time in Naval Messages

In order that the same time may be used throughout the service, GMT or GCT is used to indicate the time of origin of most naval messages. This eliminates any doubt as to which time the originator is using. As previously stated, the designating letter for GMT is "Z." A 4-digit group is the approved method of expressing time in the 24-hour system. The first two digits of the group indicate the hour, the third and fourth indicate the minutes. Thus 6:30 a.m. becomes 0630; noon is 1200; and 6:30 p.m. is 1830. Midnight is usually expressed as 0000—rarely 2400—and one minute past midnight becomes 0001. The time designation 1543Z indicates 43 minutes after 3:00 p.m. GMT. To form a DATE TIME GROUP (DTG), two numbers are prefixed to the time to indicate the day of the month. The DTG 060824Z means the sixth day of the current month plus the GMT time.

Days of the month, from the first through the ninth, are preceded by the numeral zero. When local time is used in the text of messages, it must be accompanied by the zone designating letter—as in the DTG 121847R. If a local time is referred to frequently in the text, the suffix may be omitted provided a covering expression, such as ALL TIMES ROMEO, is used.

Solving Time Problems

The following four rules should be MEMORIZED:

RULE I - To find GMT, APPLY local zone to local time.

RULE II - To find time in another zone, REVERSE the sign of the zone and APPLY to GMT.

RULE III - If it is necessary to add 24 hours, SUBTRACT one day from the date.

RULE IV - If it is necessary to subtract 24 hours, ADD one day to the date.

These four rules, if learned and applied to all calculations, will enable an individual to work any time problem correctly.

The following examples show the applications of these rules.

PROBLEM: It is 2357 local time on the 30th of September in the +12 time zone. What is the local time and date in the -5 time zone?

(Note: The first step in working any time problem is to determine GMT.)

	Time/Date	Month	Zone
	2357/30	Sep	+12
Step 1, use Rule I:	+12		
	3557/30	Sep	GMT
Step 2, use Rule II:	+05		
	4057/30	Sep	-5
Step 3, use Rule IV:	-24		
Answers:	1657/01	Oct	-5

PROBLEM: It is 2357/30 September in the +12 zone. What is the time and date GMT?

	Time/Date	Month	Zone
	2357/30	Sep	+12
Step 1, use Rule I:	+12		
	3557/30	Sep	GMT
Step 2, use Rule IV:	-24		
Answers:	1157/01	Oct	GMT

PROBLEM: It is 0342/01 January 1963 in the -12 zone. What is the time, date, month, and year in the +12 zone?

	Time/Date	Month	Year	Zone
	0342/01	Jan	1963	-12
Step 1, use Rule III:	+24			
	2742/31	Dec	1962	-12
Step 2, use Rule I:	-12			
	1542/31	Dec	1962	GMT
Step 3, use Rule II:	-12			
Answers:	0342/31	Dec	1962	+12

The foregoing examples have dealt with times and time zones where the time is indicated only in hours and minutes and the zones only in hours. The following problem is presented to show that the four rules are equally applicable when time and time zone are given as hours, minutes, and seconds.

PROBLEM: It is the 16th of March on a tiny island in the South Pacific where the local time differs from GMT by -12 hours, 14 minutes, and 39 seconds. A missile has been fired. From monitoring its signals, it is determined that the local time at the launching site was exactly 0953:51 when the missile impacted on the target island. Local time on the target island differs from GMT by +06 hours, 52 minutes, and 57 seconds. What was the exact local time on the target island when the missile impacted?

	Time/Date	Month	Zone
	0953:51/16	Mar	-1214:39
Step 1, use Rule III:	+24		
	3353:51/15	Mar	-1214:39
Step 2, use Rule I:	-1214:39		
	2139:12/15	Mar	GMT
Step 3, use Rule II:	-0652:57		
Answers:	1446:15/15	Mar	+0652:57

(Note: Since 52 could not be subtracted from 39, and 57 could not be subtracted from 12, it was first necessary to borrow 1 hour (60 minutes) and add this to the minutes given. Then it was necessary to borrow 1 minute (60 seconds) and add this to the seconds given. This conversion resulted in a time of 2098:72 from which 0652:57 could be subtracted.)

APPENDIX IV

MATHEMATICAL REVIEW

POWERS OF 10

In electronics and communication work it is often necessary to solve problems involving very large or very small numbers. Solving such problems by the rules of ordinary arithmetic is laborious and sometimes time consuming. Also, there is often the problem of accurately placing the decimal point in the results. These difficulties can be greatly reduced by a working knowledge of the powers of 10 and their use.

Greek and Latin words are used as prefixes to identify units of such quantities as the volt, ampere, cycle, and coulomb. The following table lists the most commonly used prefixes, together with their decimal equivalents and the number expressed in powers of 10.

MEGA	1,000,000	10^6	1 million
MYRIA	10,000	10^4	10 thousand
KILO	1,000	10^3	1 thousand
HECTO	100	10^2	1 hundred
DECA	10	10^1	ten
DECI	.1	10^{-1}	one-tenth
CENTI	.01	10^{-2}	one-hundredth
MILLI	.001	10^{-3}	one-thousandth
MICRO	.000001	10^{-6}	one-millionth

When working problems, it is often convenient to convert terms such as megacycle, kilocycle, milliampere, and microsecond to the correct power of 10; for example,

1 megacycle = 1,000,000 or 10^6 cycles
1 kilocycle = 1,000 or 10^3 cycles
1 milliampere = .001 or 10^{-3} amperes
1 microsecond = .000001 or 10^{-6} seconds
1 micromicrosecond = .000000000001 or 10^{-12} seconds

From the foregoing examples, you can see that you can express any number, large or small, times the correct power of 10. There are two basic rules to follow in making conversions.

TO EXPRESS A LARGE NUMBER AS A SMALLER NUMBER TIMES A POWER OF 10, SHIFT THE DECIMAL POINT TO THE LEFT TO THE DESIRED POSITION AND COUNT THE NUMBER OF PLACES TO THE ORIGINAL DECIMAL POINT. THIS NUMBER OF PLACES COUNTED IS THE POSITIVE POWER OF 10.

For example:

$60{,}000 = 6 \times 10{,}000$ or 6×10^4
$538 = 5.38 \times 100$ or 5.38×10^2
$543{,}000{,}000 = 543 \times 10^6$ or 5.43×10^8
$234.01 = 2.3401 \times 10^2$

NOTE: The positive (plus value) power of 10 is the number of places the decimal point was moved to the LEFT.

TO EXPRESS A SMALL NUMBER AS A LARGER NUMBER TIMES A POWER OF 10, SHIFT THE DECIMAL POINT TO THE RIGHT TO THE DESIRED POSITION AND COUNT THE NUMBER OF PLACES TO THE ORIGINAL DECIMAL POINT. THIS NUMBER OF PLACES COUNTED IS THE NEGATIVE POWER OF 10.

For example:

$$0.00657 = 6.57 \times .001 \text{ or } 6.57 \times 10^{-3}$$

$$0.348 = 34.8 \times .01 \text{ or } 34.8 \times 10^{-2}$$

$$0.00000584 = 5.84 \times 10^{-6} \text{ or } 58.4 \times 10^{-7}$$

$$234.01 = 23401 \times 10^{-2}$$

NOTE: The negative (minus value) power of 10 is the number of places the decimal point was moved to the RIGHT.

LAWS OF EXPONENTS

Powers of 10 make use of the laws of exponents. They also make use of the fact that any number may be expressed as the product of two factors, one of which will have the digit sequence of the original number and the other will be some power of 10 (as illustrated in the foregoing examples). Two of the laws of exponents, the multiplication law and the division law, need to be understood in order to solve problems involving numbers expressed in powers of 10.

The law of exponents for multiplication states: TO MULTIPLY TWO OR MORE POWERS OF THE SAME BASE, ADD THEIR EXPONENTS.

For example:

$$10^4 \times 10^2 = 10^{4+2} = 10^6$$

$$2.5 \times 10^4 \times 4 \times 10^{-2} = 2.5 \times 4 \times 10^{4+(-2)}$$
$$= 10 \times 10^2 = 10^3$$

The law of exponents for division states: TO DIVIDE POWERS OF THE SAME BASE, SUBTRACT THE EXPONENT OF THE DENOMINATOR FROM THE EXPONENT OF THE NUMERATOR.

For example:

$$\frac{10^7}{10^3} = 10^{7-3} = 10^4$$

$$\frac{4.8 \times 10^3}{2 \times 10^{-6}} = \frac{4.8}{2} \times 10^{3-(-6)} = 2.4 \times 10^9$$

TAKING A SQUARE ROOT

When working problems concerned with electronics, it is often necessary to determine the square root of a number. A simple method which you can use to extract a square root from any number, is presented in a sample problem. Study the sample problem, paying close attention to the explanation of each step in the procedure.

Sample Problem: Find the square root of 208743.9 (to the nearest hundredth).

$\overline{20\ 87\ 43.90\ 00\ 00}$ — First, divide the number into parts or groups of two, starting at the decimal point and working in both directions.

```
  4
|20 87 43.90 00 00
|16
  4 87
```

Second, consider the extreme left hand group (20). Determine the largest number, which when it is squared, is equal to or less than the group. Write this number (4) above the first group as the first number of the square root. Write the square of this number below the first group and subtract it from the first group. Bring down the next group, forming the remainder 487.

```
       4  6
      |20 87 43.90 00 00
      |16
8 6    |4 87
       |5 16
```

Next, double the first number of the square root (4). Set down this number (8) as the first part of the trial divisor. Divide this first part of the trial divisor (8) into all but the last digit of the remainder (48). Write the quotient (6) as the next figure of the square root, and also write it as the final digit of the trial divisor. Multiply the quotient (6) times the completed trial divisor (86), place the product (516) under the remainder (487).

```
       4  5
      |20 87 43.90 00 00
      |16
8 5    |4 87
       |4 25
          62 43
```

Normally this product will be less than the remainder, but if as in this case it is larger, reduce the quotient by one (6 - 1 = 5). Multiply the quotient minus one (5) times the new completed trial divisor (85). Then subtract the product (425) from the remainder (487) to give a remainder of 62. Bring down the next group (43) to form a new remainder of 6243.

```
       4  5  6
      |20 87 43.90 00 00
      |16
8 5    |4 87
       |4 25
90 6      |62 43
          |54 36
             8 07 90

          4  5  6. 8
         |20 87 43.90 00 00
         |16
8 5        |4 87
           |4 25
90 6          |62 43
              |54 36
912 8            |8 07 90
                 |7 30 24
                    77 66 00
```

Follow the procedure of doubling the known digits of the square root to obtain all but the last digit of the trial divisor, that is, 2 x 45 = 90. Divide this number (90) into all but the last digit of the remainder (624). Write the quotient (6) as the next number of the square root and also as the last digit of the trial divisor. Follow this procedure until the desired square root has been found. Note that when the square root is found by this method, the decimal point in the answer is above the decimal point in the original problem.

```
              4   5   6. 8   8
            |20  87  43.90  00  00
            |16
8 5           |4 87
              |4 25
90 6              |62 43
                  |54 36
912 8               |8 07 90
                    |7 30 24
9136 8                  |77 66 00
                        |73 09 44
                           4 56 56 00
```

```
              4 5    6. 8   8   4
            |20  87  43.90  00  00
            |16
8 5           |4 87
              |4 25
90 6              |62 43
                  |54 36
912 8               |8 07 90
                    |7 30 24
9136 8                  |77 66 00
                        |73 09 44
91376 4                   |4 56 56 00
                          |3 65 50 56
                              91 05 44
```

The square root, 456.884, is rounded off to the nearest hundredth, 456.88.

To round off a number to the nearest place, you simply carry the figure one additional place beyond the desired place. For example, to find a number to the nearest tenth, determine the number to the hundredth, to find a number to the nearest hundredth, determine the number to the thousandth, and so forth.

If this additional figure is less than 5, leave the original figure unchanged. If the figure is 5 or more, increase the original figure by 1. For example, when rounding off to the nearest hundredth:

$$456.784 = 456.78$$
$$456.789 = 456.79$$

SAMPLE PROBLEMS

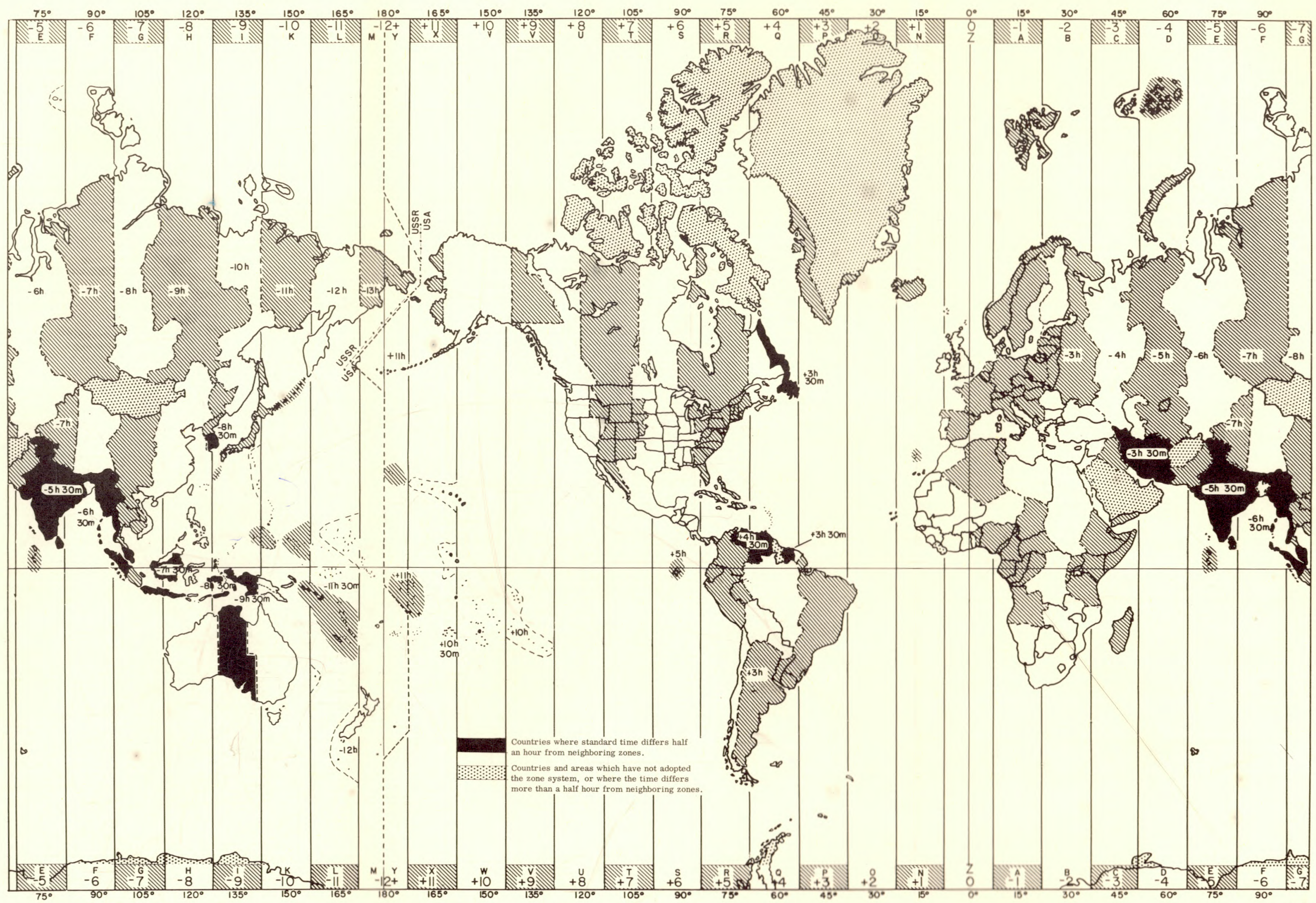
The application of mathematical prefixes and the use of powers of ten can best be illustrated by problems which are typical of those which you will encounter in electronics and communications work. Three sample problems have been included to assist you in understanding the procedures for obtaining correct solutions.

SAMPLE PROBLEM 1

$$\text{Solve: } \frac{2000 \times 250 \times 700}{3500 \times .0002 \times .05}$$

Step 1. Write the numbers using powers of 10.

$$\frac{2 \times 10^3 \times 2.5 \times 10^2 \times 7 \times 10^2}{3.5 \times 10^3 \times 2 \times 10^{-4} \times 5 \times 10^{-2}}$$



Appendix III-1.—Time zone chart of the world.

Step 2. Group the factors and powers of 10, writing the problem as

$$\left(\frac{2 \times 2.5 \times 7}{3.5 \times 2 \times 5}\right)\left(\frac{10^3 \times 10^2 \times 10^2}{10^3 \times 10^{-4} \times 10^{-2}}\right)$$

Step 3. Solve for the factors.

$$\frac{2 \times 2.5 \times 7}{3.5 \times 2 \times 5} = \frac{35}{35} = 1$$

Step 4. Solve for the powers of 10.

$$\frac{10^3 \times 10^2 \times 10^2}{10^3 \times 10^{-4} \times 10^{-2}} = \frac{10^{3+2+2}}{10^{3+(-4)+(-2)}} = \frac{10^7}{10^{-3}} = 10^{7-(-3)} = 10^{10}$$

Step 5. Using the values obtained in steps 3 and 4, perform the operation indicated in step 2.

$$1 \times 10^{10} = 10^{10} \text{ or } 10{,}000{,}000{,}000$$

SAMPLE PROBLEM 2

Find the inductive reactance of a 200 microhenry coil at one megacycle. (Inductive reactance $(X_L) = 2\pi fL$)

Step 1. Convert the information given in the problem into terms which can be substituted into the formula for inductive reactance.

f = 1 megacycle = 1,000,000 cycles or 10^6 cycles

L = 200 microhenries = 200×10^{-6} henries

Step 2. Substitute these values into the formula.

$$X_L = 2 \times 3.14 \times 10^6 \times 200 \times 10^{-6}$$

Step 3. Solve for the factors and the powers of 10.

$$X_L = 6.28 \times 200 \times 10^{6+(-6)}$$

$$X_L = 6.28 \times 200 \times 1 \qquad (\text{Since } 10^0 = 1)$$

$$X_L = 1256 \text{ ohms.}$$

SAMPLE PROBLEM 3

Find the resonant frequency of a tuned circuit containing an inductance of 20 microhenries and a capacitance of 200 micromicrofarads.

Step 1. Convert to usable terms.

L = 20 microhenries = 20×10^{-6} henries

C = 200 micromicrofarads = 200×10^{-12} farads.

Step 2. Substitute the known values into the formula for the resonant frequency.

$$f = \frac{1}{2\ \pi \sqrt{LC}}$$

$$f = \frac{1}{6.28\sqrt{20 \times 10^{-6} \times 200 \times 10^{-12}}}$$

Combine the factors and powers of 10 under the radical (square root sign).

$$f = \frac{1}{6.28\sqrt{4{,}000 \times 10^{-6+(-12)}}}$$

$$f = \frac{1}{6.28\sqrt{4 \times 10^{3} \times 10^{-18}}}$$

$$f = \frac{1}{6.28\sqrt{4 \times 10^{-15}}}$$

Step 4. Consider the portion of the problem under the radical

$$\sqrt{4 \times 10^{-15}}$$

Rewrite this so that the power of 10 will be an even number

$$\sqrt{40 \times 10^{-14}}$$

Step 5. The square root of 40 can be determined either by the method described earlier or by the use of a square root table.

$$\sqrt{40} = 6.32$$

Since the square root of 10 raised to an even power can be found by dividing the exponent by 2

$$\sqrt{10^{-14}} = 10^{-7}$$

Step 6. Since $\sqrt{40 \times 10^{-14}} = \sqrt{40}\ \sqrt{10^{-14}} = 6.32 \times 10^{-7}$ the equation found in step 3 can be written as

$$f = \frac{1}{6.28 \times 6.32 \times 10^{-7}}$$

$$f = \frac{1}{39.69 \times 10^{-7}}$$

Step 7. The quantity 10^{-7} in the denominator can be moved to the numerator by changing the sign of the exponent.

$$\frac{1}{10^{-7}} = \frac{10^{0}}{10^{-7}} = 10^{0-(-7)} = 10^{7}$$

At this point you can either divide 10,000,000 (10^7) by 39.69, to find the exact value, or perform the following operations, to find a close approximation of the value.

$$f = \frac{10^7}{39.69} = \frac{10^2 \times 10^5}{39.69} = \frac{100}{39.69} \times 10^5$$

100 divided by 39.69, to the nearest tenth is 2.5. The resonant frequency (f) is 2.5×10^5 cycles or 250 kilocycles.

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