NONRESIDENT TRAINING COURSE

Aviation Electricity and Electronics—Undersea Warfare (USW)

NAVEDTRA 14340

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PREFACE

About this course:

This is a self-study course. By studying this course, you can improve your professional/military knowledge, as well as prepare for the Navywide advancement-in-rate examination. It contains subject matter about day-to-day occupational knowledge and skill requirements and includes text, tables, and illustrations to help you understand the information. An additional important feature of this course is its references to useful information to be found in other publications. The well-prepared Sailor will take the time to look up the additional information.

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CHAPTER 1

ACOUSTIC SYSTEMS

INTRODUCTION

Undersea Warfare (USW), formerly known as Antisubmarine Warfare (ASW), includes the detection, localization, and identification of potentially hostile forces or objects below the surface of the sea. One of the major tasks of the Navy today is the detection of concealed submarines.

Detecting the stealthy submarine starts with maintaining a tool kit of several different electronic sensors (fig. 1-1). Each sensor has specific applications that counter different submarine operations. Many of these sensors complement and corroborate with each other to enhance USW effectiveness.

Airborne USW sensors are divided into two basic types—acoustic and nonacoustic. This chapter will introduce you to acoustic sensors as currently employed by naval aircraft. Acoustic systems include components that detect, process, and display sonobuoy-detected data for analysis. Nonacoustic systems include radar, navigation, MAD, ECM, ESM, and infrared detecting sets.

SONAR PRINCIPLES

LEARNING OBJECTIVE: Identify the factors that affect the behavior of a sound wave in seawater.

The word *sonar* is derived from the initial letters of SOund, NAvigation, and Ranging, and is used to describe equipment that locates targets by transmitting and receiving sound energy propagated through water.

Each sound we hear is the result of an object that vibrates. The vibrations are transmitted through a medium (for example, air, water molecules) and detected by the sensor. For USW purposes, sound originates from either natural (for example, whales, rain, and so forth) or manmade sources (for example, submarines, shipping, drilling, sonar transducers). The sound travels through the complex ocean medium and arrives at the hydrophone sensor (an underwater microphone). The particular sound waves of interest to the sonar operator are the waves that leave the sonar transducer (an underwater speaker) and go out into the water in search of a submarine. If the sound wave finds

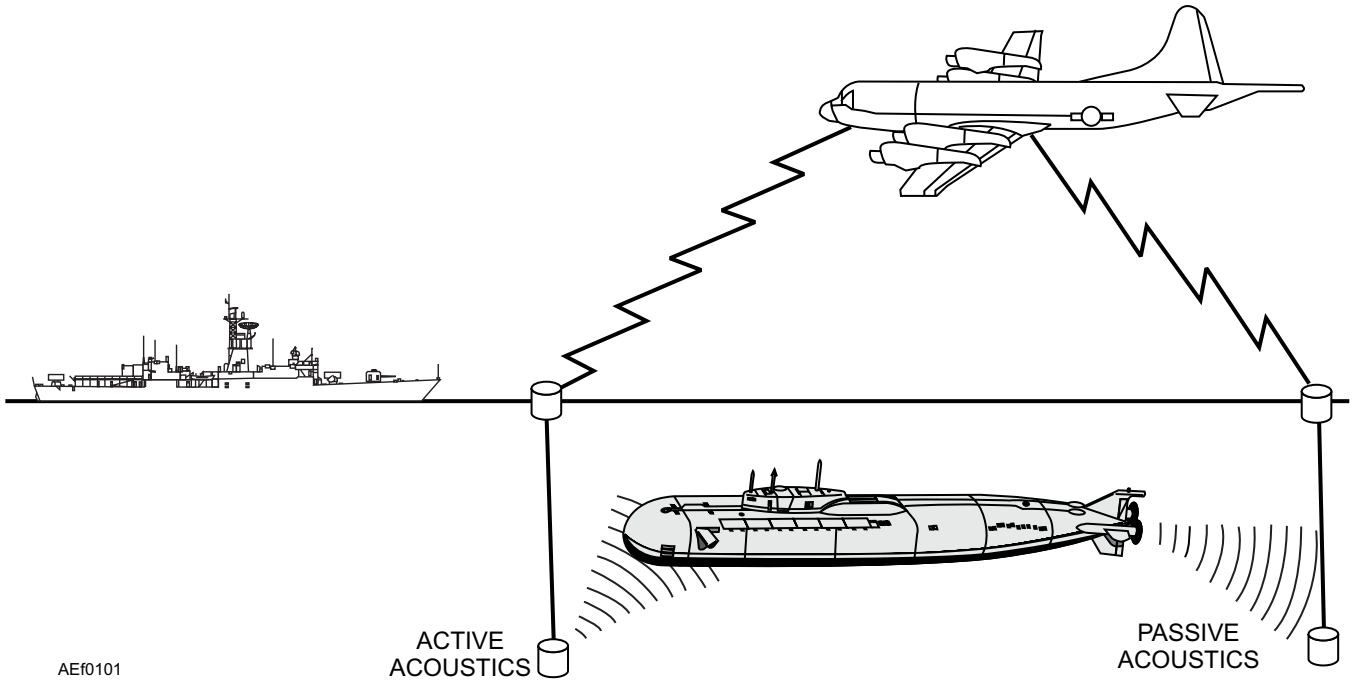

Figure 1-1.—Acoustic Sensors.

a target, it will return (reflect) as an echo. Depending upon the vibration frequency and the signal strength (or volume), some sounds can be transmitted long distances underwater.

The sonar operator should know what factors can weaken the sound wave as it travels through water, what factors in the seawater determine the path and speed of the sound wave, and what factors affect the strength and character of the echo.

FACTORS AFFECTING SOUND WAVE TRANSMISSION LOSS IN SEAWATER

Signal strength lost during the wave's travel through the water is known as *transmission loss*. As sound travels underwater, the ocean absorbs the sound and reduces its loudness. Additionally, sound waves can be bent or scattered in different directions and sound velocity can be affected by water temperature and salinity.

Absorption and Scattering

Some of the sound energy emitted by the source will be absorbed while passing through the water. The amount absorbed this way depends on the sea state. Absorption is high when winds are great enough to produce whitecaps and cause a concentration of bubbles in the surface layer of the water. In these circumstances, part of any sound striking the surface is lost in the air, and part is reflected in scattering directions in the sea. In areas of wakes and strong currents, such as riptides, the loss of sound energy is greater. Therefore, echo ranging through wakes and riptides is difficult because of the combined effect of false echoes, high reverberations, and increased absorption. Absorption is greater at higher frequencies than at lower frequencies. As a result, lower frequencies tend to travel farthest.

Sound waves are weakened when they reach a region of seawater that contains foreign matter, such as seaweed, silt, animal life, or air bubbles. This foreign matter scatters the sound wave and causes loss of sound energy. The practical result of scattering is to reduce echo strength, especially at long range.

Reflection

Echoes occur when the sound wave hits an object or a boundary region between transmission mediums in such a manner as to reflect the sound or to throw it back to its origin. Reflection of sound waves sometimes happens when a wave strikes a medium of different density from that through which it has been traveling. This will occur in cases where the two mediums are of sufficiently different densities, and the wave strikes at a large angle. This happens because the sound wave travels at different speeds through the two different densities. For example, a sound wave traveling through seawater is almost entirely reflected at the boundary of the water and air. The speed of sound in seawater is about four times greater than the speed of sound in air, and the density of water is more than 800 times greater than that of air. Therefore, practically all of the sound wave will be reflected downward from the sea surface.

Likewise, sound waves bounce off the ocean bottom and reflect upward. If the ocean bottom is a smooth, hard surface, there is little signal loss. In cases of extremely deep waters (600 feet or more), the sound may never strike the bottom! This happens because the water pressure is so great that the sound velocity actually begins to speed up and forces the sound waves to refract (or bend) back toward the surface.

Similarly, when a sound wave traveling through the seawater strikes a solid object like a submarine, the difference in the density and the sound velocity in the two mediums is such that all but a small amount of the sound wave will be reflected. That portion of the wave that strikes surfaces of the submarine perpendicular to the wave will be reflected directly back to the origin as an echo.

Reverberation

When sound waves echo and re-echo in a large hall, the sound reverberates. *Reverberations* are multiple reflections. Lightning is an example of this from nature. When lightning discharges, it causes a quick, sharp sound; but by the time the sound of the thunder is heard, it is usually drawn out into a prolonged roar by reverberations.

A similar case often arises in connection with sonar. Sound waves often strike small objects in the sea, such as fish or air bubbles. These small objects cause the waves to scatter. Each object produces a small echo, which may return to the transducer. The reflections of sound waves from the sea surface and the sea bottom also create echoes. The combined echoes from all these disturbances are called reverberations. Since they are reflected from various ranges, they seem to be a continuous sound. Reverberations from nearby points may be so loud that they interfere with the returning echo from a target.

There are three main types of reverberation, or backward scattering of the sound wave. They are as follows:

- **From the mass of water.** Causes of this type of reverberation are not completely known, although fish and other objects contribute to it.
- **From the surface.** This is most intense immediately after the sonar transmission; it then decreases rapidly. The intensity of the reverberation increases markedly with increased roughness of the sea surface.
- **From the bottom.** In shallow water, this type of reverberation is the most intense of the three, especially over rocky and rough bottoms.

Divergence

Just as the beam from a searchlight spreads out and becomes weaker with distance, so does a sound wave. The farther the target is from the sonar transducer, the weaker the sound waves will be when they reach it. This is known as spreading or *divergence*.

Refraction

If there were no temperature differences in the water, the sound wave would travel in a straight line. This happens because the speed of sound would be roughly the same at all depths. The sound wave would spread and become weaker at a relatively constant rate.

Unfortunately, the speed of sound is not constant at all depths. The speed of sound in seawater increases from 4,700 feet per second to 5,300 feet per second as the temperature increases from 30°F to 85°F. Because of the varying temperature differences in the sea, the sound wave does not travel in a straight line, but follows curved paths. This results in bending, splitting, and distorting of the sound wave.

When the sound wave is bent, it is said to be *refracted*. A sound wave is refracted when it passes from a medium of a given temperature into a medium with a different temperature. An example of this is a sound wave traveling from an area of warm water into an layer of cold water. The sound wave will bend away from the area of higher temperature (higher sound velocity) toward the lower temperature (lower sound velocity).

As a result of refraction, the range at which a submarine can be detected by sound may be reduced to less than 1,000 yards, and this range may change sharply with changing submarine depth.

FACTORS AFFECTING THE SPEED OF THE SOUND WAVE IN SEAWATER

There are two main characteristics of seawater that affect the speed of the sound wave traveling through it—temperature (the effect of which is calculated in terms of slopes or gradients) and salinity (the amount of salt in the water). Although the speed of a sound wave is also affected by water pressure as depth increases, the difference in speed is very small and has little effect for the operator.

Temperature

Temperature is the most important factor affecting the speed of the sound wave in seawater. The speed will increase with increasing temperature at the rate of 4 to 8 feet per second per degree of change, depending on the temperature.

The temperature of the sea varies from freezing in the polar seas to more than 85°F in the tropics. The temperature can also decrease by more than 30°F from the surface to a depth of 450 feet. Thus, the temperature is the most important factor because of the extreme differences and variations. Remember, the speed of sound in water increases as the temperature increases. Except at the mouths of great rivers where salinity may be a factor, the path of the sound wave will be determined by temperature.

Figure 1-2 shows what happens when temperature increases steadily with depth. When the surface of the sea is cooler than the layers beneath it, the temperature increases with depth, and the water has a positive thermal gradient. This is an unusual condition, but

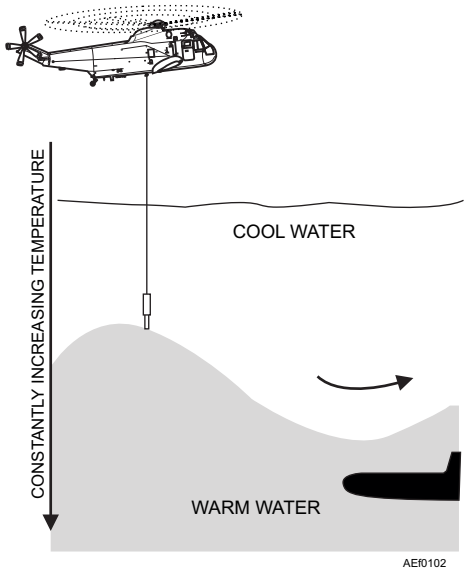

Figure 1-2.—The effect of a positive thermal gradient.

when it does happen, it causes the sound wave to be refracted sharply upwards.

When the sea gets colder as the depth increases, the water has a negative thermal gradient. In this situation, the effect of temperature far outweighs the effect of depth, and the sound wave is refracted downward.

If the temperature remains the same throughout the water, the temperature gradient is isothermal (constant temperature). Refer to figure 1-3 as you read the following text. The surface layer of water in the figure is isothermal, but beneath this layer the temperature decreases with depth. This causes the sound wave to split and bend upward in the isothermal layer and downward below it.

When the temperature changes with depth, the sound wave bends away from the warmer water.

Under normal conditions the temperature structure of the sea is similar to that shown in figure 1-4. This structure consists of three layers as follows:

1. A surface layer of varying thickness with uniform temperature (isothermal) or a relatively slight temperature gradient
2. The thermocline, which is a region of relatively rapid decrease in temperature
3. The rest of the ocean, with slowly decreasing temperature down to the sea floor

If this arrangement changes, the path of the sound wave through the water will change.

Layer depth is the depth from the surface to the top of a sharp negative gradient. Under positive thermal gradient condition, the layer depth is the depth of maximum temperature. Above layer depth, the temperature may be uniform, or a weak positive or negative gradient may be present.

Layer effect is the partial protection from echo ranging and listening detection, which a submarine gains when it submerges below layer depth. Reports from surface vessels indicate that effective ranges on submarines are greatly reduced when the submarine dives below a thermocline, and that the echoes received are often weak and sound "mushy."

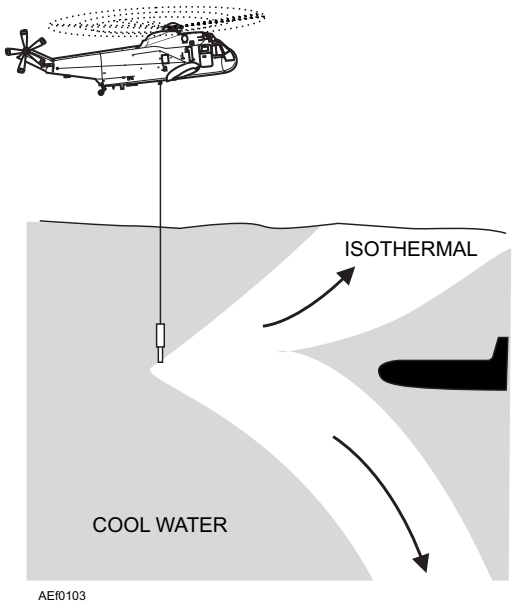

Figure 1-3.—Isothermal conditions.

Salinity

The effect of salinity on sound speed in the sea is less than the large effect that temperature has on sound speed in seawater.

There is a high mineral content in seawater. The density of seawater is approximately 64 pounds per cubic foot, while fresh water has a density of about 62.4 pounds per cubic foot. This difference is caused by the salt in the seawater. Salt content in seawater is called the *salinity* of water.

The overall effect of increasing the salinity is an increase in the speed of the sound wave in the water. This means that as the sound travels through water of

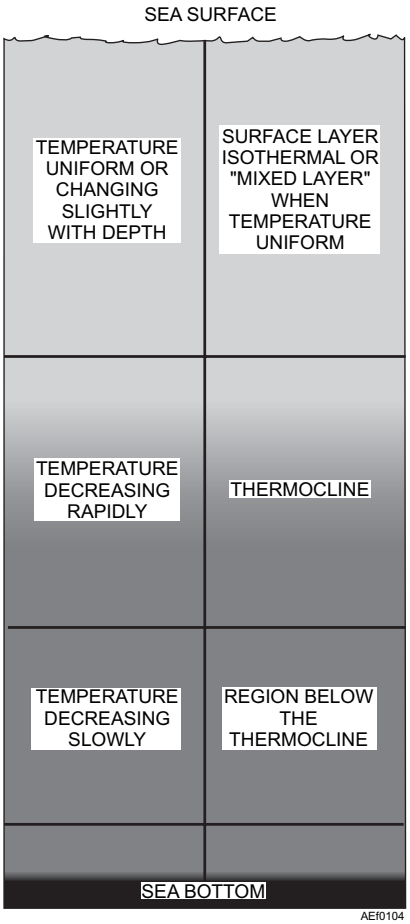

Figure 1-4.—Normal sea temperature structure.

varying salinity, it travels faster through the water with more salt content. Such a change in salinity is considerable at the mouth of a river emptying into the sea. Elsewhere, the difference in salinity is too small to change the rate of travel of the sound wave significantly and may be ignored.

DOPPLER EFFECT

When there is relative motion between the source of a wave of energy and its receiver, the received frequency differs from the transmitted frequency. When the source of wave motion is moving towards the receiver, more waves per second are received than when the source remains stationary. The effect at the receiver is an apparent decrease in wavelength and, therefore, an increase in frequency. On the other hand, when the source of wave motion is moving away from the receiver, fewer waves per second are encountered, which gives the effect of a longer wavelength and an apparent decrease in frequency. This change in wavelength is called the *Doppler effect*. The amount of change in wavelength depends on the relative velocity between the receiver and the source. Relative velocity is the resultant speed between two objects when one or both are moving.

You have heard the term *Doppler effect* many times, but may not have known what the phenomenon was. An example of this is what you hear at a railroad crossing. As a train approaches, the pitch of the whistle is high. As the train passes you, the pitch seems to drop. Then, as the train goes off in the distance, the pitch of the whistle is low. The Doppler effect causes the changes in the pitch.

Sound waves generated by the whistle were compressed ahead of the train. As the waves came toward you, they were heard as a high-pitched sound because of the shorter distance between waves. When the train went by, the sound waves were drawn out, resulting in the lower pitch. Refer to figure 1-5 as you read the following explanation of Doppler effect.

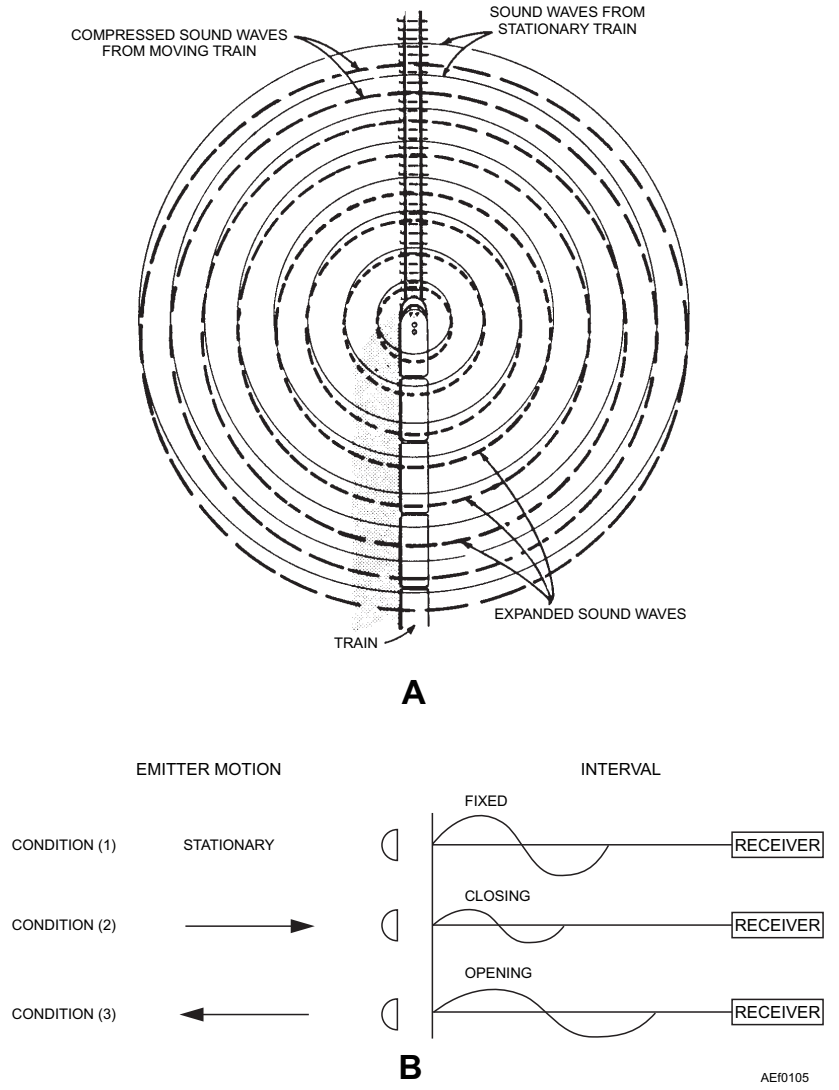

Figure 1-5.—Doppler effect. (A) One-second audio signal; (B) One sine wave of the audio signal.

If you examine 1 second of the audio signal radiated by the train whistle, you will see that the signal is composed of many cycles of acoustical energy. Each cycle occupies a definite period of time and has a definite physical wavelength. (Because of space limitations, only every 10th wave is illustrated in view A of figure 1-5.) When the energy is transmitted from a stationary source, the leading edge will move out in space the distance of one wavelength by the time the trailing edge leaves the source. The cycle will then occupy its exact wavelength in space. If that cycle is emitted while the source is moving, the source will move a small distance while the complete cycle is being radiated. The trailing edge of the cycle radiated will be closer to the leading edge.

Figure 1-5, view B, shows the effect of relative motion on a radiated audio signal. Notice the wavelength of the sound from the stationary emitter, as illustrated in condition (1) of view B.

In condition (2) of view B, the emitter is moving towards the listener (closing). When the cycle is compressed, it occupies less distance in space. Thus, the wavelength of the audio signal has been decreased, and the frequency has been proportionately increased (shifted). This apparent increase in frequency is known as *UP Doppler.*

The opposite is true in condition (3) of view B. The emitter is moving away from the listener (opening). The wavelength occupies more distance in space, and the frequency has been proportionately decreased. This apparent decrease in frequency is known as *DOWN Doppler.* The factors that determine the amount of Doppler shift are the velocity of the sound emitter, the velocity of the receiver, and the angle between the direction of motion of the receiver and the direction of motion of the sound emitter.

The Doppler shift works both ways. If you were on the train and had listened to a car horn at the crossing, the pitch of the horn would have changed. The effect is the same because the relative motion is the same.

The sonar equipment deals with three basic sounds. One of these sounds is the sound actually sent out by the equipment. The second sound is the reverberations that come from echoes returning from all the particles in the water—seaweed, fish, and so forth. The third sound is the most important one, the echo from the submarine.

The sound sent into the water (the actual ping) is seldom heard by the operator. Most of the equipment blanks out this signal so that it doesn't distract the operator.

Consider just one reverberation particle for a moment. A sound wave from the transducer hits the particle and bounces back, just as a ball would if thrown against a wall. If the particle is stationary, it will not change the pitch of the sound. The sound will return from the particle with the same pitch that it had when it went out.

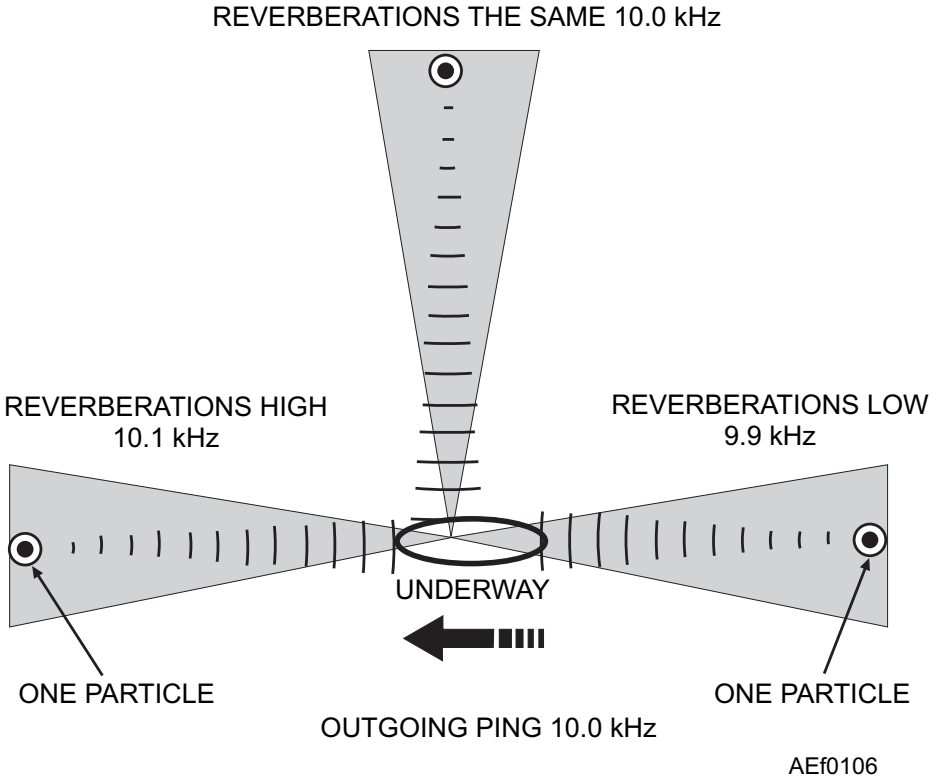

Figure 1-6.—Transducer installed on a moving ship.

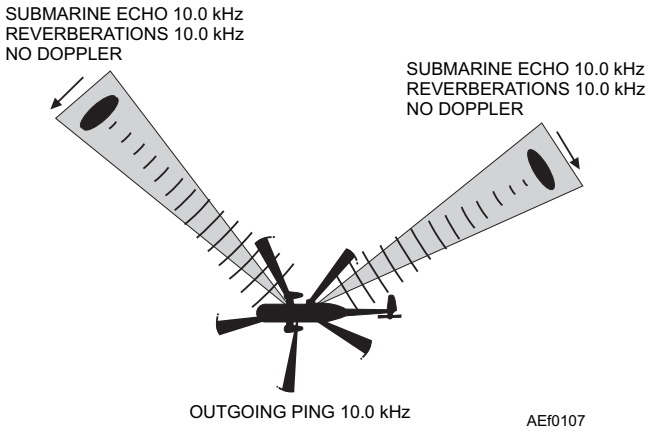

Figure 1-7.—Transducer supported by helicopter. Doppler effect is absent when submarine is stationary or moves at right angles to the sound wave.

If the sonar transducer is stationary in the water and sends out a ping of 10 kilohertz (kHz), the particles all send back a sound that has the same 10 kHz pitch. Now suppose that the transducer acquires forward motion and a ping is sent out dead ahead. It is just as if the transducer were the oncoming train, and the particles were occupants of the car. Remember that as the train came forward, the pitch of the whistle sounded higher to the occupants of the car. In the same way, the particles "hear" a higher note and reflect this higher note. Therefore, the sonar equipment will detect a higher note than the one sent out. If the transducer in this example is pointed dead astern, a lower note than the one sent out will be heard.

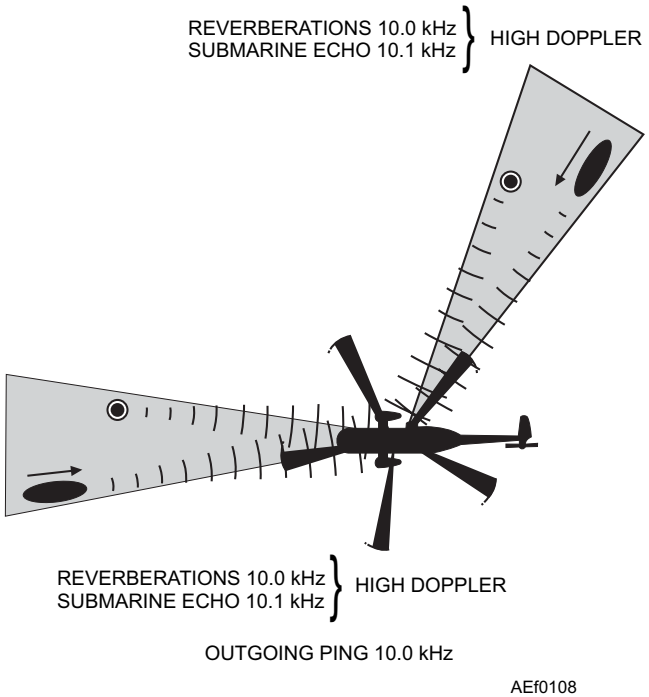

Figure 1-8.—Comparison of echo frequency and reverberation frequency when submarine moves toward transducer.

If the transducer is aimed perpendicular to the direction of motion, the particles in the water will echo the same note sent out because the transducer is neither going toward the particles nor away from them. (See fig. 1-6.)

Now consider the echo from the submarine, shown in figure 1-7. Again, the transducer is shown stationary. When the submarine is neither going toward nor away from the transducer, it must be either stopped or crossing the sound wave at a right angle. If it is in either condition, it reflects the same sound as the particles in the water. Consequently, the submarine echo has exactly the same pitch as the reverberations from the particles.

Suppose that the submarine is going toward the transducer, as shown in figure 1-8. It is as though the submarine is the train heading toward the car that is blowing its horn at the crossing. The pitch of the horn sounds higher as the train approaches the car. In the same manner, the pitch of the transducer sounds higher to the submarine as it approaches the transducer.

The submarine reflects an echo of higher pitch than that caused by the particles in the water, which are not moving. When the echo from the oncoming submarine is higher in frequency than the echoes from the reverberations, the Doppler is high. The opposite form of Doppler shift will occur when the submarine is heading away from the transducer. In this case, the pitch of the echo is lower than the pitch of the reverberations. (See fig. 1-9.)

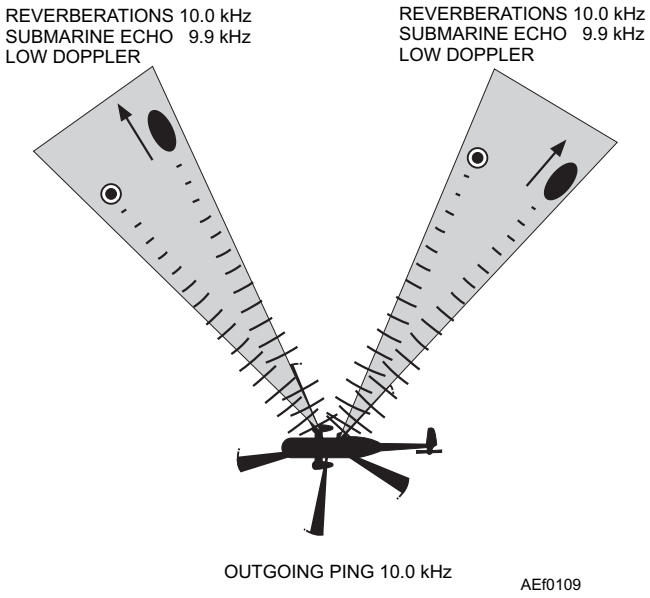

Figure 1-9.—Comparison of echo frequency and reverberation frequency when submarine moves away from transducer.

The degree of Doppler indicates how rapidly the submarine is moving relative to the transducer. For example, a submarine moving directly toward the transducer at 6 knots returns an echo of higher frequency than one moving at only 2 knots. Also, a submarine moving at 6 knots directly at the transducer returns an echo of higher frequency than one moving only slightly at the transducer. Refer to figure 1-10. This figure shows 12 submarines traveling at various speeds and courses with respect to a stationary transducer supported by the helicopter. Notice how the Doppler of each submarine is influenced by its speed and direction.

Doppler also makes it possible to distinguish the difference between a wake echo and a submarine echo. Relatively speaking, the submarine's wake is stationary. Therefore, its wake returns an echo with a frequency different from that of the Doppler shifted submarine echo.

PROPAGATION PATHS

Sound arrives at the hydrophone sensor by several ways called propagation paths. The three most common sound paths are *direct path* (directly from the sound source to the hydrophone sensor), *bottom bounce* (reflected from the bottom), or *convergence zone* (refracted from deep water).

Direct path sound propagation is normally limited to short ranges. Sound transmission through the bottom bounce path irregularly occurs at medium ranges depending upon the reflective angle between the sound wave and the bottom. Convergence zone detection is limited to deep ocean waters and is found in narrow detection rings (or annuli) at distant ranges. Each transmission path affects sound in distinct ways that enables the aircrew to determine their follow-on localization tactics after initial acoustic detection.

Q1-1. What are the two main factors that affect the velocity of sound in seawater?

Q1-2. A sound wave traveling from an area of warm water into an area of cold water will be affected in what way?

SONOBUOY-BASED SONAR SYSTEMS

LEARNING OBJECTIVE: Recognize the major components and operating principles of a typical sonobuoy-based airborne sonar system, to include the typical sonobuoy receiver, spectrum analyzer, and the classifications and operating principles of sonobuoys currently in use.

Fixed-wing aircraft and certain rotary-wing aircraft, such as the P-3C Orion and the SH-60B

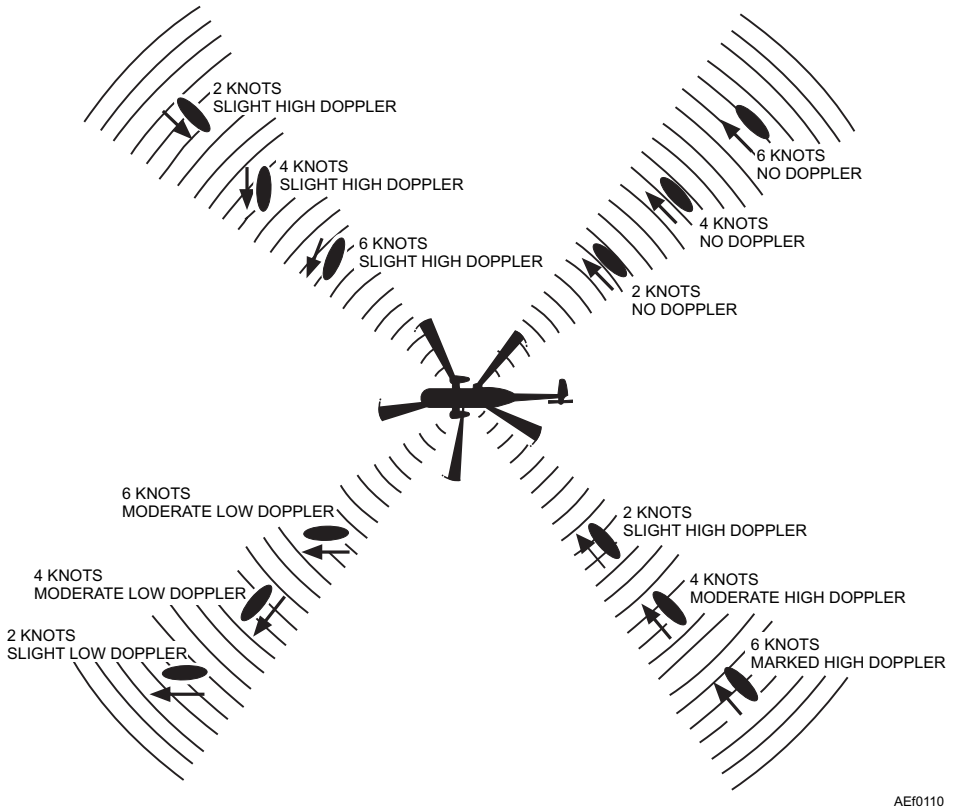

Figure 1-10.—Varying degrees of Doppler effect due to differences in course and speed of submarines.

Seahawk, use a sonobuoy-based sonar system in support of their USW mission. In such a system, sonobuoys are dropped from the aircraft into an area of the ocean thought to contain a submarine.

The sonobuoys are usually dropped in patterns involving three or more buoys. The sonobuoys detect underwater sounds, such as submarine noise and fish sounds. These sounds modulate an oscillator in the radio frequency (RF) transmitter portion of the sonobuoy. The output of the transmitter is a frequency-modulated (FM), very high frequency (VHF) signal that is transmitted from the antenna. The signal is received by a sonobuoy receiver in the aircraft and sent to the spectrum analyzer where the acoustic information is extracted. By analyzing the detected sounds, the USW operator can determine various characteristics of the detected submarine. The use of several sonobuoys operating on different VHF frequencies in a tactical pattern enables the USW operator to localize, track, and classify a submerged submarine.

Each sonobuoy type is designed to meet a specific set of specifications that is unique to that particular sonobuoy. Even though sonobuoys are produced by different manufacturers, the specifications and operational performance characteristics are the same for all manufacturers. There are differences in the methods used for prelaunch selection of life and depth settings from one manufacturer to another for the same sonobuoy types. These differences are found in the *Sonobuoy Instruction Manual*, NAVAIR 28-SSQ-500-1. You should refer to this manual prior to storing, handling, or disposing of sonobuoys.

SONOBUOYS

The detection, localization, and identification of submarines is the primary mission of the Navy's airborne USW forces. The ability of the Navy to complete this mission is dependent upon the sonobuoy. The sonobuoy has undergone a great deal of change in the past 25 years. These improvements have provided the fleet with large numbers of very reliable sonobuoys that perform various missions.

Using the basic sound (or sonar) theory, experimental sonobuoys were developed during World War II to detect hostile submarines. Aircrews used sonobuoys to hear the acoustic sounds radiated from a submarine (passive sonobuoys) or to detect an echo bounced off a submarine using an acoustic pulse generated by an acoustic source (active sonobuoy). Additionally, special purpose sonobuoys were developed to measure the water temperature profile and to communicate with submerged submarines.

Sonobuoys are expendable devices; they are never recovered after they are launched from the aircraft. It may sound like a costly endeavor, but in actuality, it is the cheapest, fastest, and most reliable way to search the ocean. This inexpensive USW method not only considers the cost of the sonobuoy, but also the operating costs for the aircraft. Before any sonobuoy is developed, a careful analysis is always conducted to determine the cost effectiveness versus the expected performance. An expensive buoy may perform superbly, but if it costs too much, the Navy will never be able to buy sufficient quantities. In fact, these complex analyses have in the past led to the cancellation of several developmental sonobuoy programs.

USW aircraft can search the same area much faster and with less chance of being attacked by the hostile submarine. By comparison, a naval vessel searching the same area is limited by its own self-noise, search speed, and much greater operating costs for the ship itself. Additionally, friendly submarines and naval combatants conducting a USW search must always be on guard for potential torpedo or missile attacks. Dollar for dollar and performance for performance, sonobuoys are the most economical and efficient way to conduct air USW.

A sonobuoy is a cylindrical metal tube ("can") about three feet long and nearly five inches in diameter (fig. 1-11). The sonobuoy normally weighs 20 to 39 pounds, depending upon the type. It is encased within a plastic cylindrical housing called a sonobuoy launch container (SLC).

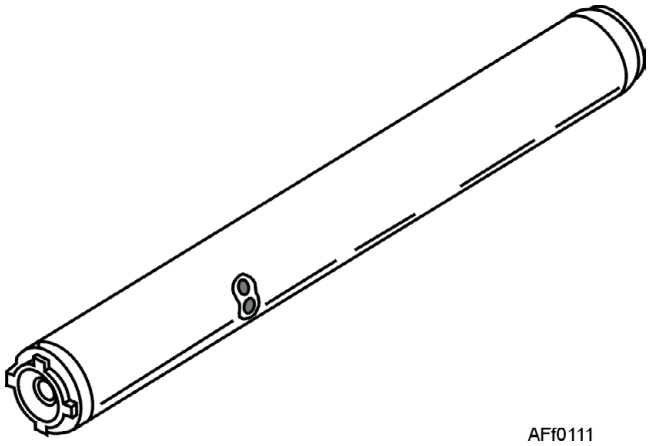

Figure 1-11.—Sonobuoy.

Deployment

The sonobuoy is aircraft-deployable by any of three methods: pneumatic, free-fall, or cartridge.

The SLC is loaded into special launch chutes found on USW aircraft and launched by using either a small explosive charge (P-3 aircraft) or pneumatically (SH-60 helicopters). On some aircraft, a sonobuoy can be gravity-launched from an open chute or door ("free fall"). Once released, the plastic SLC remains inside the aircraft launch chute. The now empty SLC remains with the aircraft and is properly disposed of or recycled upon aircraft landing.

Sonobuoys are deployed from altitudes approaching 30,000 feet at speeds approaching 370 knots. Because descent velocities can exceed 120 feet per second, a descent-retarding device is used to increase aerodynamic stability and to reduce water-entry shock. A parachute or a rotating-blade assembly (rotochute) is used as the descent-retarding device. Because of the different descent characteristics of the parachute and rotochute, do not intermix the two. With intermixed sonobuoys, the spacing of the tactical pattern will not be right and submarines might be missed.

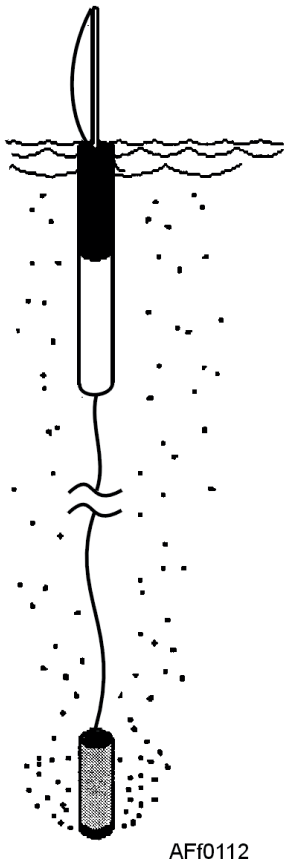

Figure 1-12.—Deployed sonobuoy.

Water Entry and Activation

Once a sonobuoy hits the water, it descends approximately 40-60 feet underwater until its battery is activated by the seawater and initiates the deployment or jettison of the various sonobuoy components. A CO_2 bottle inflates a plastic float. The plastic float returns the sonobuoy back to the surface where the attached uplink antenna becomes energized. Jettisoning of the bottom plate allows the hydrophone and other internal components to descend to the preselected depth. Most sonobuoys are capable of deploying a hydrophone a thousand feet below the ocean surface.

As shown in figure 1-12, a termination mass and/or drogue stabilizes the hydrophone at the selected depth, while the buoyant sonobuoy section or float follows the motion of the waves. A section of elastic suspension cable isolates the hydrophone from the wave action on the buoyant section.

Most of the sonobuoys in the fleet today are equipped with seawater-activated batteries, which provide the power required for the sonobuoy electronics. Data transmission from the buoys usually begins within 3 minutes after the buoy enters the water. In cold water and/or water with low salinity, the activation time might be increased. Some sonobuoys now have non-water-activated lithium batteries. It is quite an engineering feat to stuff these hydrophones, float bags, electronic processors, inflation bottles, environmentally friendly batteries, and hundreds of feet of cable all inside a 3-foot long, 5-inch diameter steel or aluminum can.

After several hours of operation, the sonobuoy battery fails and water-soluble seals dissolve, which allows the sonobuoy to sink to the bottom. All sonobuoy material is non-toxic and is carefully specified per international, federal, and local regulations to prevent adverse environmental impact.

Sonobuoy Frequency Channels

Certain sonobuoy designs are equipped with an electronic function select (EFS) system. The EFS system provides each sonobuoy with a selectable 99-channel capability. (Table 1-1 shows sonobuoy channels and their assigned frequencies.) EFS also provides each sonobuoy with 50 life and 50 depth setting selections. The operator must reset all three settings any time any of the three are changed.

Table 1-1.—Sonobuoy Channel Allocations (Listed in Frequency Order)

Ch.	Frequency (kHz)	Ch.	Frequency (kHz)	Ch.	Frequency (kHz)	Ch.	Frequency (kHz)
32	136.000	57	145.375	82	154.750	20	164.875
33	136.375	58	145.750	83	155.125	5	165.250
34	136.750	59	146.125	84	155.500	21	165.625
35	137.125	60	146.500	85	155.850	6	166.000
36	137.500	61	146.875	86	156.250	22	166.375
37	137.875	62	147.250	87	156.625	7	166.750
38	138.250	63	147.625	88	157.000	23	167.125
39	138.625	64	148.000	89	157.375	8	167.500
40	139.000	65	148.375	90	157.750	24	167.875
41	139.375	66	148.750	91	158.125	9	168.250
42	139.750	67	149.125	92	158.500	25	168.625
43	140.125	68	149.500	93	158.875	10	169.000
44	140.500	69	149.875	94	159.250	26	169.375
45	140.875	70	150.250	95	159.625	11	169.750
46	141.250	71	150.625	96	160.000	27	170.125
47	141.625	72	151.000	97	160.375	12	175.500
48	142.000	73	151.375	98	160.750	28	170.875
49	142.375	74	151.750	99	161.125	13	171.250
50	142.750	75	152.125	1	162.250	29	171.625
51	143.125	76	152.500	17	162.625	14	172.000
52	143.500	77	152.875	2	163.000	30	172.375
53	143.875	78	153.250	18	163.375	15	172.750
54	144.250	79	153.625	3	163.750	31	173.125
55	144.625	80	154.000	19	164.125	16	173.500
56	145.000	81	154.375	4	164.500		

Sonobuoy Classification

Sonobuoys are grouped into three categories: passive, active, and special purpose.

PASSIVE SONOBUOYS.—Passive sonobuoys listen to underwater sounds. They rely on the submarine to produce characteristic sounds, either intentionally or unintentionally, that can be used for detection, classification, and localization. This acoustic signature or fingerprint consists of sounds emitted by propellers, various machinery equipment, electrical systems, and active sonar emissions. By evaluating the signature characteristics, the sonar operator aboard the aircraft (an Aviation Warfare Systems Operator) can classify the sounds as either a submarine, a ship, or biologics, such as a whale. Depending upon the type of acoustic contact, the operator can further analyze the specific sources that are detected.

LOFAR Sonobuoy.—Low frequency and ranging (LOFAR) sonobuoys detect sounds emitted by the submarine by using an omnidirectional (equal reception from all directions) hydrophone that has been lowered from a passive sonobuoy. Data regarding the frequency and amplitude of these sounds are then transmitted by the sonobuoy antenna to the receiving station, where the sound data is analyzed, processed, displayed, and recorded. The basic LOFAR system plots the frequency of the sound waves against the intensity of their acoustic energy and against the duration of the sound emission.

The omnidirectional hydrophone used by LOFAR sonobuoys has several advantages over the directional hydrophones used in other sonobuoys. With a frequency range of 5 to 40 kHz, the amount of aural data from a LOFAR sonobuoy can be four times the amount as that from a DIFAR sonobuoy, which has a

maximum range of only 2400 Hz. This wide frequency range provides the best audio for aural listening. Since aural data is the only real-time acoustic data available to the operator, this characteristic is essential. Omnidirectional hydrophones also provide improved data in the lower frequency range (5 to 30 Hz) and are less susceptible to thermal noise (changes in water temperature) and high shear currents associated with fronts, eddies, straights, choke-points, and littoral areas. In most situations, LOFAR sonobuoys are the best sensor for initial detection.

DIFAR Sonobuoy.—The directional frequency analysis and recording (DIFAR) sonobuoy uses two hydrophone elements mounted perpendicular to each other. These hydrophones measure differences in the pressure strength of individual sounds and convert the measured pressure strengths into voltages that are then used to determine from which direction the sound arrived relative to magnetic north (fig. 1-13). This signal is then transmitted to the aircraft via a VHF transmitter, where it is processed and the bearing is computed. Subsequent bearing information from the buoy can be used to pinpoint, by triangulation, the location of the sound or signal source. Today's aircrews normally use a combination of both DIFAR and Doppler information to determine the position of a concealed submarine.

VLAD Sonobuoy.—The vertical line array DIFAR (VLAD) specification is CONFIDENTIAL and impacts on the level to which this sensor may be described in an unclassified document. We will use generic descriptions and material to provide the information necessary to understand the concept of the VLAD sensor.

As submarines become quieter, it is more difficult to separate ambient noise from the sounds of threat signals. This serves to complicate acoustic USW detection and tracking. A sonobuoy with a higher signal-to-noise ratio (S/N) counters this problem.

Distant shipping contributes to high levels of local ambient noise in the lower portion of the frequency spectrum, and the angle at which this noise arrives at a deployed hydrophone is within a narrow band of near horizontal angles. By eliminating or greatly attenuating reception of horizontally arriving sound, a VLAD buoy reduces this major contributor to low-frequency noise while still being capable of receiving threat signals of interest from targets. In a like manner, high-frequency noise from locally produced disturbances at the ocean surface, such as wind, waves, and rain, arrive at a sonobuoy hydrophone at near vertical angles. By eliminating or greatly attenuating reception of vertically arriving sound, a VLAD buoy reduces undesirable high-frequency noise.

VLAD sonobuoys use beam-forming technology to reject reception of unwanted noise and to enhance reception of desired signals of interest. The

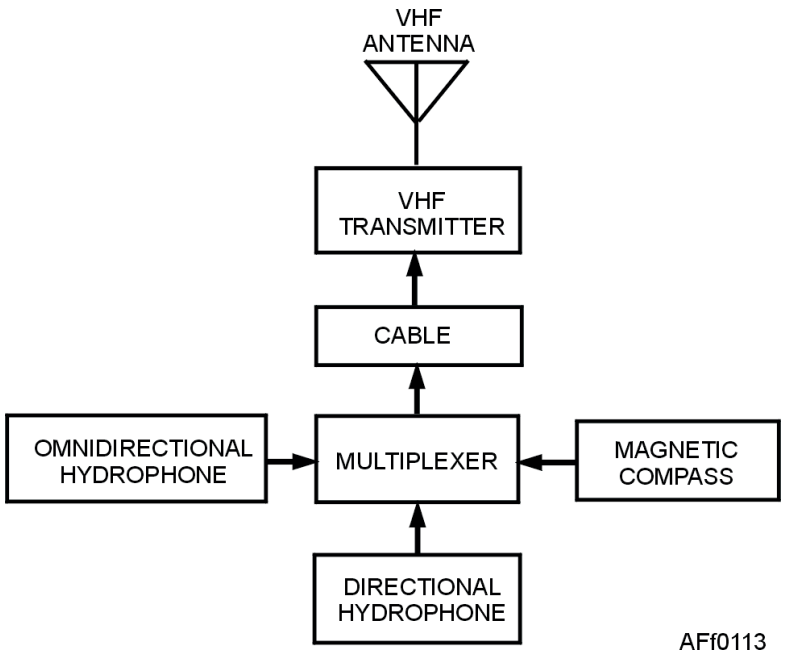

Figure 1-13.—Block diagram of the DIFAR sonobuoy.

beam-forming array of a VLAD buoy consists of several hydrophones placed at fixed points along a vertical line. Each hydrophone is tuned to a predetermined frequency band and will process only acoustic signals within that range. Beam-forming technology results in an acoustic reception pattern that attenuates horizontally arriving low-frequency noise and vertically arriving high-frequency noise. This enhances reception of sound from bottom bounce and surface-reflected propagation paths that reveal the presence of a submarine.

VLAD sonobuoys are designed to provide long-range detection of submarines operating in deep water and are not intended to replace DIFAR as a near field detection sensor.

ACTIVE SONOBUOYS.—Active sonobuoys rely upon the principle of sending out an acoustic pulse that strikes the hull of a submarine and is reflected back to the sonobuoy. The operating principles are similar to that of radar, except sound waves are used instead of RF waves. When the sound wave strikes an object, some of the energy reflects back to the source from which it came.

Today's modern active sonobuoys use a principle called “extended echo ranging,” where the echo is detected by one or more passive sonobuoys. This system provides an exceptional search sensor for detecting the ever-quieter submarine.

DICASS Sonobuoy.—The directional command activated sonobuoy system (DICASS) relies on an ultrahigh frequency (UHF) command signal from the USW aircraft to send an acoustic pulse, or ping. Upon receipt of a valid radio signal from the aircraft, the DICASS sonobuoy transmits a sonar pulse in all directions (omnidirectional). This acoustic pulse reflects off any obstructions in its path, and the sonobuoy directional hydrophones receive the returning echoes. Data from received reflections is transmitted on the VHF uplink channel to the monitoring USW aircraft, where the aircraft acoustic analysis equipment processes range and bearing information for a precise fix on the submarine position.

The DICASS allows the aircraft to deploy the sonobuoy, but the buoy will remain passive until commanded to ping. This allows the aircrew to surprise the submarine.

EER Sonobuoy.—The extended echo ranging (EER) sonobuoy transmits an acoustic energy pulse into the water. This broadband pulse is incoherent in nature. The pulse travels through the water until it is reflected off natural and man-made objects. When it strikes the hull of a submarine, the pulse forms an echo that is detected by a passive receiving sonobuoy, such as the VLAD. The EER sonobuoy provides long-range, active detection of submarines.

SPECIAL-PURPOSE SONOBUOYS.—Special purpose sonobuoys are designed for special USW functions. There are two types of special purpose sonobuoys in use today—bathythermograph (BT), and data link communication (DLC).

Bathythermograph Sonobuoy.—The BT sonobuoy is used to measure water temperature versus depth. The water depth is determined by timing the descent of a temperature probe. Once the BT buoy enters the water, the probe descends automatically at a constant 5 feet per second.

The probe uses a thermistor, which is a temperature-dependent electronic component, to measure the temperature. The electrical output of the probe is applied to a voltage-controlled oscillator. The oscillator's output signal frequency modulates the sonobuoy transmitter. The frequency of the transmitted signal is linearly proportional to the water temperature. The water temperature and depth are recorded on graph paper that is visible to the USW operator. The sonobuoy signal is processed by the acoustic equipment onboard the aircraft.

The BT buoy is normally the first sonobuoy dropped in any USW mission. Its real time assessment of the temperature profile allows the aircrew to optimize the success in detecting the submerged threat.

Data Link Communication Sonobuoy.—The DLC sonobuoy provides short-range, one-way acoustic communications with friendly submerged submarines. A series of acoustic frequencies are transmitted in encoded sonic patterns at different depths to ensure they are heard by the friendly submarine. The coded messages are brief in nature, but once decoded, allow the submarine to receive sufficient information to proceed without having to come to the surface to receive radio communications.

SONOBUOY RECEIVERS

The sonobuoy radio receiver recovers the acoustic information that the sonobuoy transmits. As indicated

in table 1-2, the currently used equipment may be an ARR-78 or ARR-84, depending on the aircraft platform and its configuration. The receiver units listed above actually contain 20 or 4 individual receivers, respectively. Each subunit can operate simultaneously and independently on a channel selected by the operator or a computer. Some receiver units also have control inputs that enable selection of digital data reception modes or wide bandwidths for reception of future sonobuoy systems. An indication of received signal strength is provided by most units as well as the required outputs (audio and signal strength) to drive the on-top position indicator (OTPI) system.

AN/ARR-78 Receiver

This receiver is intended to be configured in either a 20-channel (16 acoustic receivers, 4 auxiliary) or a 10-channel (8 acoustic receivers, 2 auxiliary) version for employment with a fixed-wing or rotary-wing USW aircraft. This system is currently used in aircraft such as the P-3C Orion.

DESCRIPTION.—The ARR 78 is a solid-state hybrid single-frequency conversion receiving system. It receives, demodulates, and amplifies sonobuoy analog and digital transmissions in the VHF band from 136 to 173.5 megahertz (MHz) and provides demodulated outputs to analysis, recording, and display equipments. The receiver operates in such a manner that any of the aircraft processing channels may be used interchangeably. Each synthesized receiver channel is capable of being tuned by computer or manual control to any one of 99 VHF channels on 375 kHz channel spacing in the narrowband mode or, in the wideband mode, operates on the channels with 750 kHz superimposed channel spacings.

COMPONENTS.—The ARR-78 receiver system consists of five units: a dual preamplifier, a receiver assembly, an indicator control unit, an RF status panel, and an OTPI control unit.

The RF preamplifier assembly contains two identical preamplifier modules and is capable of driving two receiver assemblies. Each preamplifier accepts and amplifies FM signals in the VHF frequency bands with RF signal levels between 0.5 and 100,000 μV. Each amplifier can withstand RF input levels of up to 0.5 V without incurring damage.

The receiver assembly consists of a receiver chassis assembly, 20 synthesizer tuned receivers (16 acoustic, 4 auxiliary), a built in test equipment (BITE) module, dual power supplies, ADF preamplifier/RF

Table 1-2.—Comparison of Sonobuoy Receivers Currently Used in the Navy

	AN/ARR-78	**AN/ARR-84**
Platform	P-3C	SH-60B/F
Frequency Range	136-173.5 MHz (99 RF channels)	136-173.5 MHz (99 RF channels)
Channels	20 including OTPI channel	4
Control Mode	Manual and computer (all functions, high speed Proteus serial words)	Manual and computer (all functions, high speed Proteus serial words)
BITE	Manual or computer initiated BIT via internal RF generator and extensive monitor circuits.	Manual or computer initiated BIT via internal RF generator and extensive monitor circuits
Weight	114 lbs.	25 lbs.
Cubic Inches	3,560	1,125
Power Consumption	418 watts	100 watts
Units	1 Receiver 1 Control/Indicator 1 RF Status Panel 1 Dual Preamp 1 OTPI Control	1 Receiver 1 Control/Indicator (4 channels)

amplifier/multicoupler, reference oscillator, clock generator, and computer interface for control. Each acoustic receiver is identical and capable of receiving FM and/or frequency shift key (FSK) modulated RF signals (only 4 receivers are capable of FSK) of a level between 0.5 and 100,000 microvolts (μV). The four auxiliary receivers are capable of outputs for audio monitor, RF monitor and OTPI functions.

The indicator control unit provides a centralized control and status display of the receiver modes. Each indicator control unit command status word to or from the receiving system is comprised of a serial digital word, fully compatible with the advanced signal processor (ASP) input/output (I/O) channel.

The RF status panel displays on a continuous basis the control mode (computer/manual), RF channel assignment, and the IF level for each acoustic receiver actively being processed.

The OTPI control unit provides a remote control of the OTPI receiver. The operator of the control unit can manually tune the OTPI receiver to any one of the VHF frequencies.

AN/ARR-84 Receiver

This lightweight receiver is designed to accommodate the weight restrictions of aircraft such as the SH-60 series helicopter.

DESCRIPTION.—The ARR 84 is a solid-state receiver that receives and processes analog and digital transmissions from any of the 99 sonobuoy channels in the VHF band between 136.0 and 173.5 MHz. It contains four receiver modules that operate independently so that transmission from four different sonobuoys may be monitored simultaneously. Each receiver module processes both analog and digital data, according to buoy type.

The receiver system provides analog and digital data outputs, retrieved from sonobuoy transmissions, for use by other equipment in the aircraft.

COMPONENTS.—The receiver system is of modular design and consists of seven sections: four receiver modules, a power supply assembly, BITE circuits, and preamplifier circuits, which are electrically connected and mechanically bolted to a chassis.

The preamplifier circuits filter, amplify, and split antenna signals before they are applied to the four receiver modules. The preamplifier circuits include the antenna relay, filter circuit, amplifiers, a coupler circuit, and a four-way splitter. The sonobuoy antenna receives all signals from all frequencies and is connected through normally closed contacts of the antenna relay to the filter circuit, which allows only the 136 to 173.5 MHz frequencies in the sonobuoy band to pass. Output of the filter is amplified, and then fed through the coupler circuit to the four-way splitter to provide the amplified sonobuoy signals (if present) on four separate electrically isolated lines to each of the four receiver modules. Amplified signals from any sonobuoys within line-of-sight range are connected to each receiver module.

The receiver system contains four receiver modules. Each module is a complete receiver capable of receiving both analog and digital FM radio signals. All four receiver modules are identical and directly interchangeable. Each receiver module can be tuned and configured to amplify and process signals from any sonobuoy or the BITE circuit. Transmissions from up to four different sonobuoys may be received and processed simultaneously by the receiver system. The receiver modules may be tuned via the remote control unit (RCU) or through the aircraft computer.

ACOUSTIC DATA PROCESSING

When acoustic signals are received from deployed sonobuoys by the sonobuoy receiver, the data must be extracted and converted to a format usable by the sensor operator. This task is accomplished by the AN/UYS-1 single advanced signal processor (SASP) system. There are several versions of the UYS-1 system currently in use, but all perform the same basic function.

Operating Principles

The SASP processes sonobuoy audio in active and passive processing modes to provide long-range search, detection, localization, and identification of submarines. The RF signals from the sonobuoys are received by the sonobuoy receivers and sent to the SASP. After processing, signals are sent to the displays and the recorders for operator use. The SASP also generates command tones for controlling the CASS and DICASS sonobuoys.

Components

The major components include the spectrum analyzer (SA), power supply, and the control-indicator (SASP power control).

SPECTRUM ANALYZER.—The spectrum analyzer is a high-speed signal processor that extracts acoustic target information from both active and passive sonobuoy data. The SA determines frequency, amplitude, bearing, Doppler, range, and other characteristics for acoustic targets.

POWER SUPPLY.—The power supply converts 115 volts ac into 120 volts dc operating voltages. The 120-volt dc power is then converted to low-level dc voltages for operation of individual circuits. A power interrupt unit protects the data against transient power interruptions that normally occur during airborne operations.

CONTROL-INDICATOR.—The control-indicator provides SASP power control and monitoring. A switch-indicator labeled POWER ON/OFF controls the power to the SA, the display computer (DCU), the CASS transmitter, and the displays. The AU/DCU CAUTION/OVHT indicator indicates the temperature status in the SA and the DCU. The CAUTION section will flash on when the thermal warning is activated in either unit. The OVHT section indicates an overheat in either unit. The STA OVHT indicator indicates an over-temperature condition exists at the sensor stations 1 and 2 consoles. The OVERRIDE-NORMAL switch will override the over- heat warnings for the sensor stations 1 and 2 consoles.

Q1-3. Sonobuoys that transmit an acoustic pulse and detect a resulting echo are classified as what type of sonobuoy?

Q1-4. Sonobuoys equipped with an EFS system have what capability?

Q1-5. What information can a DIFAR sonobuoy provide that a LOFAR sonobuoy cannot?

Q1-6. Which of the following sonobuoys provides water temperature data?

ON-TOP POSITION INDICATOR (OTPI) SYSTEM

LEARNING OBJECTIVE: Recognize the purpose, major components, and operating principles of an On-Top Position Indicator system.

When sonobuoys are deployed from fixed-wing and/or rotary-wing aircraft, the aircrew must have a way of determining the location of the deployed sonobuoy. The OTPI system provides a means of locating deployed sonobuoys.

SYSTEM DESCRIPTION

The OTPI system operates in conjunction with the direction finder (DF) antenna to provide sonobuoy bearing with respect to aircraft heading (relative bearing). The OTPI receiver receives signals from sonobuoys transmitting in the VHF range of 136,000 to 173,500 megahertz (MHz) via the DF antenna. (The SH-60 uses the AN/ARN 146 radio receiver, and the P-3 uses an auxiliary receiver housed inside the AN/ARR-78 sonobuoy receiver for OTPI functions.)

SYSTEM OPERATION

Sonobuoy signals received through the DF antenna are routed to the OTPI receiver. Receiver audio is routed to an electronic control amplifier that provides drive signals to the antenna. As the antenna scans toward the sonobuoy, the drive signals from the receiver are reduced. When the antenna reaches the low point, or null, the antenna stops scanning. The resulting position indicates the direction of the sonobuoy.

Sonobuoy bearing is displayed on the number one needle of the aircraft horizontal situation indicator, HSVD, or equivalent indicator. The pilot can adjust the course of the aircraft to coincide with the location of the sonobuoy. When the aircraft flies over the sonobuoy, the number one needle will swing 180 degrees, indicating the sonobuoy is directly beneath the aircraft.

Q1-7. The OTPI system provides what information to the USW pilot?

DIPPING SONAR SYSTEM

LEARNING OBJECTIVE: Recognize the major components, operating principles, and modes of operation of an airborne dipping sonar system.

Dipping sonar sensors, or *dunkers*, are retrievable sonar devices that are deployed from USW helicopters or from some naval ships. The dipping sonar device can provide both passive and active sonar detection of submarines. Normally, they are used in the active mode, which generally provides longer ranges as compared to active sonobuoys. Conversely, the noise associated with helicopter or surface ship operations makes passive dipping sonar sensors less sensitive as compared to passive sonobuoys. One of the distinct advantages of the USW helicopter dipping sonar over sonobuoys is that the Aviation Warfare Systems Operator running the dipping sonar can choose an optimum search depth to maximize the performance of the dipping sonar. Once

active sonar contact is gained, the aircrew quickly raises the dipping sonar, "jumps" the aircraft to a new position (dip point), lowers the dipping sonar, and re-acquires the now-evasive submarine. Once a dipping sonar helicopter is in hot pursuit, the submarine commander's job of evasion is extremely difficult. Adding a second dipping sonar helicopter into the chase makes the submarine commander's job nearly impossible! In addition to the passive and active sonar modes of the dipping sonar, the system is used for communications and measuring the water temperature profile. The AN/ASQ-13F dipping sonar is the current system used by naval aircraft, and it is used only in the SH-60F carrier-based helicopter (fig.1-14).

AN/AQS-13F SONAR SYSTEM

The AN/AQS-13F sonar set is a multimode, multifunction, airborne sonar system. It is used to locate, classify, and track submerged targets. It can operate in either active or passive mode, using deployed dipping sonar or sonobuoys. Target data from the sonar transducer is processed by the sonar receiver and sonar data computer, and is displayed on the azimuth-range indicator (ARI) and/or multifunction displays (MFD).

The following components make up the sonar set:

- IP-1607/ASQ-13F azimuth range indicator
- R-2433/ASQ-13F sonar receiver
- CP-1971/ASQ-13F sonar data computer
- TD-1421/ASQ-13F multiplexer
- C-12056/ASQ-13F dome control
- RL-299/ASQ-13F reeling machine
- MX-18320A/ASQ-13F cable and reel assembly
- TR-348/ASQ-13F sonar transducer

The following systems/components directly or indirectly interface with the sonar set:

- Sonobuoy receiver
- Intercommunication system controller
- Mission tape recording set
- Digital automatic flight control system (DAFCS)
- Tactical navigation set data processors, control display units (CDU), and multifunction displays
- Horizontal situation video display (HSVD) set

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Figure 1-14.—SH-60F dipping sonar.

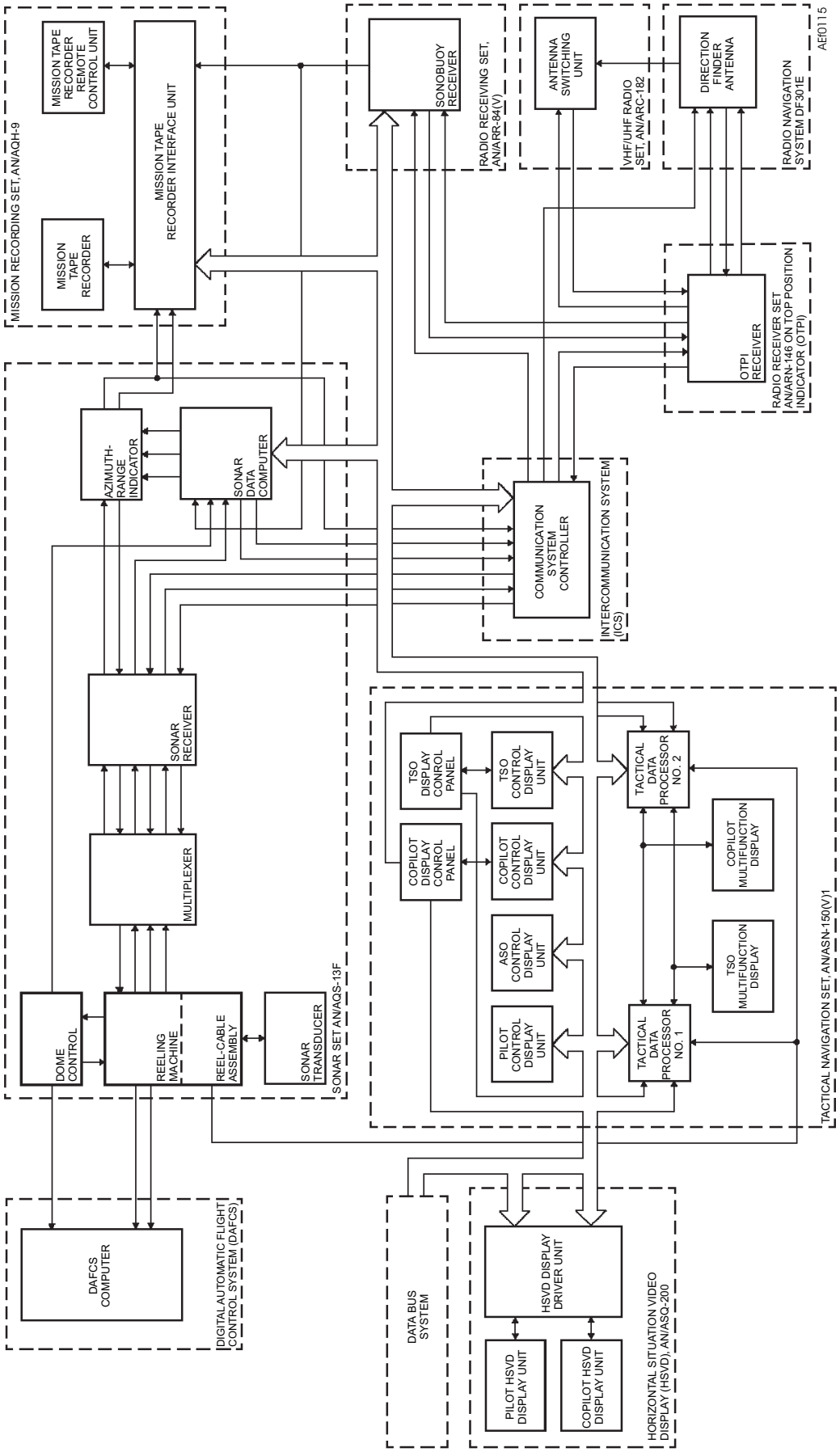


Figure 1-15.—Dipping sonar block diagram.

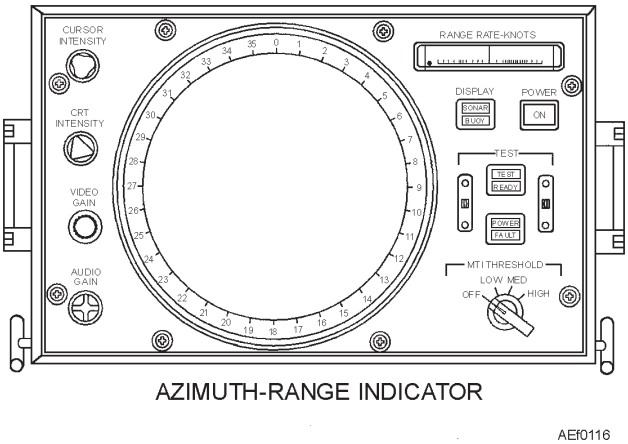


Figure 1-16.—Azimuth-range indicator.

Figure 1-15 is a simplified block diagram of the AN/ASQ-13F and its associated subsystems.

IP-1607/ASQ-13F Azimuth-Range Indicator

The azimuth-range indicator (ARI) (fig. 1-16) is positioned at the sensor station and produces a visual representation of range and bearing information, providing a means for the operator to track targets. The 7-inch cathode-ray tube (CRT) is marked in 10-degree increments to aid in determining target bearing. There are four controls on the left-hand side of the indicator for operator comfort. The CURSOR INTENSITY switch controls the brightness of the cursor. The CRT INTENSITY controls the brightness of the overall CRT. The VIDEO GAIN controls the level of the video signal applied to the CRT. The AUDIO GAIN switch controls the level of the audio signal.

The right side of the indicator face contains a meter called the RANGE RATE-KNOTS meter. This meter displays the opening or closing speed of the selected target. The MTI THRESHOLD switch selects the range rate threshold of targets to be displayed on the CRT. The DISPLAY switch selects either sonobuoy signals or sonar signals to be shown on the CRT. To activate the sonar set, press the POWER switch. This activates the entire system with the exception of the dome control. The TEST switch initiates the built-in test functions and analyzes the results.

R-2433/ASQ-13F Sonar Receiver

The sonobuoy receiver (fig. 1-17) generates the transmit signal and receives and processes sonic signals from the transducer for display on the ARI. The receiver also provides audio to the intercommunication system (ICS) for aural monitoring of acoustic signals. The R-2433 receiver should not be confused with the AN/ARR-84 sonobuoy receiver, which detects RF signals from deployed sonobuoys.

CP-1971/ASQ-13F Sonar Data Computer

The sonar data computer (fig. 1-18) is a programmed array processor that provides improved operation of the dipping sonar and processes signals from multiple passive and active sonobuoys.

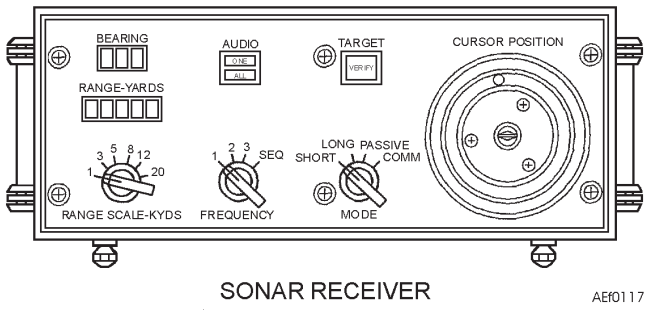


Figure 1-17.—Sonar receiver.

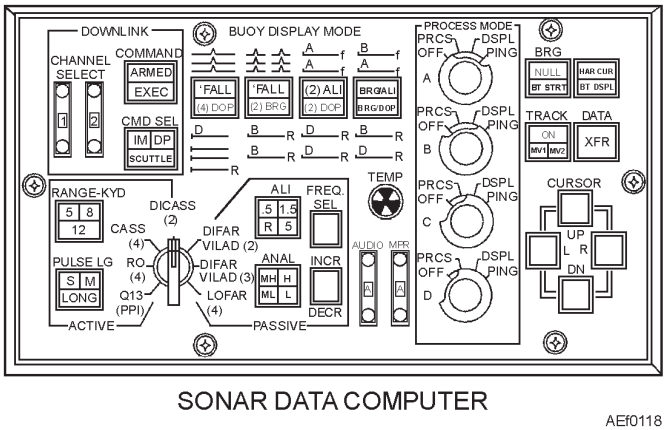


Figure 1-18.—Sonar data computer.

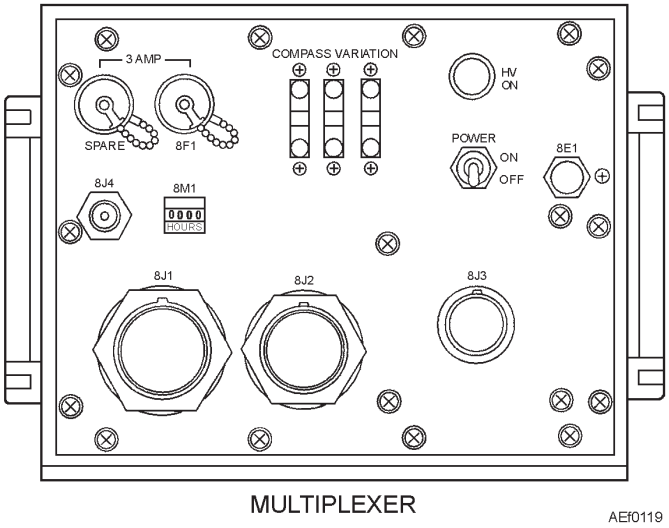


Figure 1-19.—Multiplexer.

TD-1421/ASQ-13F Multiplexer

The multiplexer (fig. 1-19) provides the electrical interface between the sonar set units mounted in the helicopter and the sonar transducer submerged in the water. The multiplexer is located in the cabin area, parallel to the reeling machine.

C-12056/ASQ-13F Dome Control

The dome control (fig. 1-20) provides controls for raising and lowering the sonar transducer and indicators for monitoring the sonar transducer and reeling machine. The dome control is located at the sensor station.

RL-299/ASQ-13F Reeling Machine and MX-18320A/ASQ-13F Cable and Reel Assembly

The reeling machine (fig. 1-21) is a hydraulic hoist that raises and lowers the sonar transducer. It operates from utility hydraulic power at a pressure of 3000 pounds per square inch, requiring a flow of approximately 13.4 gallons-per-minute at maximum speed. The reeling machine is located in the cabin area. It houses the cable and reel assembly (fig. 1-22), which contains a sonar cable 1550 to 1600 feet in length. The sonar cable is a jacketed triax cable with an armor braid used as the strength component of the cable. The inner electrical conductors allow for the passage of signals between the transducer and multiplexer.

TR-348/ASQ-13F Sonar Transducer

The sonar transducer (fig. 1-23) generates and transmits sonar pulsed (ping) energy or voice signals into the water. The sonar transducer also acts as a listening device, converting sound energy received in the water into electrical signals.

The sonar transducer is connected to the wet end of the reel-cable assembly cable, which is mounted in the reeling machine. The transducer tail structure provides hydrodynamic stability during raising and lowering. The tail structure is seated or caged against the upper

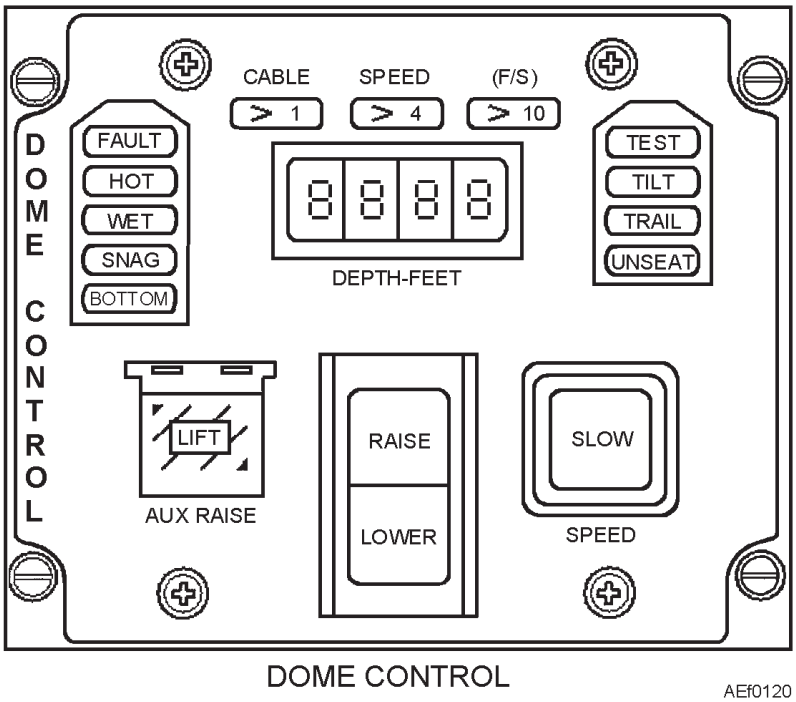


Figure 1-20.—Dome control.

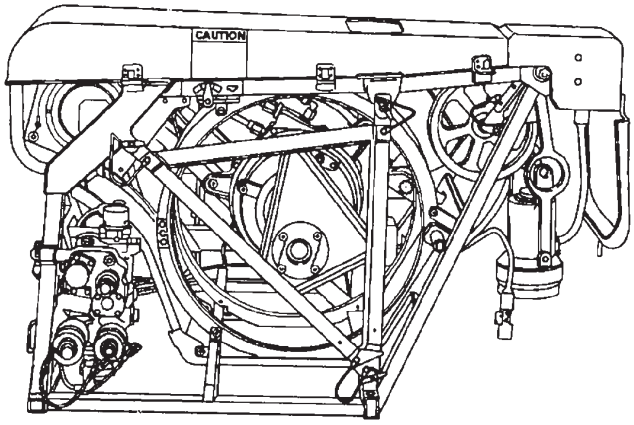


Figure 1-21.—Reeling machine.

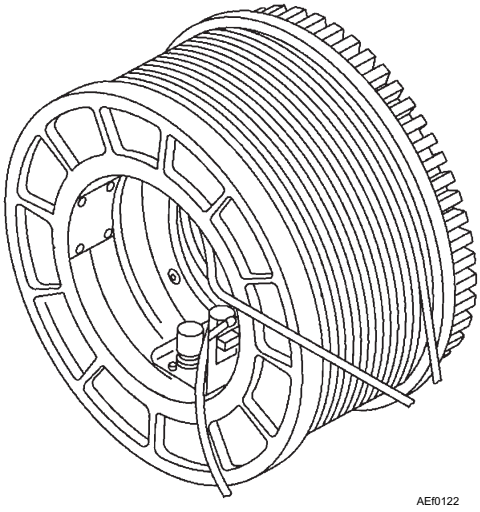


Figure 1-22.—Cable and reel assembly.

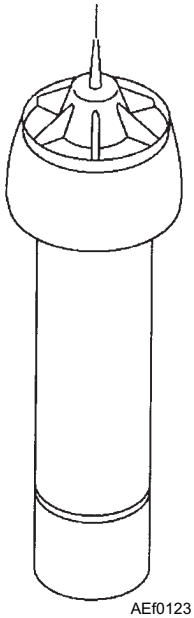


Figure 1-23.—Sonar transducer.

stop plate of the transducer body during lower and is free to move or is uncaged during raise by the dashpot assembly that is housed under a rubber bladder on the top of the transducer body. Also contained in the dashpot assembly is a universal joint that allows free movement of the transducer body when uncaged. The universal joint also facilitates mechanical connection of the transducer to the sonar cable termination.

The center body of the transducer contains an outer acoustic array and an inner pressure vessel. The sonar transducer acoustic array consists of piezoelectric elements electrically connected in vertical staves for the receive or *hydrophone* portion and circular rings for the transmit or *projector* portion. It is surrounded by a castor oil-filled neoprene boot for proper acoustic interface with seawater. The boot provides little or no mechanical protection for the sensitive acoustic elements and should be handled with extreme care.

The inner pressure vessel contains the transmitter assembly and an electronics assembly. Also contained within the pressure vessel are catalysts that combine hydrogen generated by the battery with oxygen contained in the air within the vessel to form water. The vessel also contains desiccants to absorb the water. The oxygen must be refreshed and the catalyst and desiccant must be replaced periodically.

The electronics assembly provides the circuits necessary to send and receive signals via the sonar cable, to monitor various fault conditions, to condition the signals from the hydrophone, pressure, and temperature sensors, and to drive the transmitter.

The transmitter provides the electrical signal to the projector for the acoustic transmit pulse. The nose assembly contains a lead-acid battery that provides power for the transmitter during acoustic transmissions.

WARNING

A lethal dc potential of up to 176 V is present on the connector pins of the battery connector P1. During handling, do not touch the P1 connector pins or battery plug receptacle pins. Do not allow any foreign objects to fall into the nose assembly.

The battery is charged when the sonar power is on. Periodic charging is required to maintain the proper charge. When the transducer is removed from the aircraft, the transducer should be charged prior to

removal. After removal, the battery should be disconnected by removing the battery connector.

MODES OF OPERATION

The sonar set can be operated in a variety of modes and controlled from various components to achieve specific functions. Table 1-3 contains a list of the sonar set modes and a general description of the functions they provide.

AIRBORNE LOW-FREQUENCY SONAR

The SH-60R is the newest addition to the Navy's fleet of helicopters. The SH-60R combines the traditional mission areas of the SH-60B and SH-60F into a more versatile and up-to-date weapons platform. One of the most drastic improvements is the airborne low-frequency sonar (ALFS).

The airborne low-frequency sonar (ALFS) provides a dipping sonar with demonstrated capabilities typically three to six times (square miles of ocean searched per hour) the ASQ-13F deep water capability. ALFS provides longer detection ranges and a greater detection capability by using lower frequencies, less signal attenuation, longer pulse lengths, improved processing, and increased transmission power. ALFS uses the Enhanced Modular Signal Processor, designated UYS-2A, for improved sonobuoy processing capability.

Remanufacture of the SH-60B fleet has started and will continue through FY 2009. Remanufacture of the SH-60F and HH-60H fleets will begin in FY 2004 and continue through FY 2012. The SH-60R is scheduled to reach operational capability in 2002.

Q1-8. What type of naval aircraft employs the AN/ASQ-13F dipping sonar system?

Q1-9. On a dipping sonar system, what component generates and transmits sound energy into the water?

Table 1-3.—AN/AQS-13F Operating Modes

Operating Mode	Mode Description
Dipping sonar-active	Uses submerged, actively pinging sonar transducer to locate, identify, and track a target.
Dipping sonar-passive	Uses submerged sonar transducer to listen to target noises.
Sonobuoy-active	Uses CASS and DICASS sonobuoys to actively locate, identify, and track a target.
Sonobuoy-passive	Uses LOFAR, DIFAR, and VLAD sonobuoys to locate targets by their noise signatures via returned up-link target data.
Underwater voice communication (UVC)	Uses submerged sonar transducer to transmit and receive voice signals to and from other USW helicopters, submarines, or similarly equipped surface ships.
Bathythermograph (BT) recording	Uses submerged sonar transducer or BT sonobuoy to record the difference in water temperature vs. depth.

CHAPTER 2

MAGNETIC ANOMALY DETECTION (MAD)

INTRODUCTION

While vigilant lookouts carefully scan the turbulent ocean surface for submarine periscopes and wakes, nonacoustic sensors (fig. 2-1) augment acoustic sensors to locate potentially hostile forces below the surface of the sea. These sensors include radar (to detect exposed periscopes and hull surfaces), electromagnetic systems (to intercept the radar emissions from submarines), infrared receivers (to detect the heat signatures of surfaced submarines), and magnetic anomaly detectors (MAD) (to sense small changes in the Earth's magnetic field caused by the passage of a submarine). This chapter covers the MAD sensor and describes magnetic detection principles, magnetic noise compensation, helium magnetometer theory, and a typical airborne MAD system and its subsystems.

PRINCIPLES OF MAGNETIC DETECTION

LEARNING OBJECTIVE: Recognize the operation principles of magnetic anomaly detection.

Light, radar, and sound energy cannot pass from air into water and return to the air in any degree that is usable for airborne detection. On the other hand, lines of force in a magnetic field are able to make this transition almost undisturbed because the magnetic permeability of water and air are practically the same. Specifically, the lines of force in the Earth's magnetic field pass through the surface of the ocean essentially undeviated by the change of medium (from water to air or vice versa) and undiminished in strength. Consequently, an object under the water can be detected from a position in the air above if the object has magnetic properties that distort the Earth's magnetic field. A submarine has sufficient ferrous mass and electrical equipment to cause a detectable distortion (anomaly) in the Earth's field. Detection of this anomaly is the function of magnetic anomaly detection (MAD) equipment.

MAGNETIC ANOMALY

The lines comprising the Earth's natural magnetic field do not always run straight north and south. If

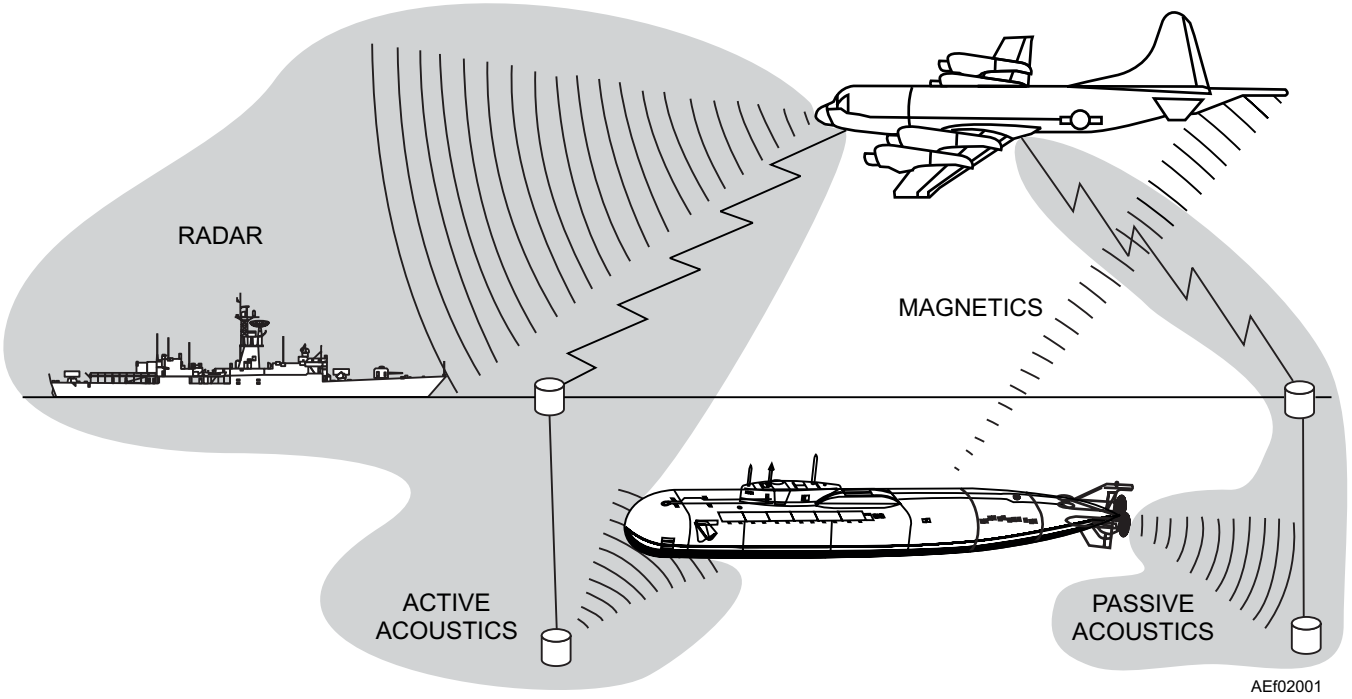


Figure 2-1.—Nonacoustic sensors.

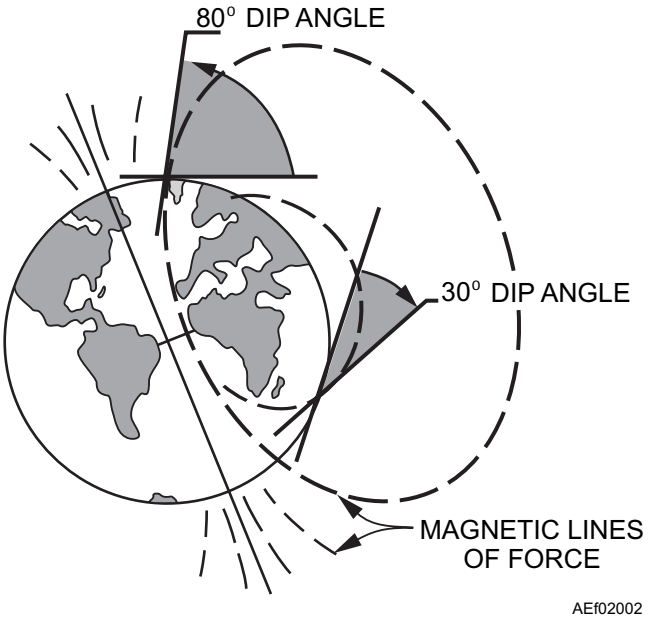


Figure 2-2.—Dip angles.

traced along a typical 100-mile path, the field twists at places to east or west and assumes different angles with the horizontal. Angles of change in the east-west direction are known as *variation angles*, while angles between the lines of force and the horizontal are known as *dip angles* (fig. 2-2). At any given point between the equator and the magnetic poles, the relationship of the angle between the Earth's surface and the magnetic lines of force is between 0 degrees and 90 degrees. This dip angle is determined by drawing two imaginary lines tangent to the Earth's surface and to the line of force where it enters the Earth's surface.

If the same lines are traced only a short distance, 300 feet for instance, their natural changes in variation and dip over such a short distance (short-trace) are almost impossible to measure. However, short-trace variation and dip in the area of a large mass of ferrous material, though still extremely minute, are measurable with a sensitive anomaly detector. This is shown in figure 2-3. The dashed lines represent lines of force in the Earth's magnetic field.

View A of figure 2-3 shows the angular direction at which natural lines of magnetic force enter and leave the surface of the Earth. Note that the dip angles are considerably steeper in extreme northern and southern latitudes than they are near the equator. View B represents an area of undisturbed natural magnetic strength. In views C and D, the submarine's magnetic field distorts the natural field as shown. The density of the natural field is decreased in view C and increased in view D. The natural dip angle is also affected, but only very slightly.

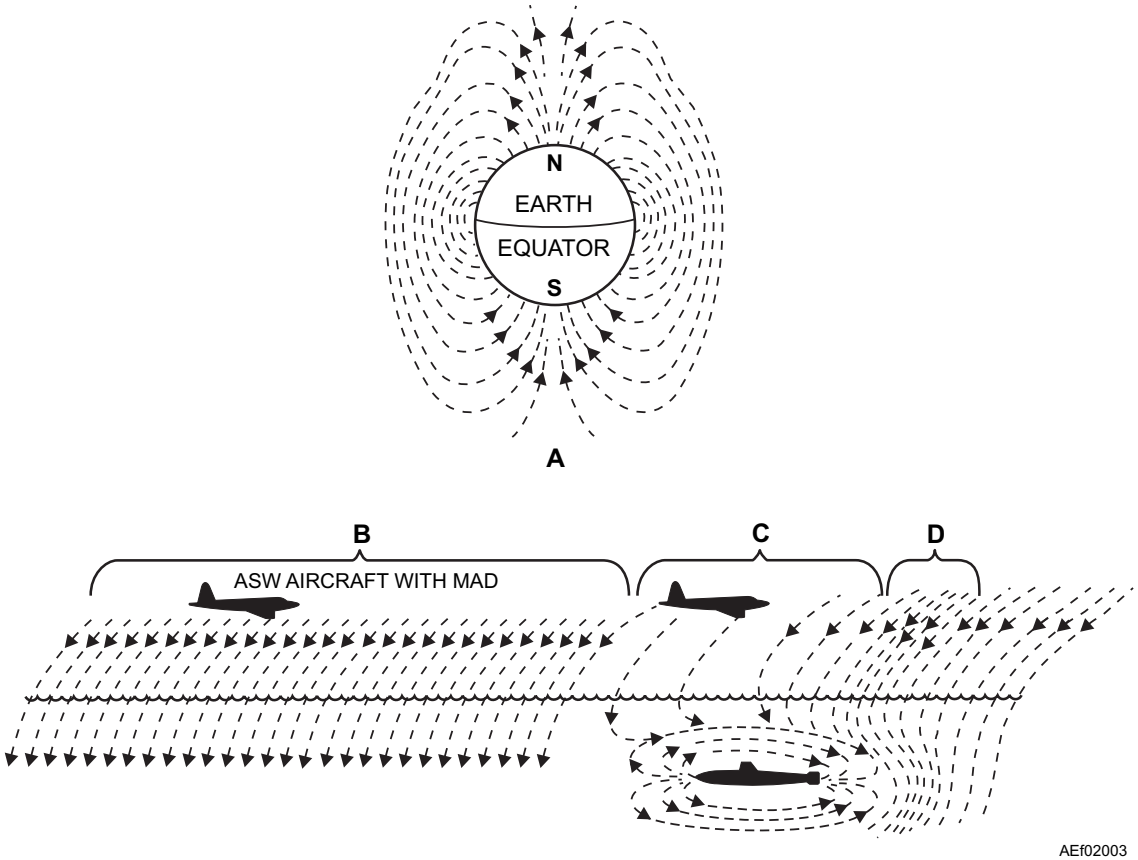


Figure 2-3.—Simplified comparison of natural field density and submarine anomaly.

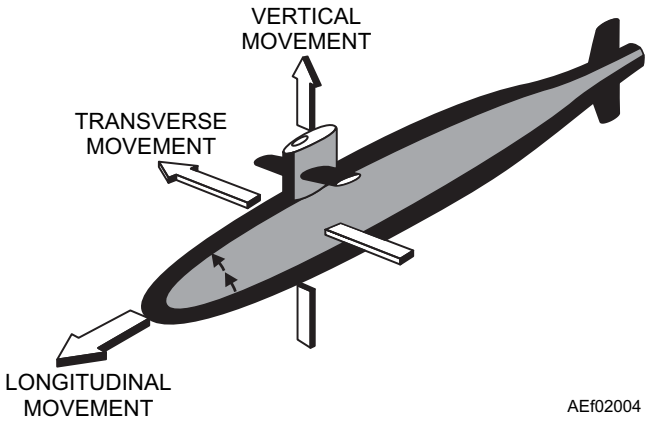


Figure 2-4.—Submarine's magnetic moment.

SUBMARINE ANOMALY

The maximum range at which a submarine may be detected depends on the intensity of its magnetic anomaly and the sensitivity of the detector. A magnetometer is used as the detector in MAD equipment.

A submarine's magnetic moment (magnetic intensity) (fig. 2-4) determines the intensity of the anomaly. It is dependent mainly on the submarine's alignment in the Earth's field, its size, the latitude at which it is detected, and the degree of its permanent magnetization.

MAD equipment is very sensitive, but the submarine's anomaly, even at a short distance, is normally very weak. The strength of a complex magnetic field (such as that associated with a submarine) varies as the inverse cube of the distance from the field's source. That is, if the detectable strength of a field source has a given value at a given distance and the distance is doubled, the detectable strength of the source at the increased distance will then be one-eighth of its former value. Therefore, from the foregoing, at least two facts should be clear. First, MAD equipment must be operated at a very low altitude to gain the greatest proximity possible to enemy submarines. Second, the searching aircraft should fly at a predetermined speed and follow an estimated search pattern. This ensures systematic and thorough searching of the prescribed area so that no existing anomalies are missed.

ANOMALY STRENGTH

Up to this point, the inferred strength of a submarine's anomaly has been exaggerated for purposes of explanation. Its actual value is usually so small that MAD equipment must be capable of detecting a distortion of approximately one part in 60,000. This fact is made apparent by pointing out that the direction of alignment of the Earth's magnetic lines of force is rarely changed more than one-half of 1 degree in a submarine anomaly.

Figure 2-5, view A, represents a contour map showing the degree of anomaly caused by a submarine. The straight line is approximately 800 feet in length and represents the flight path of a searching aircraft through the area of the submarine anomaly. If the submarine were not present, the undisturbed magnetic intensity in the area due to its assumed natural characteristics would be 60,000 gamma. (The gamma, symbolized by the Greek letter γ, is a measure of magnetic intensity.) All variations in the field, when the submarine is

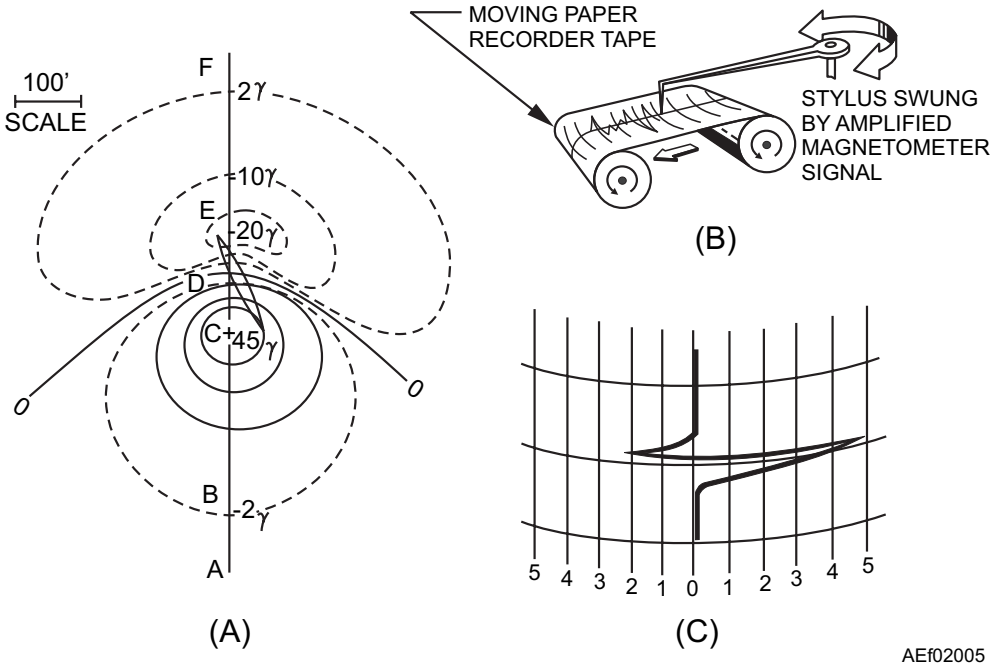


Figure 2-5.—(A) Degree of anomaly; (B) anomaly stylus; (C) sample anomaly record.

present, would then be above or below this natural intensity. Therefore, 60,000 γ is the zero reference drawn on the moving paper tape shown in figure 2-5, view C.

Refer to view A of figure 2-5. Starting with the aircraft at point A, where the anomaly is undetectable, the Earth's field concentration decreases to an intensity of -2 (59,998) at point B. Its intensity then increases until a peak value of +45 is reached at point C. From that point it decreases to zero at point D. Beyond point D, another zone of what amounts to magnetic rarefaction is encountered. The Earth's field is less intense than its normal value. Consequently, anomalous values in this zone are considered as minus quantities. A peak minus intensity is reached at point E, and thereafter, the signal rises back to its normal, or undetectable, intensity at point F.

As the varying degrees of intensity are encountered, they are amplified and used to drive a swinging stylus, as shown in figure 2-5, view B. The tip of the stylus rides against the moving paper tape, leaving an ink trace. (Some recorders use electrosensitive paper tape and a chain-driven stylus. Some other recorders use a cathode-ray tube (CRT) display.) The stylus is swung in one direction for positive and in the opposite direction for negative. The magnitude of its swing is determined by the intensity of the anomaly signal. Figure 2-5, view C, is a sample of paper recording tape, showing the approximate trace caused by the anomaly in view A.

In the illustration just given, the search aircraft's altitude was 200 feet. At a lower altitude, the anomaly would be stronger. Likewise, the anomaly would be weaker at a higher altitude.

Q2-1. The angle between an imaginary line tangent to the Earth's surface and to the magnetic line of force where it enters the Earth's surface is known by what term?

Q2-2. The gamma, the measure of magnetic intensity, is symbolized by what Greek letter?

MAGNETIC NOISE COMPENSATION

LEARNING OBJECTIVE: Identify sources of magnetic noise. Recognize the purpose and procedures of magnetic compensation.

Any noise or disturbance originating in the aircraft or its equipment that could produce a signal on a MAD equipment recorder is classified as magnetic noise.

NOISE SOURCES

In an aircraft, there are many sources of magnetic fields, such as engines, struts, control cables, equipment, and ordnance. Many of these fields are of sufficient strength to seriously impair the operation of MAD equipment. Consequently, some means must be employed to compensate for "magnetic noise" fields. The noise sources fall into two major categories—maneuver noises and dc circuit noises.

Maneuver Noises

When the aircraft maneuvers, the magnetic field of the aircraft is changed, causing a change in the total magnetic field at the detecting element. The aircraft maneuver rates are such that the signals generated have their major frequency components within the bandpass of the MAD equipment. Induced magnetic fields, eddy current fields, or the permanent field cause maneuver noises.

The variations in the induced magnetic field detected by the magnetometer are caused by changes in the aircraft's heading. This causes the aircraft to present a varying size to the Earth's magnetic field, and only the portion of the aircraft parallel to the field is available for magnetic induction.

Eddy current fields produce maneuver noise because of currents that flow in the aircraft's skin and structural members. When an aircraft's maneuver causes an eddy current flow, a magnetic field is generated. The eddy current field is a function of the rate of the maneuver. If the maneuver is executed slowly, the effect of the eddy current field is negligible.

The structural parts of the aircraft exhibit permanent magnetic fields, and, as the aircraft maneuvers, its composite permanent field remains aligned with it. The angular displacement between the permanent field and the detector magnetometer during a maneuver produces a changing magnetic field, which the detector magnetometer is designed to detect.

DC Circuit Noises

The dc circuit noise in an aircraft comes from the standard practice in aircraft design of using a single-wire dc system with the aircraft skin and structure as the ground return. The resulting current loop from the generator to load to generator serves as a large electromagnet that generates a magnetic field similar to a permanent magnetic field. Whenever the dc

electrical load of the aircraft is abruptly changed, there is an abrupt change in the magnetic field at the detector.

COMPENSATION

Regardless of its source, strength, or direction, any magnetic field may be defined in terms of three axial coordinates. That is, it must act through any or all of three possible directions—longitudinal, lateral, or vertical in relation to the magnetometer detector.

Compensation for magnetic noises is necessary to provide a magnetically clean environment so that the detecting system will not be limited to the magnetic signal associated with the aircraft itself.

Experience has shown that the induced fields and eddy current fields for a given type of aircraft are constant. That is, from one aircraft to another of the same type, the difference in fields is negligible. These fields may be expected to remain constant throughout the life of the aircraft, provided significant structural changes are not made. In view of these factors, the aircraft manufacturer provides compensation for induced fields and eddy current fields.

Eddy current field compensation is usually achieved by placing the detector magnetometer in a relatively quiet magnetic area. In some aircraft, the magnetometer (detecting head) is placed at least 8 feet from the fuselage. This is done by enclosing the detecting head in a fixed boom (fig. 2-6, view A). Helicopters tow the detector head by use of a cable (fig. 2-6, view B).

Induced magnetic field compensation is accomplished by using Permalloy strips. The aircraft is rotated to different compass headings, and the magnetic moment is measured. The polarity and the variation of the magnetic moment are noted for each heading, and Permalloy strips are oriented near the detector magnetometer to compensate for field changes due to aircraft rotation. Additional compensation is needed for the longitudinal axis, and is provided for by the development of outrigger compensators of Permalloy near the detecting element.

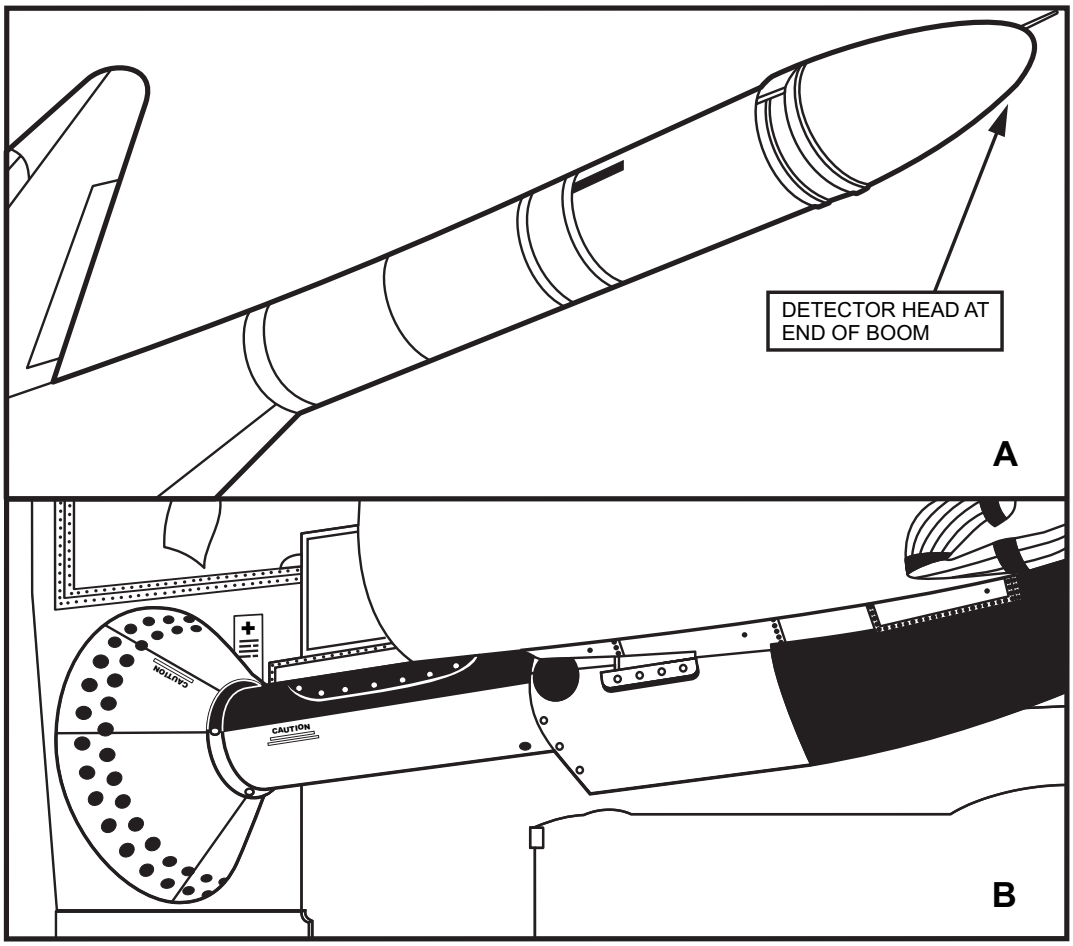


Figure 2-6.—(A) Stationary detector boom; (B) cable deployed towed detector.

Permanent field compensation must be done in three dimensions rather than in two, and it is accomplished by three compensating coils mounted mutually perpendicular to each other (fig. 2-7, view A). The aircraft is rotated in 5-degree and 10-degree steps around its three axes. Adjustment of the field strength is accomplished by controlling the amount of direct current that flows through a particular coil. Figure 2-7, view B, shows a circuit for a single compensating coil.

Compensation for the dc magnetic field is accomplished by using electromagnetic compensating loops. The loops are arranged to provide horizontal, vertical, and longitudinal fields, and are adjusted to be equal and opposite to the dc magnetic field caused by the load current. The compensating loops are connected across a variable resistor for a particular distribution center, and are adjusted to allow current flow proportional to the load current for correct compensation. Different types of aircraft have several sets of compensating loops, depending upon the number of distribution centers. In newer aircraft, production changes have been made to use ground return wires to minimize loop size.

The procedure for adjustment of the dc compensation system makes use of straight and level flight on the four cardinal headings. For example, actuation of a cowl flap motor will cause dc field changes representative of those caused by any nacelle load. The load is energized, the size and polarity of the signal are noted, and the compensation control is adjusted. The load is re-energized, and the compensation control is adjusted again. Adjustments are continued until the resulting signals from the dc field are minimized.

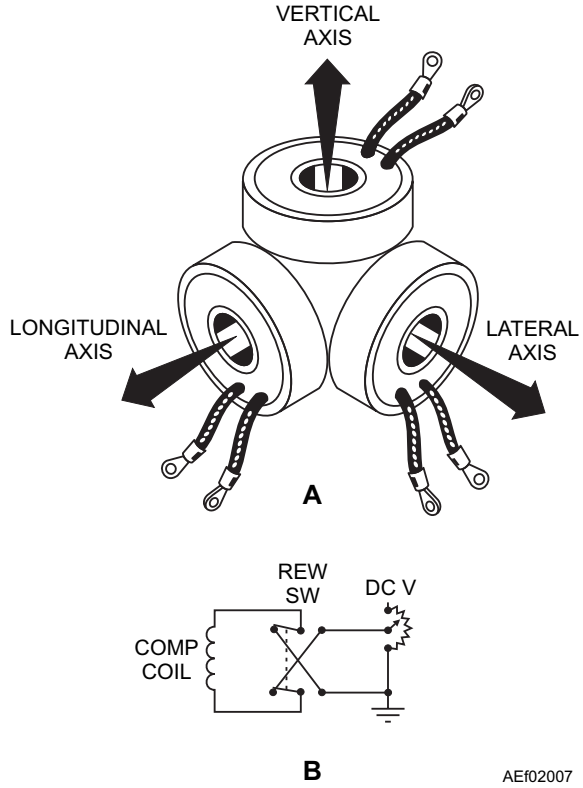


Figure 2-7.—(A) Arrangement of compensating coils; (B) compensating coil circuit.

Under ideal conditions, all magnetic fields tending to act on the magnetometer head would be completely counterbalanced. In this state, the effect on the magnetometer is the same as if there were no magnetic fields at all. This state exists only when the following ideal conditions exist:

1. The aircraft is flying a steady course (no maneuvers) through a magnetically quiet geographic area.
2. Electric or electronic circuits are not turned on or off during compensation.
3. Direct current of the proper intensity and direction has been set to flow through the compensation coils, so that all stray fields are balanced.

To approximate these conditions, the compensation of MAD equipment is usually performed in flight, well at sea. The equipment is compensated under operating conditions, which closely resemble those of actual undersea warfare (USW) search flights.

From the foregoing, it should be clear that the objective of compensation is to gain a state of total balance of magnetic forces around the magnetometer. Thereafter, any sudden shift in one of the balanced forces (such as an anomaly in the Earth's field force) upsets the total balance. This imbalance is indicated on the recorder. Unfortunately, a shift in **any** of the balanced forces will be indicated. Shifts in any of the forces other than the Earth's natural field are regarded as noise.

Q2-3. Magnetic noise sources fall into what two major categories?

Q2-4. The compensation of MAD equipment for magnetic noise is usually performed at what location?

HELIUM MAGNETOMETER THEORY

LEARNING OBJECTIVE: Recognize the theory and operation of helium magnetometers. Define Larmor frequency and the metastable state.

The detection of disturbances in the Earth's magnetic field requires extremely sensitive equipment. Today's naval aircraft currently employ helium magnetometers to detect these anomalies. In order to understand how a MAD system works, the theory and operation of the helium magnetometer must be discussed.

MAGNETIC RESONANCE

Magnetic resonance is based on the theory of atomic structure, which states "the atom is considered to be a nucleus around which one or more electrons are orbiting." The nucleus has a positive charge because protons are part of it. The electrons have a negative charge that causes the atom to be neutral. The electrons and the nucleus have a spin and, because of the spin and the charge, a magnetic moment results.

The electron also is spinning about its own axis (much like the Earth orbits around the sun once a year and spins about its axis once a day). This spin causes the electron to have a magnetic moment, much like a small magnet, and to exhibit the characteristics of a tiny gyro. As is the case with a mechanical gyro, a force applied to the electron causes it to precess, resulting in the wobble motion of the electron's spin axis, as shown in figure 2-8, view A. Furthermore, the magnetic characteristics of an electron make it possible to substitute a magnetic field force (Earth's magnetic field) for the mechanical force normally used to precess a conventional gyro. In addition to this, if a rotating magnetic field at a radio frequency (RF) is applied perpendicularly to the main magnetic field, the electron precesses further. The dash lines depict this condition in figure 2-8, view B, as an increased wobble motion of the electron's spin axis.

When the frequency of rotation of the magnetic field is adjusted until it is the same as the natural frequency of the particular material in use (helium in this case), the deviation of the spin axis of the electrons tends to increase and paramagnetic resonance is achieved. Electron paramagnetic resonance is resonance in which the electron is the only particle shifting energy states. This resonance occurs when the angular velocity of the rotating magnetic field is approximately the natural spin axis wobble rate, or precession rate, of helium electrons. The natural spin axis wobble rate is also called the *Larmor frequency*. As the electrons are caused to precess more by the external RF magnetic field, the amplitude of the precession becomes so great that the electrons jump to a higher energy level, at which time light energy is absorbed by the helium. Light is used initially to increase the energy level of the electrons to a metastable energy state, which is a higher energy level with a much longer lasting duration than any other excited level. Helium gas is one of the elements or materials that can assume a metastable energy level.

The ASQ-81 solid-state MAD system uses a beam of low-frequency light to periodically increase the energy level of the electrons and orient the magnetic moments of the atoms and their electrons on a plane in the direction of the light beam. This procedure is known

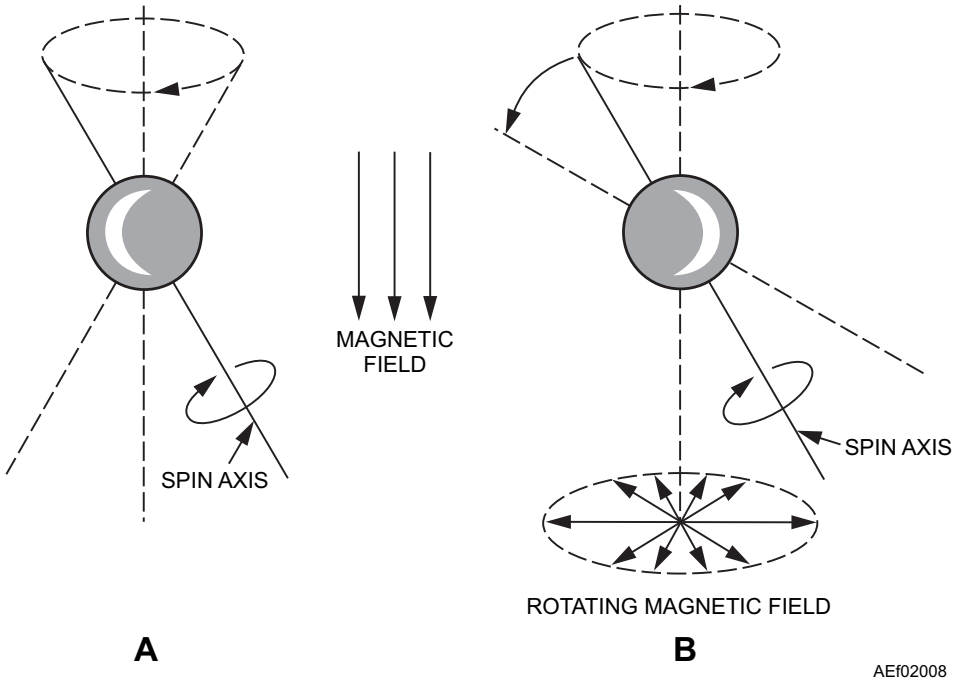


Figure 2-8.—Electron precession.

as optical pumping. The pumping action of the light energy causes the electrons to jump two energy levels; that is, from ground energy level (E_0) to excited energy level (E_2). Excited energy state 2 (E_2) has a very short lifetime without external excitation. Since the light is pumping, the electrons tend to fall back toward the stationary state (E_0), but must pass through the metastable excited state—energy state 1 (E_1).

If the pumping action is made continuous, the majority of electrons at any one time will congregate at the (E_1) or metastable excited state. This is necessary because if resonance of unaligned ground state helium were attempted with an external rotating magnetic field, only a small percent of the gas would change state and absorb light energy. This would make detection of resonance difficult. However, with the helium's atomic system aligned and excited when resonance occurs, a great majority of the atoms change state and an easily monitored amount of light is absorbed. The metastable state in the gas is necessary to have a relatively stable higher energy level in a much larger number of atoms. This produces a much greater change when resonance occurs.

Optical energy is absorbed and released by the electron during these energy level transitions. It should be noted here that resonance can be achieved only in certain solids and liquids with loosely knit atomic structures and in gases such as helium.

This discussion so far has concerned the energy level change of the helium atom electrons by the use of an external magnetic field (supplied through coils) oriented 90 degrees to the Earth's field. The external field rotates at the Larmor frequency of the electron, which was determined by the Earth's magnetic field strength. Since the precession or Larmor frequency of electrons varies with magnetic field intensity at the rate of 28 hertz (Hz) per γ, monitoring the Larmor frequency changes is a convenient method for detecting and measuring changes in the Earth's magnetic field.

However, a small change in the Larmor frequency of electrons is difficult to measure directly. It is more convenient and accurate to make an indirect measurement by monitoring the definite increase in light energy absorption that occurs at resonance. The atoms then radiate some of this light energy as the Larmor frequency shifts away from the externally applied field's frequency, and resonance is lost. Thus, variations in the Earth's magnetic field strength are reflected by the changes in the quantity of light passing through the helium gas. Helium gas is contained in a transparent container called an absorption cell.

As shown in figure 2-9, view A, energy is absorbed in forcing electrons to jump from one orbit to another orbit at a greater distance from the nucleus. Figure 2-9, view B, depicts the atom giving up energy as the electrons move back to their original orbit.

When the oscillator supplying the coils (resonance oscillator) reaches the Larmor frequency, light is absorbed. When the resonance oscillator comes off the Larmor frequency, light is emitted. Thus, the Larmor frequency (which represents the Earth's magnetic field strength) can be tracked by knowing the resonant oscillator frequency when the absorption cell is absorbing energy.

As shown in figure 2-10, the light energy source for the magnetic resonance magnetometer is a helium lamp. The infrared (IR) detector, which is a very sensitive and trouble-free device, is used to track the light energy level changes.

HELIUM MAGNETOMETER OPERATION

The necessary components for a magnetic resonance magnetometer are shown in figure 2-10. The external energy source, the helium discharge lamp, applies light energy to the transparent helium-filled absorption cell. Helium atoms in the absorption cell absorb or give up light energy in relation to slight

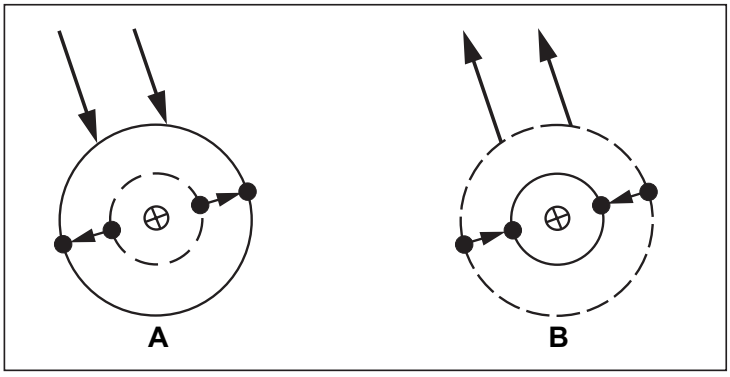


Figure 2-9.—Helium atom (A) absorbing energy and (B) radiating energy.

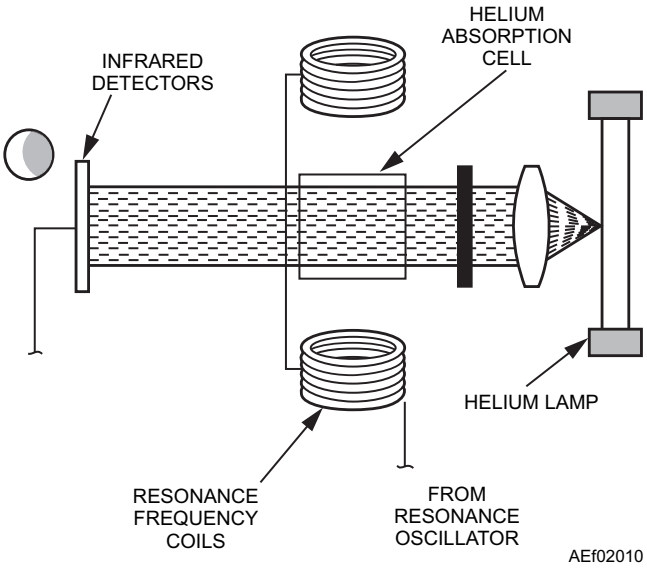


Figure 2-10.—Essential parts of helium magnetometer.

changes in the Earth's magnetic field. This causes the absorption cell to go in and out of resonance. The IR detector, mounted on the other side of the absorption cell from the light source, picks up these energy level changes and produces an electrical output. The energy level is low when the cell is resonant and high when it is not resonant. The IR detector output signal can then be used to keep the resonance oscillator on or about the Larmor frequency of the helium in the cell regardless of changes in the Earth's magnetic field. A magnetic anomaly can then be detected when the resonance oscillator center frequency makes a typical swing within the bandpass relative to the flight envelope of the MAD-equipped type of aircraft.

If the resonance oscillator frequency were always maintained precisely at resonance, the IR output would simply be a very low dc level. This low dc level would be difficult to monitor and would not provide a phase change above and below resonance. For this reason the RF energy applied to the resonance coils is frequency modulated by 430 Hz. The resultant variation in the magnetic field forces the helium atoms in and out of resonance around the null and provides a phase reference signal to a phase detection circuit. Figure 2-11 depicts the phase reversal above and below resonance. Note also that at resonance, which is the normal operating point, the IR detector acts much like a full wave rectifier. Because of rectifying action, the IR

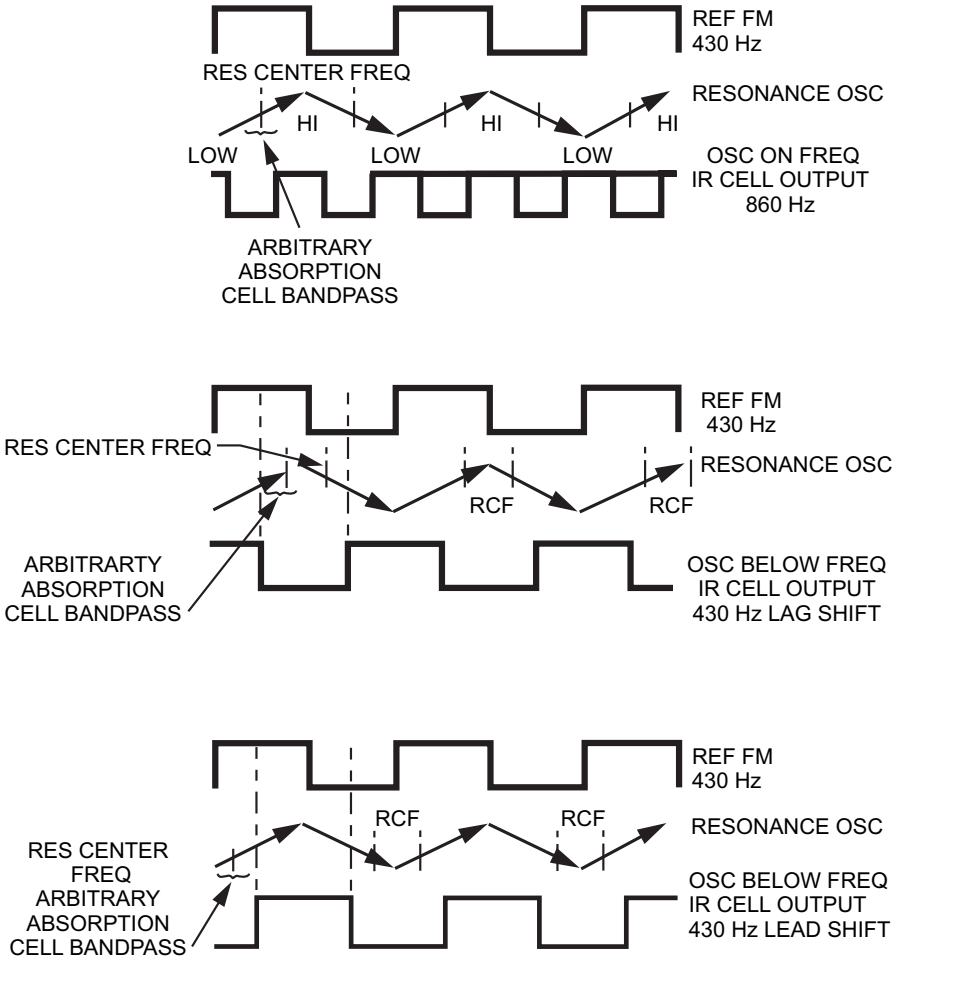


Figure 2-11.—Resonance waveforms from a phase detection circuit.

output at resonance is a pulsating 860-Hz signal. The detector also acts like a discriminator in that the frequency modulation (FM) swing of the resonance oscillator is converted to an amplitude modulation (AM) output when near the resonant frequency of the helium atoms in the absorption cell. This is true because its output goes positive with each increase in light energy given off by the absorption cell.

Q2-5. When electrons are excited to an energy level that is higher in energy and longer lasting in duration, this energy state is known as what type of energy state?

Q2-6. The Larmor frequency of electrons varies with magnetic field intensity at the rate of how many Hz per γ?

Q2-7. What component of a helium magnetometer detects the energy level changes of the helium atoms and produces an electrical output?

TYPICAL AIRBORNE MAD SYSTEM

LEARNING OBJECTIVE: Recognize the components and operating principles of a typical airborne MAD system.

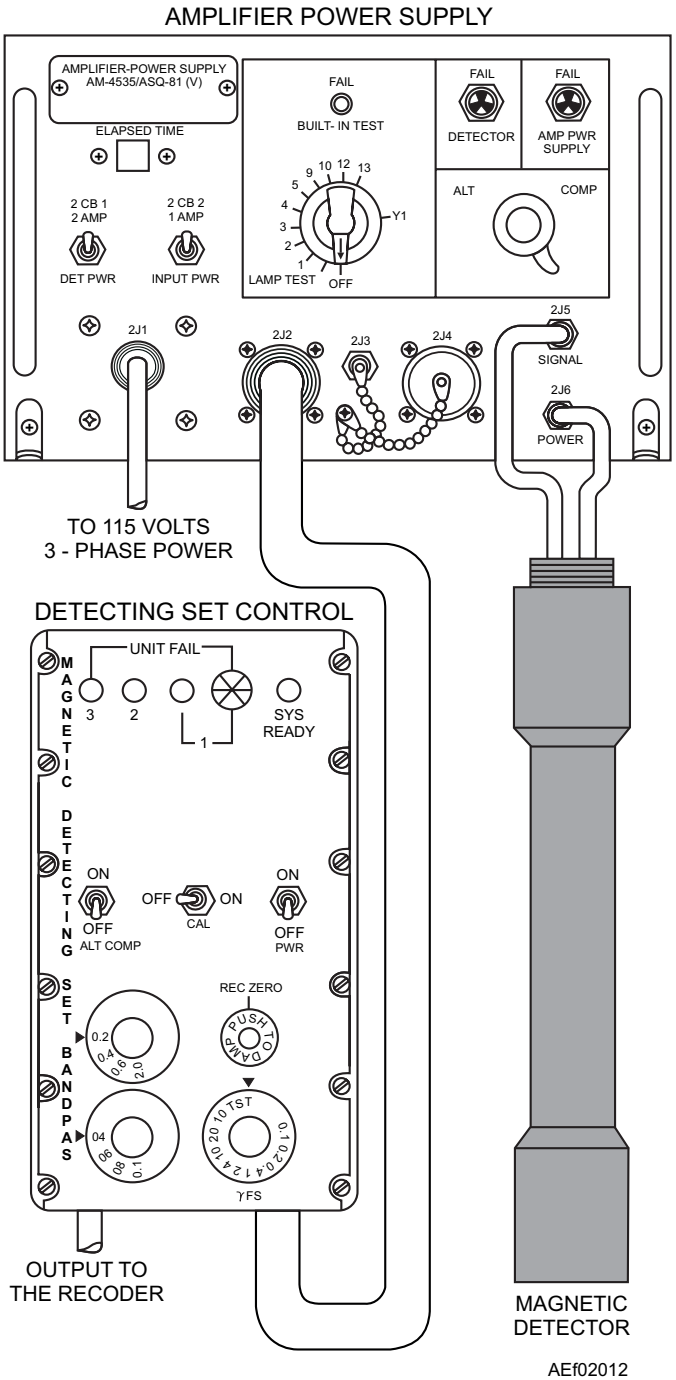
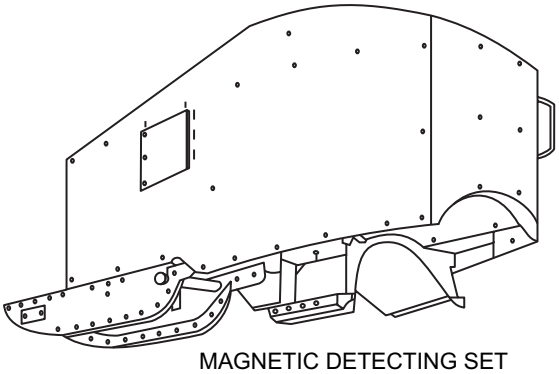


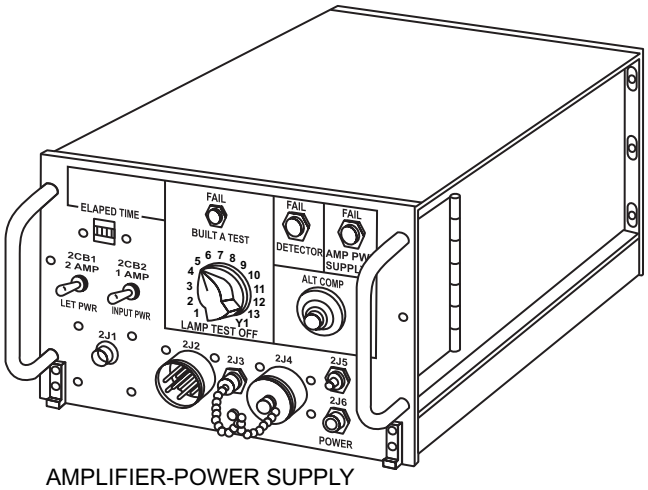
Figure 2-12.—Basic MAD system units.

The magnetic detecting set is a sensitive, metastable, helium magnetometer used to locate and classify submarines by detecting a disturbance or change in the normal Earth's magnetic field. The MAD system currently used by all naval USW aircraft is the AN/ASQ-81 system. The basic platform includes a magnetic detector, amplifier-power supply, and detecting set control. Figure 2-12 shows the controls and indicators as they appear on the equipment.

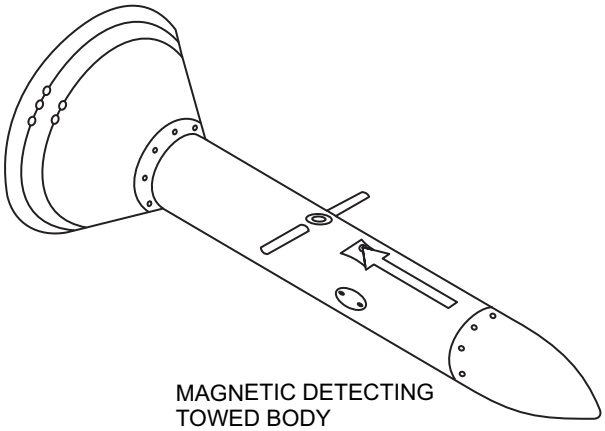
Helicopters use the same basic AN/ASQ-81 equipment with the addition of special equipment designed to trail the detector behind the aircraft to minimize the effects of magnetic fields generated by the helicopter. This special equipment includes the towed body, a reeling machine, and a reeling machine control (fig. 2-13).



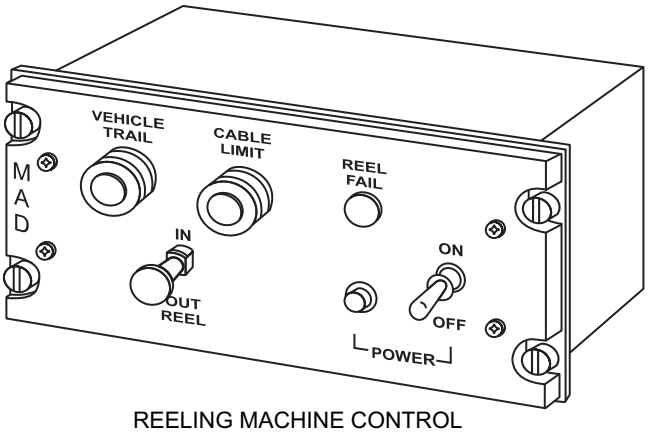
MAGNETIC DETECTING SET
REELING MACHINE
RL-305



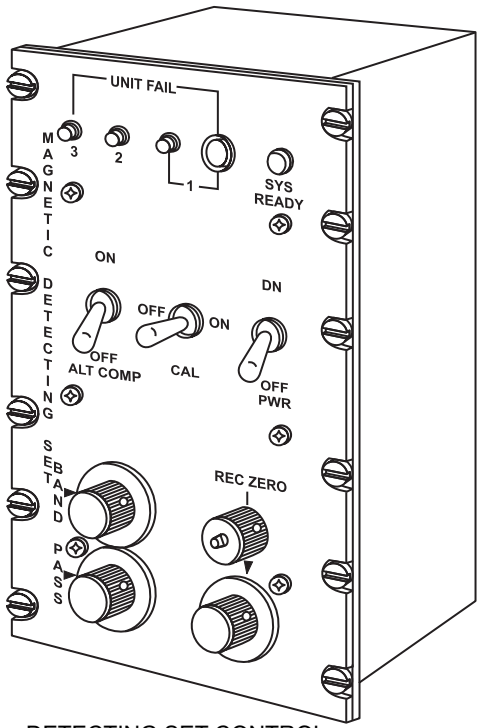
AMPLIFIER-POWER SUPPLY
AM-4535



MAGNETIC DETECTING
TOWED BODY
TB-623



REELING MACHINE CONTROL
C-10556



DETECTING SET CONTROL
C-10557

AEf02013

Figure 2-13.—Helicopter MAD system units.

MAGNETIC DETECTOR

The detection element includes six separate helium absorption cells and six IR detectors arranged in pairs, with the pairs oriented at 90 degrees to each other. The arrangement of the magnetometer is shown in figure 2-14. This configuration ensures that one or more of the pairs is at least partially in line with the Earth's field regardless of aircraft attitude or direction of flight. The signals from all three detector pairs are combined in a summing amplifier; thus, the final output to the amplifier-power supply is not affected by aircraft maneuvers.

Two helium discharge lamps provide light energy to the three absorption cell pairs in the magnetic detector. The lamps are ignited by a 52 kilohertz (kHz), 1,500 volt supply (fig. 2-15). After ignition, the lamps are maintained in an ionized state by the 49.6 megahertz (MHz) output of the exciter-regulator.

In addition, the magnetic detector unit includes a pressure transducer and an altitude compensator circuit. The output of the pressure transducer varies the frequency of a 5.4-kHz oscillator in the altitude compensator at the rate of 1 Hz/ft of altitude change. The total swing of the oscillator is 5.0 to 5.8 kHz, which

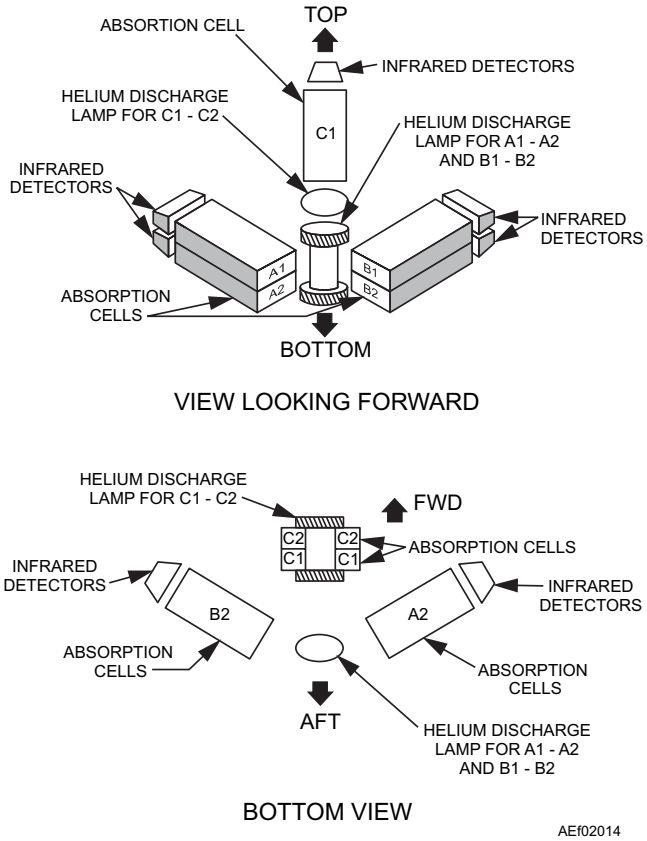


Figure 2-14.—Magnetometer axis orientation.

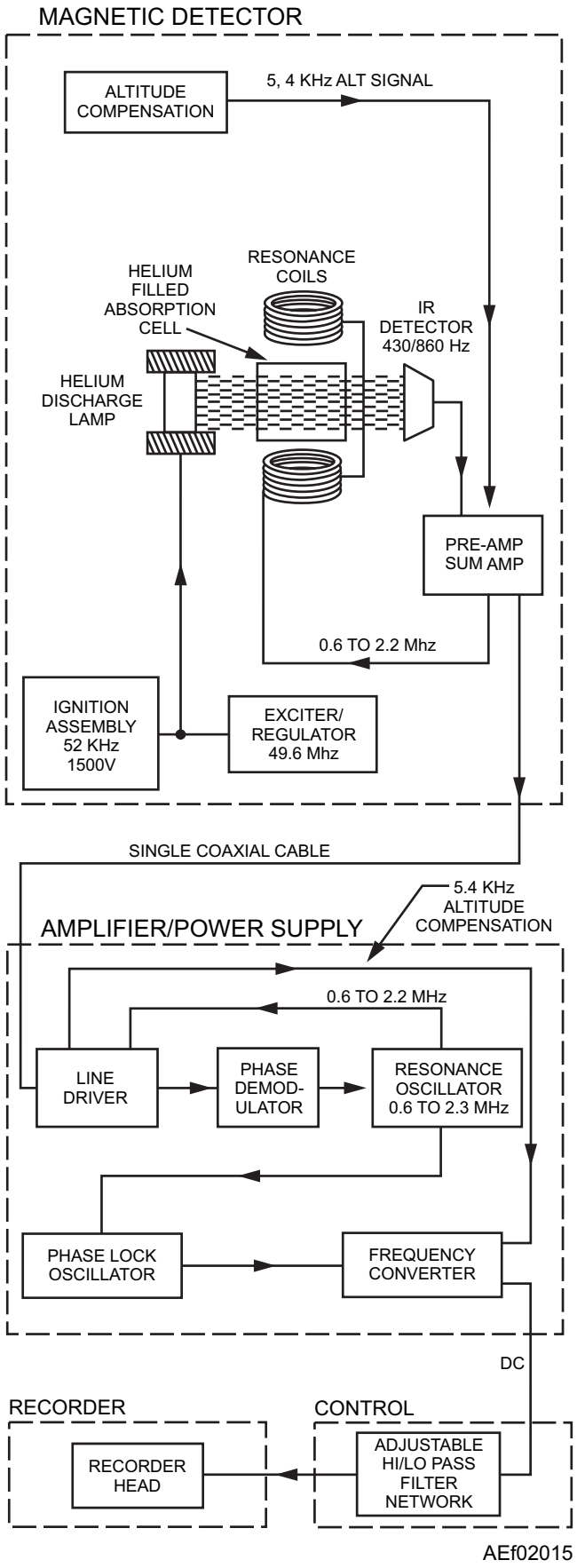


Figure 2-15.—Simplified block diagram of a MAD system.

can compensate for a maximum of 400-foot rapid altitude variations. Additional circuitry in the amplifier-power supply converts the altitude-induced frequency change to a varying dc level. At the operator's discretion, this dc level may be used to correct the final signal output.

CAUTION

When maintenance is performed on or near the magnetometer head, special nonferrous tools MUST be used. Additionally, any parts (nuts, bolts, or screws) that are replaced MUST be made of a special nonferrous metal. Always consult the maintenance instruction manual (MIM) for the system being worked on before attempting repairs.

AMPLIFIER-POWER SUPPLY

A single coaxial cable carries all signals between the magnetic detector and the amplifier-power supply. The signals on the coaxial cable include the 5.4-kHz altitude signal, the 430/860-Hz IR signal, the 0.6- to 2.2-MHz resonance coil excitation, and the 52-kHz ignition signal. The 52-kHz ignition signal is monitored first by system BITE (built-in test equipment) for its presence and, with the latest configuration, is checked approximately 5 minutes later (maximum warm-up time) for its absence. If the signal is not present initially, the system timer stops and shows a detector head failure. Approximately 5 minutes later, the absence of the signal is checked. The absence of the signal indicates that the intensity of both helium lamps was sufficient to cause the system to switch from ignition to the normal 49.6-MHz exciter signal. If this switchover did not occur, the system removes power to the detector head and illuminates the detector failure indicator. Bandpass filters at both ends of the coaxial cable route the frequencies to their respective circuits.

The IR detector error signal (anytime 430 Hz is present, this represents an error between the Larmor frequency and the resonance oscillator center frequency; 860 Hz indicates matched frequencies) is phase-detected in the phase demodulator to produce a variable positive or negative dc voltage. The variable dc is used to change the resonance oscillator frequency. This closed-loop action keeps the oscillator always at resonance as the Earth's field strength changes or as an anomaly is detected. When neither 430 Hz nor 860 Hz is coming back from the magnetic detector, the system senses this and causes the resonance oscillator to sweep its entire range (0.6 MHz to 2.2 MHz). During the down sweep of the resonance oscillator, when 430/860 Hz is detected, the sweep is stopped and the loop is closed. The resonance oscillator output is routed to the resonance coils via the line driver and the preamplifier/summing amplifier. It is also applied to the phase lock oscillator assembly.

The purpose of the phase lock oscillator is to reproduce the resonance oscillator frequency, retain the magnetic anomaly, and eliminate the 430-Hz modulation signal. The oscillator is voltage controlled by a dc signal from the acquisition circuit until it locks on to the resonant frequency. After lock-on, the phase detector provides the control necessary for tracking the resonant frequency. This tracking is similar to the way the resonant oscillator tracks the Larmor frequency.

The frequency converter develops a variable dc signal proportional to the frequency shift of the phase lock oscillator. The frequency converter also generates a variable dc voltage proportional to the frequency shift of the 5.4-kHz altitude compensation signal input supplied by the magnetic detector unit. If the operator selects ALT COMP (altitude compensation) on the control unit, a summary network combines the two dc signals to compensate for magnetometer altitude change effects. Two driver-amplifiers provide a primary output to the detecting set control unit and an auxiliary output for test purposes.

The primary output is passed through a series of high- and low-pass filters in the control unit. The filters remove all extraneous frequencies and noise from the variable dc except the anomaly signal. The filtered dc output drives the pen of a recorder to produce a permanent record of the submarine anomaly.

CONTROL BOX

The detecting set control box (fig. 2-12) contains the operating switches and indicators for the MAD system. Across the top of the faceplate are five indicators that indicate faults in the other units. The indicator labeled 3 indicates a magnetic detector failure when lit. The indicator labeled 2 indicates amplifier failure. The next two indicators indicate a control box fault. The SYS READY (system ready) indicator illuminates when the system is ready for operation. This indicator will blink during warm-up.

There are three toggle switches across the middle portion of the control box. The one on the right is the power switch. This switch applies power to the system. The middle switch is labeled CAL. It selects the

calibration signal for use. The switch on the left is labeled ALT COMP. This switch is used to connect the altitude compensator to the system.

The bottom portion of the control box contains four knobs. The two on the left side are labeled BANDPASS. These knobs select the high and low frequencies. The knob labeled REC ZERO (record zero) is a dual-purpose knob. Turning this knob controls the pen deflection on the recorder. Depressing the knob inhibits system output. The bottom right knob is labeled γFS, and is used to select one of nine sensitivity ranges (from 0.1γ to 40γ full scale) or self-test. In the TST (test) position, the self-test function will be initiated.

Q2-8. How many helium absorption cell/IR detector pairs are contained in the detector element?

Q2-9. The signals between the magnetic detector and the amplifier-power supply are transmitted through what type of cable?

Q2-10. The fault indicator on the detecting set control labeled 3 indicates a failure in what component?

MAGNETIC COMPENSATOR GROUP

LEARNING OBJECTIVE: Identify the three magnetic field terms associated with the compensation process. Recognize the components and operating features of the AN/ASA-65 magnetic compensator group.

The AN/ASA-65 magnetic compensator group is used in conjunction with the AN/ASQ-81 MAD system to reduce the effects of unwanted magnetic disturbances (anomalies) during MAD system operation. The MAD compensator generates opposing magnetic fields to nullify noise interference caused by the search aircraft.

MAGNETIC FIELD TERMS

Relative to MAD compensation theory, the word *term* refers to a magnetic field component. Permanent field terms are designated by a single capital letter such as T, L, or V, which stand for transverse, longitudinal, and vertical, respectively. These three axes, which are references to the three aircraft axes, remain fixed regardless of aircraft orientation with respect to the

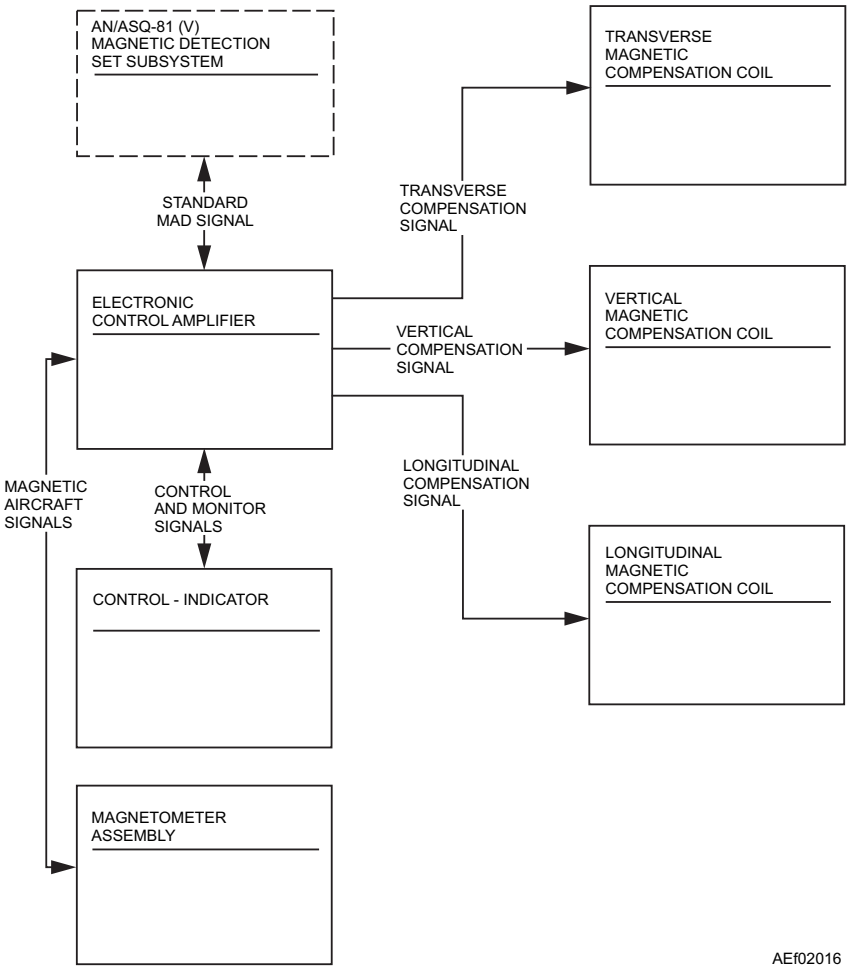


Figure 2-16.—Magnetic compensator group interface diagram.

Earth. Induced terms are designated by two capital letters, which may be any combination of L, T, or V, such as LL, VL, or TT. The first capital letter designates the inducing aircraft's structure axis, and the second capital letter designates the resulting field axis as seen at the detector head. The inducing axis may be different from the resulting field axis at the detector head. Eddy-current terms are designated by two lowercase letters, which may be any combination of the three basic components in the same manner as induced terms, such as ll, vl, or tt.

The total interfering field at the sensor can be resolved theoretically into 16 terms comprising three permanent, five induced, and eight eddy-current terms. Generating an opposing field at the detector containing 16 terms, which cancel their interfering counterparts, could eliminate the interference. In practice, not more than nine terms need to be opposed to compensate any aircraft satisfactorily because not all the induced and eddy-current terms are significant.

AN/ASA-65 COMPENSATOR COMPONENTS

AN/ASA-65 magnetic compensator group components involved in the magnetic compensation of the AN/ASQ-81 MAD system include a few system component variations. The basic system contains a control-indicator unit, an electronic control amplifier (ECA), a magnetometer assembly, and compensation coils. However, the upgraded ASA-65(V)4/5 includes the addition of the compensator group adapter (CGA). As you read about the components, refer to figure 2-16 and observe the relationship between the various signals and components involved. Refer to figure 2-17 to see the physical appearance of the components comprising the AN/ASA-65 magnetic compensator group.

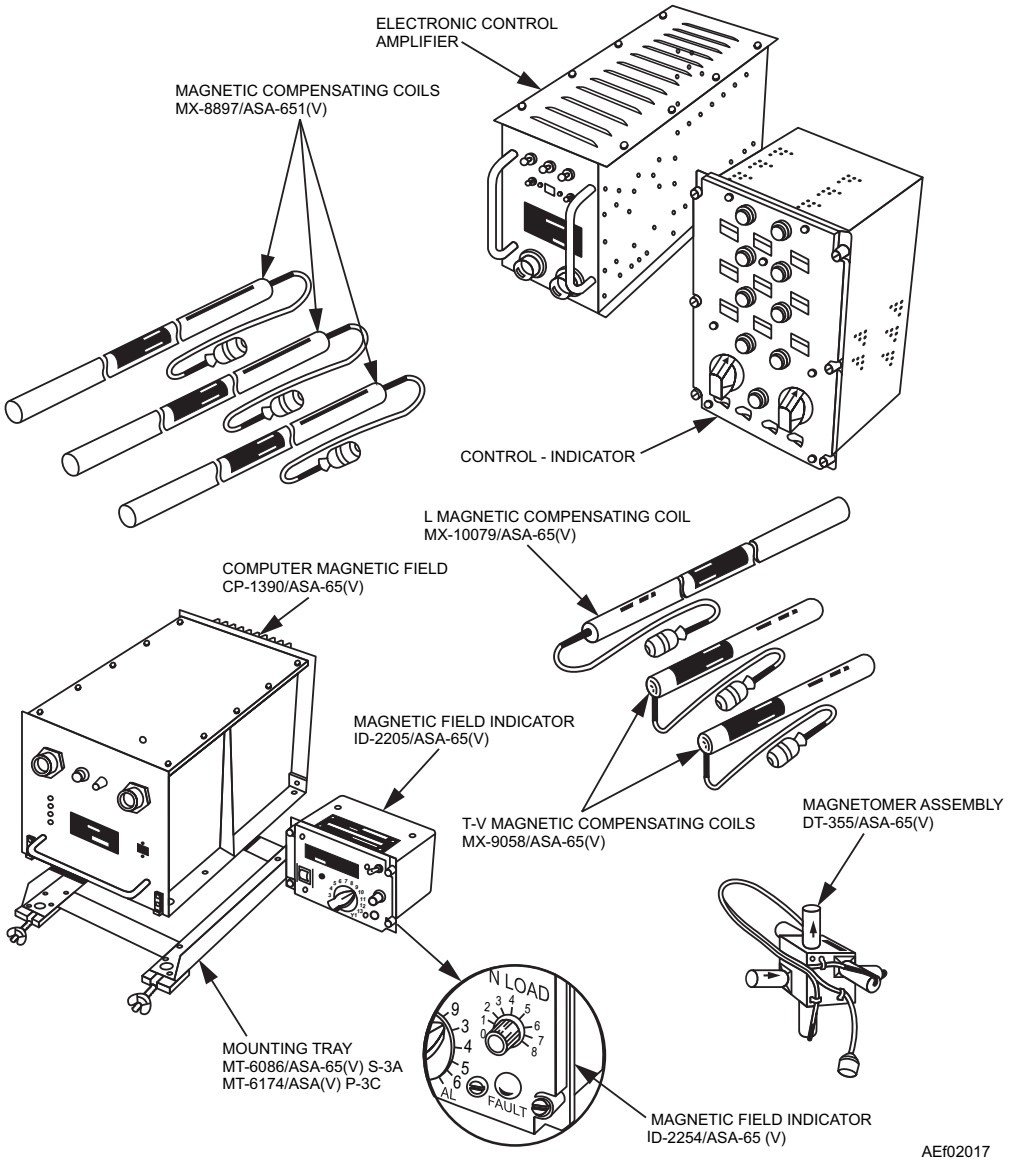


Figure 2-17.—Magnetic compensator groups AN/ASA-65(V)4 and 5.

Control-Indicator Unit

The control unit contains all the controls and indicators required for system operation and all the elements necessary for term adjustment. The control unit provides the operator with a numeric indication of compensation potentiometer position.

Electronic Control Amplifier (ECA)

The ECA processes standard MAD signals from the MAD subsystem, operator compensation adjustments, and maneuver signals from the magnetometer. The ECA provides compensation currents, which are sent to the MAD boom compensation coils. The ECA provides all necessary interconnections and receives all inputs to the system. It converts nine separate term adjustment outputs from the control-indicator to three current outputs, which energize the magnetic compensating coils.

Magnetometer Assembly

The magnetometer contains three coils oriented to sense magnetic strength in each of the basic longitudinal, transverse, and vertical aircraft axes. This results in three output signals, which are sent to the ECA as operating voltages for induced and eddy current compensation. In the upgraded ASA-65(V)4 and 5 configurations, signals also go to the magnetic field computer. The computer calculates the difference value of the terms necessary to reduce the maneuver-related interference to a minimum.

Magnetic Compensation Coils

The L coil, MX-10079/ASA-65(V), and the T and V coils, MX-9058/ASA-65(V), generate magnetic fields that oppose the aircraft-generated noise field for compensation. These fields cancel or minimizes magnetic fields interfering with MAD operation. The coils are located in the MAD boom. When installed, the cable ends of the coils should point to port (T), forward (L), and downward (V). Refer to appropriate MIMs for proper installation and alignment procedures.

ASA-65(V)4 and 5 Magnetic Field Computer

The addition of the CGA completely computerizes the compensation calculation. Compensation is performed simultaneously on all nine terms by performing an aircraft maneuver pattern requiring only a few minutes. The computer provides interconnection between primary components of the CGA and receives 28 analog maneuver signals. These maneuver signals are digitized for data processing to provide light-emitting diode (LED) drive voltages to the magnetic field indicator.

Magnetic Field Indicator

The indicator contains the controls and indicators necessary to operate the CGA to perform semi-automatic compensation. The unit also displays term difference figures, calibration voltages, and BITE codes. The MODE control selects the various operating conditions of the computer.

Q2-11. Magnetic field terms that are designated by two capital letters, such as TT, are what type of terms?

Q2-12. The ECA of the AN/ASA-65 sends compensation currents to what component?

Q2-13. The CGA performs what function?

SUBMARINE ANOMALY DETECTOR (SAD)

LEARNING OBJECTIVE: Recognize the capability and purpose of the ASA-64/ASA-71 (SAD).

SAD works in conjunction with MAD, and increases the capability to detect submarines through evaluating MAD signals and separating submarine anomaly from magnetic noise. SAD also provides audio and visual indications that a submarine type of contact has been made. The ASA-64 SAD system block diagram (fig. 2-18) indicates some of the signal flow and shows some of the typical circuitry within the ASA-64. One of the outputs is a +15 volts dc to the threshold adjust on the C-7693/ASA-71, which then becomes the preset threshold input to the ASA-64 Threshold Detector U3. The system separates the submarine anomaly by selective filtering, full-wave rectification, short-term integration, and correlation of aircraft maneuvers through the recognition and maneuver channels.

The MAD/SAD system interface is accomplished by the AN/ASA-71 selector control group. The group includes the C-7693/ASA-71 selector control panel (A302) and the MX-8109/ASA-71 selector control subassembly (A303). The A302 selector control panel provides controls for operating the A303 selector control subassembly. The A303 receives, processes, and distributes signals between the MAD/SAD system and the central repeater system, ICS, and ADP system.

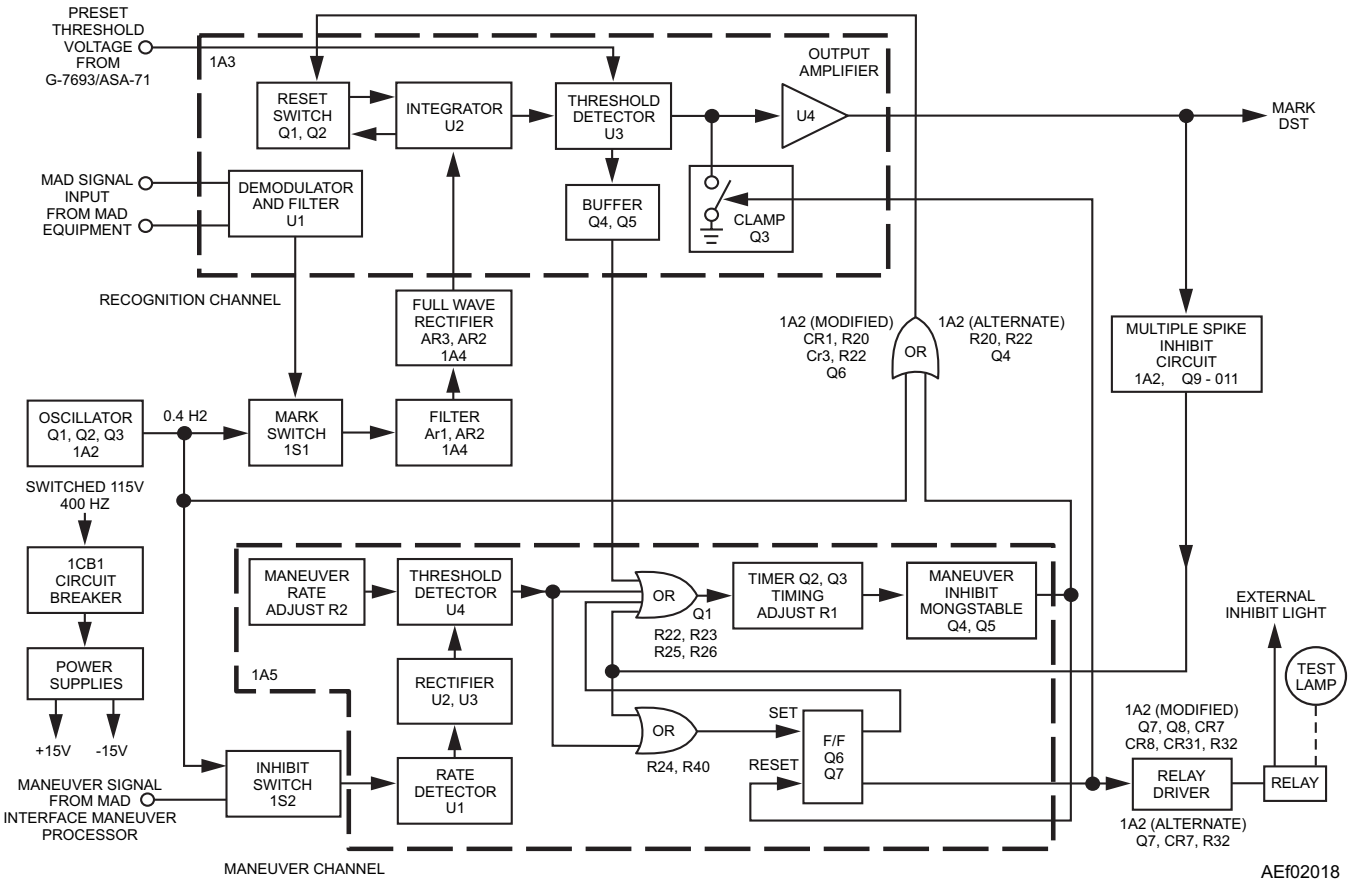


Figure 2-18.—ASA-64 system block diagram.

The A302 selects the signal to be routed through the A303, which is either the AUX, SAD, or MAD signal.

Q2-14. What are the functions of the ASA-64/ASA-71 SAD system?

APPENDIX I

REFERENCES USED TO DEVELOP THIS NONRESIDENT TRAINING COURSE

Although the following references were current when this Nonresident Training Course was published, their continued currency cannot be assured. When consulting these references, keep in mind that they may have been revised to reflect new technology or revised methods, practices, or procedures. Therefore, you need to ensure that you are studying the latest references.

Chapter 1

SH-60F IETM, A1-H60CD-60F-00, Naval Air Technical Data & Engineering Service Command, San Diego, CA, 01 July 1999.

http://sonobuoy.crane.navy.mil/indexhome.htm, Naval Surface Warfare Center Division Crane.

Chapter 2

Integrated Sensor Station 1 and 2—Update III and Block Mod Upgrade Program Wiring Data, *Navy Model P-3C Aircraft*, NAVAIR 01-75PAC-2-15.1, Naval Air Systems Command, Washington, D.C., November 2002.

APPENDIX II

ANSWERS TO REVIEW QUESTIONS

CHAPTER 1

A1-1. The temperature and salinity of the water.

A1-2. It will bend toward the area of cold water.

A1-3. Active sonobuoys.

A1-4. The capability of selecting channel, life and depth settings.

A1-5. Submarine bearing.

A1-6. BT sonobuoys.

A1-7. Sonobuoy bearing information with respect to aircraft heading.

A1-8. The SH-60F.

A1-9. The transducer.

CHAPTER 2

A2-1. Dip angle.

A2-2. The Greek letter γ.

A2-3. Dc circuit noise and maneuver noise.

A2-4. In flight at sea.

A2-5. Metastable energy state.

A2-6. 28.

A2-7. The infrared detector.

A2-8. Six (6) absorption cell/IR detector pairs.

A2-9. A single coaxial cable.

A2-10. The magnetic detector.

A2-11. Induced terms.

A2-12. The ECA provides compensation currents to the MAD boom compensation coils.

A2-13. The CGA calculates compensation data.

A2-14. The ASA-64/ASA-71 SAD system separates submarine anomalies from magnetic noise and provides visual and audio indications that a submarine contact has been made.

ASSIGNMENT 1

Textbook Assignment: "Acoustic Systems," chapter 1, pages 1-1 through 1-22. "Magnetic Anomaly Detection (MAD)," chapter 2, pages 2-1 through 2-17.

1-1. The acronym *sonar* is derived from what words?

1. Sound, navigation, and radar
2. Sound, navigation, and ranging
3. Sound, naval, and radar
4. Sound, naval, and ranging

1-2. A sonar transducer can be compared to which of the following items?

1. Microphone
2. Amplifier
3. Speaker
4. Receiver

1-3. Signal strength lost as sound waves travel through water is known by what term?

1. Saturation
2. Attenuation
3. Radiation loss
4. Transmission loss

1-4. Which of the following sea states causes the greatest amount of absorption?

1. Whitecap waves
2. Large swells
3. Small swells
4. Calm

1-5. Sound waves in seawater travel how many times faster than sound waves in air?

1. 8
2. 2
3. 10
4. 4

1-6. Which of the following sea floor surfaces has the least amount of signal loss?

1. Rocky
2. Muddy
3. Sandy
4. Smooth and hard

1-7. Multiple reflections of a sound wave is referred to by what term?

1. Resounding
2. Reverberating
3. Scattering
4. Rumbling

1-8. Which of the following statements best describes the effect of *divergence* on sound waves?

1. The wave spreads out and becomes weaker with distance
2. The beam converges and becomes stronger with distance
3. The beam divides with distance
4. The beam width remains the same with distance

1-9. What is the most important factor affecting the speed of a sound wave in seawater?

1. Salinity
2. Depth
3. Temperature
4. Frequency

1-10. An increase in the salinity of seawater has what effect on the sound wave?

1. Speed increases
2. Speed decreases
3. Scattering increases
4. Scattering decreases

1-11. According to the Doppler effect, when the source of a sound wave is moving away from the receiver, what apparent change in the sound wave takes place?

1. The intensity increases
2. The wavelength decreases
3. The frequency decreases
4. The frequency increases

1-12. What are the three most common propagation paths for sound waves?

1. Reflective, refractive, and direct
2. Direct, bottom bounce, and reflective
3. Bottom bounce, surface bounce, and reflective
4. Direct, bottom bounce, and convergence

1-13. What is the minimum number of sonobuoys normally deployed during a USW mission?

1. 1
2. 2
3. 3
4. 4

1-14. Acoustic data received from a sonobuoy is transmitted to the sonobuoy receiver using (a) what frequency band, and (b) what type of modulation?

1. (a) VHF (b) FM
2. (a) VHF (b) AM
3. (a) UHF (b) FM
4. (a) HF (b) AM

1-15. Sonobuoys that transmit an acoustic pulse and detect a resulting echo are classified as what type of sonobuoy?

1. Passive
2. Active
3. Ringing
4. Delay

1-16. What are the three methods of deploying a sonobuoy?

1. Pneumatic, free-fall, and cartridge
2. Pneumatic, free-fall, and hydraulic
3. Free-fall, hydraulic, and piston
4. Cartridge, hydraulic, and piston

1-17. Sonobuoy descent-retarding devices are necessary for what reason?

1. To prevent ice build-up
2. To allow electronic circuits to activate
3. To reduce water entry shock
4. To allow visual tracking

1-18. How are sonobuoys activated?

1. Atmospheric pressure switch during descent
2. Saltwater battery activation
3. Command signal from the operator
4. Preset timer

1-19. What happens to the sonobuoy after the battery dies?

1. It sinks to the bottom
2. A recovery pinger activates
3. A recovery float deploys
4. It remains in place and decomposes

1-20. Sonobuoys equipped with an EFS system have what capability?

1. Unlimited battery life
2. Electromagnetic pulse protection
3. Frequency discrimination
4. Selectable channel, life and depth settings

1-21. A LOFAR sonobuoy uses what type of hydrophone?

1. Unidirectional
2. Omnidirectional
3. Hybrid
4. Reactive

1-22. Under most situations, what type of sonobuoy is best for initial detection?

1. DIFAR
2. LOFAR
3. VLAD
4. DICASS

1-23. What information can a DIFAR sonobuoy provide that a LOFAR sonobuoy cannot?

1. Submarine bearing
2. Submarine depth
3. Submarine size
4. Water temperature

1-24. Which of the following sonobuoys is designed for long-range submarine detection in deep water?

1. LOFAR
2. DIFAR
3. VLAD
4. DICASS

1-25. DICASS sonobuoys operate on the same principle as what other electronic system?

1. INS
2. IFF
3. TACAN
4. Radar

1-26. DICASS sonobuoys are commanded to ping by what source?

1. A UHF signal from the USW aircraft
2. A VHF signal from a surface ship
3. A preset timer located within the sonobuoy
4. A range proximity switch located within the sonobuoy

1-27. An EER sonobuoy is typically used in conjunction with what other sonobuoy for long-range detection?

1. DICASS
2. VLAD
3. LOFAR
4. DIFAR

1-28. What are the two special-purpose sonobuoys?

1. BT and DIFAR
2. BT and DLC
3. DLC and DIFAR
4. DLC and LOFAR

1-29. What information does a BT sonobuoy provide?

1. Salinity
2. Pressure versus depth
3. Water temperature at sea surface
4. Water temperature versus depth

1-30. The ARR-78 sonobuoy receiver is capable of simultaneous reception of up to what number of sonobuoys?

1. 5
2. 10
3. 20
4. 99

1-31. The ARR 84 sonobuoy receiver is used in the SH-60 series helicopter for what reason?

1. Accommodation of weight restrictions
2. Rotor nulling circuitry
3. Higher signal to noise ratio
4. Less sonobuoy monitoring requirements

1-32. What component of the sonobuoy-based sonar system extracts acoustic target information from both active and passive sonobuoys?

1. Sonobuoy receiver
2. Power supply
3. Data display
4. Spectrum analyzer

1-33. The OTPI system works in conjunction with what other aircraft system?

1. DF
2. VOR
3. TACAN
4. ACLS

1-34. The OTPI system provides what information to the USW pilot?

1. Distance to the sonobuoy
2. Sonobuoy bearing with respect to true north
3. Sonobuoy bearing with respect to aircraft heading
4. Sonobuoy depth

1-35. Dipping sonar systems use what type of sonar detection?

1. Active only
2. Passive only
3. Active and passive
4. Active and array

1-36. What distinct advantage does a dipping sonar have over a sonobuoy based system?

1. Low operating cost
2. Operator control of the search depth
3. Longer operating time
4. Search area increased

1-37. In addition to active and passive sonar modes, a dipping sonar provides what other information?

1. Water salinity and temperature
2. Water pressure salinity
3. Communications and water temperature
4. Communications and water pressure

1-38. The electrical interface between the sonar set units mounted in the helicopter and the submerged sonar transducer is provided by what component of the ASQ-13F dipping sonar set?

1. Power supply
2. Multiplexer
3. Dome control
4. Sonar data computer

1-39. What unit of the ASQ-13F converts sound energy to electrical signals?

1. Receiver
2. Computer
3. Transceiver
4. Transducer

1-40. A submerged sonar transducer is used to transmit and receive voice signals to and from other USW helicopters, submarines, or similarly equipped surface ships during what ASQ-13F mode of operation?

1. BT
2. UVC
3. Active
4. Passive

1-41. Angles of change in the Earth's natural magnetic field in the east-west direction is known by what term?

1. Dip angle
2. Variation angle
3. Equatorial angle
4. Force angle

1-42. The maximum range at which a submarine may be detected depends on the intensity of its magnetic anomaly and what other factor?

1. The sensitivity of the detector
2. The size of the submarine
3. The salinity of the seawater
4. The temperature of the seawater

1-43. If the detectable strength of a magnetic field source has a given value at a given distance and the distance is doubled, the detectable strength of the source at the increased distance will then be how much of its former value?

1. One-half
2. One-third
3. One-fourth
4. One-eighth

1-44. Any noise or disturbance originating in the aircraft or its equipment that could produce a signal on a MAD equipment recorder is known by what term?

1. Static voltage
2. Magnetic noise
3. Stray voltage
4. Phantom noise

1-45. Maneuver noises caused by eddy current flow can be minimized by taking what action?

1. Making slow aircraft maneuvers
2. Making quick aircraft maneuvers
3. Flying in a circular pattern
4. Flying in a zigzag pattern

1-46. Any magnetic field may be defined in terms of what number of axial coordinates?

1. 1
2. 2
3. 3
4. 4

1-47. What is the purpose of magnetic compensation in USW aircraft?

1. To provide a negative polar coefficient
2. To provide a positive polar coefficient
3. To counteract the Earth's magnetic field
4. To provide a magnetically clean environment

1-48. Compensation for an aircraft's dc magnetic field is accomplished by using how many electromagnetic loops?

1. 1
2. 2
3. 3
4. 4

1-49. The natural spin axis wobble rate of a particular atom is referred to by what term?

1. Deviation frequency
2. Larmor frequency
3. Wobble frequency
4. Carver frequency

1-50. In the ASQ-81 solid-state MAD detector, the energy level of the electrons is increased, and the atoms are properly oriented by what procedure?

1. Polar excitation
2. RF induction
3. Electromagnetic pulsing
4. Optical pumping

1-51. What component or components of a helium magnetometer detect the energy level changes of the helium atoms and produces an electrical output?

1. Absorption cell
2. Helium lamp
3. Infrared detector
4. Excitation coils

1-52. What are the main components of a basic MAD detecting set?

1. Magnetic array, field compensator, and detecting set control
2. Magnetic array, magnetic detector, and detecting set control
3. Magnetic detector, amplifier-power supply, and detecting set control
4. Magnetic detector, magnetic array, and detecting set control

1-53. When maintenance is performed on or near the magnetometer head, what type of tools must be used?

1. Nonferrous
2. Stainless steel
3. Tempered steel
4. Iron

1-54. What is the approximate warm-up time for the AN/ASQ-81 MAD system?

1. 3 min
2. 5 min
3. 7 min
4. 10 min

1-55. What fault indicator on the MAD control box indicates an amplifier failure?

1. 1
2. 2
3. 3
4. 4

1-56. What is the purpose of magnetic compensation?

1. To increase the intensity of the anomaly
2. To match the magnetic field of the aircraft with the anomaly
3. To eliminate the magnetic field
4. To reduce the effects of unwanted magnetic disturbances

1-57. What are the three magnetic fields relative to MAD compensation?

1. Transverse, longitudinal, and vertical
2. Transverse, radial, and polar
3. Radial, longitudinal, and horizontal
4. Horizontal, longitudinal, and vertical

1-58. In practice, how many terms are needed to compensate any aircraft satisfactorily?

1. 16
2. 12
3. 9
4. 3

1-59. The compensator group adapter (CGA) serves what purpose?

1. Allows manual compensation
2. Provides a maintenance interface
3. Allows modules to be interchanged
4. Computerizes the compensation calculation

1-60. What is the purpose of the submarine anomaly detector (SAD) system?

1. Separates submarine anomalies from magnetic noise
2. Replaces the MAD system
3. Automatically identifies friendly submarines
4. Calculates submarine depth