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APOLLO EXPERIENCE REPORT - DEVELOPMENT AND USE OF SPECIALIZED RADIO EQUIPMENT FOR APOLLO RECOVERY OPERATIONS

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16. Abstract

New personal communications equipment was required for the Apollo Program recovery operations. Two new, small, personal radios were developed and used successfully in the Apollo recovery program.

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APOLLO EXPERIENCE REPORT

DEVELOPMENT AND USE OF SPECIALIZED RADIO EQUIPMENT FOR APOLLO RECOVERY OPERATIONS

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SUMMARY

Two specialized, personal radio-equipment items, a survival radio and a swimmer radio, were developed to support Apollo recovery operations. The survival radio is carried on board the command module to provide postlanding voice communications and direction-finding capability if either the command module very-high-frequency/amplitude-modulation transceiver or very-high-frequency recovery beacon cannot be used. Department of Defense swimmer and pararescue personnel participating in Apollo recovery operations are provided with swimmer radios to permit communications among the astronauts, recovery aircraft, and ships before the spacecraft hatch is opened. The development, testing, use, and characteristics of these radios are described in this report.

INTRODUCTION

The requirement for a small, hand-held, battery-operated radio that would provide voice communications and direction-finding signals for situations in which the spacecraft postlanding communications systems could not be used was established during the Gemini Program. Survival radios procured for this purpose were carried on all 10 manned Gemini missions. The age of the Gemini radios caused the requirement for a second-generation survival radio to be established before the operational phase of the Apollo Program; however, flight hardware did not become available until after the Apollo 11 mission. Therefore, Gemini survival radios were carried on the first five manned Apollo missions. Apollo survival radios were used for the remaining Apollo missions and will be used throughout the Skylab Program.

Another type of specialized personal radio was developed for U.S. Air Force pararescue personnel and U.S. Navy underwater demolition team swimmers to provide voice communications with recovery aircraft and ships and the Apollo command module (CM). This radio, subsequently named the Apollo swimmer radio, was developed in time to be used during recovery of the crew and CM of Apollo 7, the first manned Apollo mission. A swimmer interphone that had been developed before the Gemini

Program to provide hardline communications between swimmers and the astronauts before hatch opening was used successfully throughout the Gemini Program and was designed to be compatible with the Apollo CM. However, it became evident during the Gemini Program that the pararescue and swimmer personnel needed the capability to communicate with recovery aircraft, as well as the astronauts, during the recovery operations; therefore, the Apollo swimmer radio was substituted as the primary instrument for swimmer communications.

These two radios and the significant aspects of their development, testing, and use are discussed in this report.

DEVELOPMENT AND USE OF THE APOLLO SURVIVAL RADIO

The Apollo survival radio (fig. 1) requirement was established in 1967 and was based on the following considerations.

1. The reliability of the Gemini survival radios that had been in use since 1964 was questionable.

2. There was no requirement for parts screening and burn-in when the Gemini survival radio was procured.

3. There were not enough Gemini survival radios to support the Apollo and Skylab Programs, and reprocurement would have been almost as expensive as the development of a new radio.

4. The use of advances made in electronics since 1963 would provide a radio with improved performance and reduced size and weight.

The specification for the Apollo radio required several improvements over the Gemini radio. The major improvements are given in table I.

In addition to these improvements, a meter was installed to enable status monitoring of the battery, transmitter, and modulator (fig. 2). Also, 100-percent parts screening and burn-in were required.

Figure 1.- Apollo survival radio and battery pack.

TABLE I. - APOLLO RADIO IMPROVEMENTS

Characteristics	Gemini radio	Apollo radio
Receiver sensitivity, μV	7.5	3.0
Receiver bandwidth, MHz		
6 dB points	±1.5	[a]±150
60 dB points	±9.0	±1.0
Modulation, percent	25	100
Duty cycle, percent	40 (2 sec on, 3 sec off)	100
Tone	Fixed (1000 Hz)	Swept (1000 Hz to 300 Hz, 2.5 times/sec)
Voice modulation sensitivity (for normal voice), percent	10	100
Speaker sound-level output, dB . . .	103	118

[a]Kilohertz.

The contract, awarded in April 1968, called for production of 2 prototype radios, 3 first-article radios, 30 flight radios, and 6 training radios, as well as battery packs and battery testers. The initial design phase was completed in 4 months, and the prototype radios and batteries were delivered before the end of the year.

Operational tests of the prototype hardware consisted of voice- and beacon-ranging runs using an HC-130 aircraft with the radio being operated both from a liferaft (through the radio antenna) and from the Apollo CM test vehicle CM-007A (through the test-vehicle antenna). The quality of the radio transmitter and the receiver was excellent, and good beacon and voice ranges were attained. The prototype receiver had a partial-squelch circuit that was evaluated during this test. As a result of the test, the partial squelch was deemed undesirable for the planned application of the survival radio. The presence of receiver noise is more desirable than the lack of it when a person is in a spacecraft or liferaft awaiting rescue. Also, the receive range was extended by disabling the partial-squelch circuit. Thus, the partial squelch was deleted from the design requirements.

After the operational testing was completed, a battery-life test was conducted that revealed the first problem. The minimum battery life was specified to be 24 hours, but the life recorded during the test was 13 hours. An investigation revealed that the radio, when connected to its antenna, was drawing as much as twice the normal amount of current, depending on its proximity to other objects. The current drain was

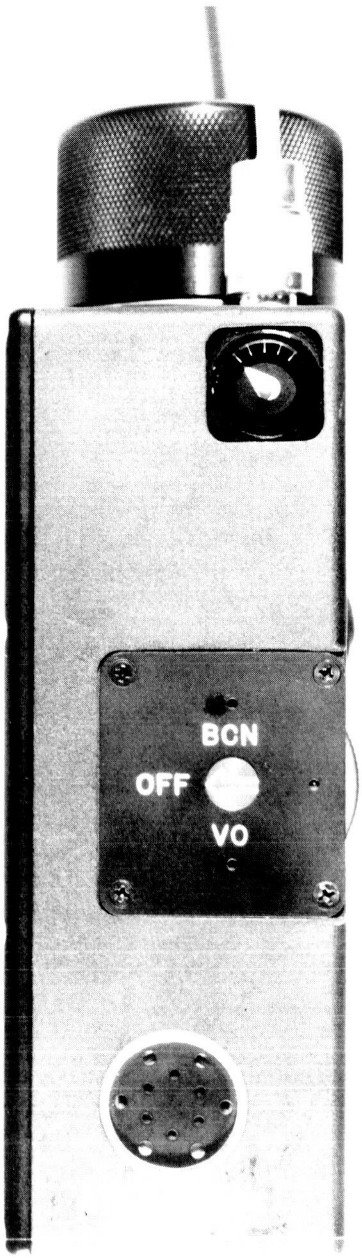

Figure 2.- Side view of Apollo survival radio.

proportional to the voltage standing wave ratio (VSWR). This was the result of the following two factors.

1. To meet the VSWR requirements of 1.5:1 or less and to make accurate VSWR measurements, the manufacturer designed the antenna so that it was connected to a large ground plane.

2. The radio transmitter contained a power-leveling circuit designed to maintain a controlled power output over the range of battery voltages encountered during the life of the battery. When the antenna was connected to the radio, the result was a fairly high VSWR that fluctuated to a large degree, depending on the location of the radio with respect to other objects. When the power-leveling circuit sensed a high VSWR, it reacted by increasing the power output of the transmitter, thereby creating a high current drain.

Extensive studies were conducted at the Lyndon B. Johnson Space Center (JSC) and by the manufacturer to resolve this problem. A solution was attained by redesigning the antenna using relative field-strength measurements made with the antenna connected to the radio. Accurate VSWR measurements are difficult to make with the antenna connected to the radio, but the optimized antenna has a VSWR in the range of 1.5:1. The VSWR is also quite stable with respect to changes in the location of surrounding objects.

As soon as the antenna design was finalized, first-article radio fabrication was initiated. A new technique was developed during the fabrication phase of the contract. Instead of potting the components on the circuit boards to meet the shock and vibration requirements, a method of applying a cellulose acetate covering was developed. The acetate is applied in a sheet form while hot and then drawn over the components by the use of a vacuum. The result is a thin, transparent coating that conforms to the shape of the various components (fig. 3). This method has advantages over potting. For example, retuning or component replacement are simplified because all the components are visible.

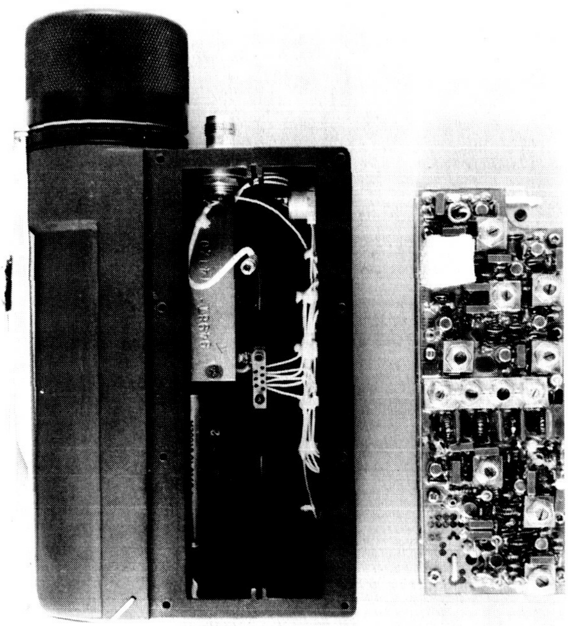

Figure 3.- Apollo survival radio with electronic assembly removed.

Waterproofing was another important aspect of the radio design. Because of the possible use of the radio in a liferaft under open-ocean conditions and because the radio can be tied to the raft by a lanyard (thereby making it possible to retrieve the radio if it falls overboard), the specification required that the radio be waterproof to a depth of 15 feet in seawater. The radio case was designed to be an investment casting with a removable back cover to permit access to the electronic components. The design also incorporated a threaded cap to allow removal and replacement of the battery pack. The possible areas where leaks could occur and the methods by which these areas were sealed are as follows.

1. The back cover was machined, and a Parker seal was installed in it (fig. 4).

2. An O-ring seal was provided for the battery cap.

3. The push-to-talk switch was installed in a waterproof housing as procured (fig. 5). The switch was secured by a plate inside the radio, and a commercial potting compound was placed around the edges.

4. The meter was waterproof as procured and was sealed from the inside of the case with an epoxy resin.

5. The function switch had magnetic-reed switches; therefore, no holes through the case were required.

6. As procured, the antenna connector was a waterproof type with an O-ring seal.

7. The speaker microphone was fastened in place from inside the case with an epoxy resin. The unit itself was waterproof as procured. A proprietary sealing method is used such that a diaphragm installed over the transducer has a porosity that allows the passage of air but not water molecules.

After delivery of the first-article units, operational tests were conducted again, and acceptable results were obtained. Unit ranges were 195 nautical miles for the beacon and 120 nautical miles for the two-way voice operating either from a liferaft or from CM-007A in conjunction with direction-finding and voice equipment on board an HC-130 aircraft flying at 25 000 feet. In addition to the operational testing, a 150-hour reliability demonstration/life test on two radios was conducted successfully by the manufacturer. During this test, battery-life ranges from 27 to 30 hours were achieved.

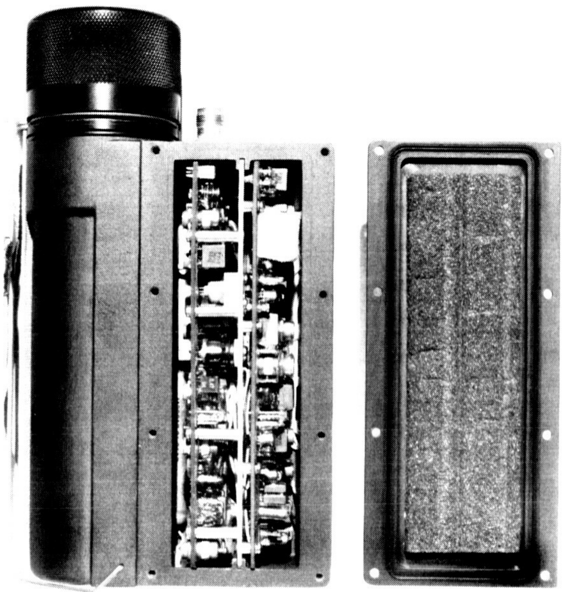

Figure 4.- Apollo survival radio with electronics compartment cover plate removed.

Figure 5.- Front view of Apollo survival radio.

The first-article units qualified on all but the water-immersion tests. An extensive analysis of water leakage revealed that too many threads had been machined on the battery cap, thereby destroying the integrity of the O-ring seal. A qualification test was performed using properly machined battery caps, and no problems were encountered. Production was initiated, and an expedited delivery schedule enabled the first radio to be used on Apollo 12 and the second radio to be used on Apollo 13. All subsequent Apollo missions were supported with this type radio, and the Skylab missions will also be supported in this manner.

DEVELOPMENT AND USE OF THE APOLLO SWIMMER RADIO

The requirement for the Apollo swimmer radio (fig. 6) developed because voice communications were needed among U.S. Air Force pararescue personnel, U.S. Navy swimmers, fixed-wing aircraft, helicopters, ships, and the CM during recovery operations. A swimmer interphone had been developed before the Gemini missions to provide hardline communications between the swimmers and the astronauts during the period of recovery operations before hatch opening. This device was used successfully throughout the Gemini Program. However, during the Gemini Program, the necessity to develop the capability for communications among all personnel involved with CM recovery became evident.

Figure 6.- Apollo swimmer radio, battery pack, and flotation bag.

Before the development of the Apollo swimmer radio, the U.S. Air Force pararescue personnel had carried their own radios (URC-59) in addition to the swimmer interphone. This radio was not compatible with the CM frequency and could only provide communications between the swimmers and the aircraft. Numerous failures also were caused by water leakage.

At the time the requirement for the Apollo swimmer radio became firm, a thorough survey of existing equipment was conducted. Two new personnel radios being developed for the military could, with certain modifications, satisfy the Apollo Program requirements. A modified version of the AN/PRC-90, manufactured for the U.S. Navy, would meet Apollo requirements and permit delivery in time to support the Apollo 7 mission.

The AN/PRC-90 is a small (24 ounce) two-channel radio/beacon transceiver that provides voice transmit/receive capability on 243.0 and 282.8 MHz and emergency beacon transmit on 243.0 MHz. This radio also had been qualified for more stringent shock and temperature environments than the Apollo Program required. Most important, however, it had been immersed to a depth of 50 feet in seawater without leaking. To satisfy the Apollo requirements, the radio would have to be modified to provide both voice transmit/receive on 282.8 and 296.8 MHz and emergency beacon transmit on 282.8 MHz. Preliminary testing verified that the power output and battery life of the AN/PRC-90 satisfied the Apollo Program needs and were acceptable.

Because of the requirement for the 296.8-MHz frequency, it was initially thought that the microcircuits used in the AN/PRC-90 (fig. 7) would need to be completely redesigned. However, it was determined that with a few component changes and some retuning, the 282.8-MHz microcircuit could be converted to the 296.8-MHz frequency. The only other problem that had to be solved was impedance matching of the transmitters and receivers to the antenna. The impedance of the AN/PRC-90 had been optimized at 243.0 MHz. The antenna had an impedance of 90 ohms at 282.8 and 296.8 MHz as opposed to 50 ohms at 243.0 MHz. To solve this problem, the 50-ohm coaxial cable and matching network (internal to the radio) was replaced with a 90-ohm coaxial cable and matching network.

Laboratory checkout, an operational test, and a battery-life test were conducted on the first Apollo swimmer radio as soon as it was received in August 1968, and the results of all the tests were excellent. All input and output parameters, as checked in the laboratory, met specifications. The battery life was determined to be approximately

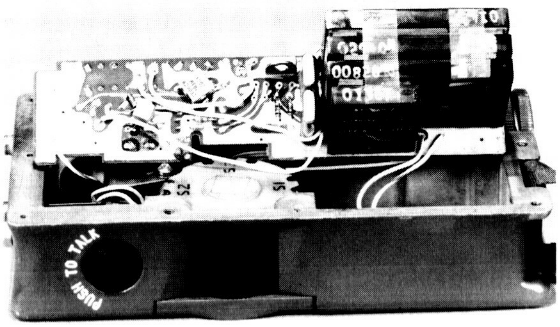

Figure 7. - Apollo swimmer radio with electronics assembly partially removed.

18 hours, which was quite satisfactory. Voice- and beacon-ranging runs were made using an airborne HC-130 aircraft with the radio being operated from a liferaft in the Gulf of Mexico. On the 296.8-MHz frequency, two-way voice ranges of 28, 42, and 67 nautical miles were obtained with the aircraft at altitudes of 1500, 5000, and 10 000 feet, respectively. Immersion tests to 40 feet in the Gulf of Mexico were conducted as part of the operational test, and there were no leaks. Some of the waterproofing techniques used on this radio represented a technological advance in the sealing of emergency radios. The AN/PRC-90 was the first multichannel radio/beacon transceiver to operate reliably from the ocean surface after repeated immersions. Three of the major factors that contributed to the successful waterproofing of this radio were as follows.

1. The use of a machined back cover plate containing a Parker seal (fig. 8) in conjunction with a cast-aluminum case.

2. A function switch with magnetic-reed switches (thereby making it unnecessary to have a hole through the case for the function switch)

3. A special speaker/microphone with a protective membrane that will allow the passage of air but not water molecules.

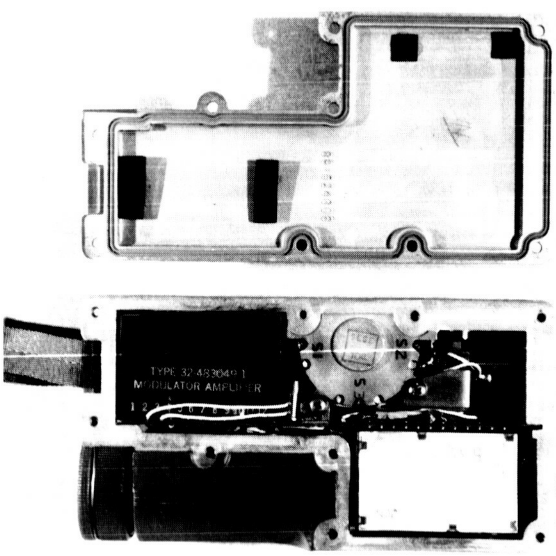

Figure 8.- Apollo swimmer radio with electronics compartment cover plate removed.

These three factors proved to be so successful that they were also incorporated in the Apollo survival radio design.

A sufficient number of swimmer radios were received in time to support the Apollo 7 recovery, and these radios were used to support all subsequent Apollo recoveries. During initial operational usage, the following four problems developed.

1. The mercury-cell battery packs frequently leaked electrolyte. (The Navy also was having this problem with their AN/PRC-90 battery packs.) The battery pack manufacturer redesigned the mercury cell to correct the problem. The redesign was successful, and no problems with the new battery were encountered during 1 year of use.

2. Because the radio normally does not float, two units were lost by swimmers during the first few months of use. To correct this, a brightly colored flotation bag was designed that completely encloses the radio and allows the swimmer to attach the bag/radio package to himself by a lanyard (fig. 9). When the swimmer needs the radio, he removes it from the bag. The radio stays attached to the bag throughout the operation. The bag/radio configuration worked quite well.

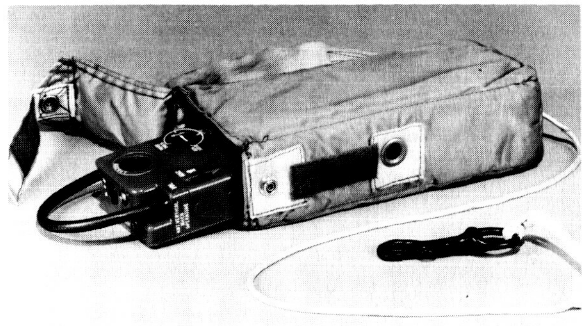

Figure 9. - Apollo swimmer radio partially inserted in flotation bag.

3. The antenna, which consisted of coaxial shield braid over a coiled spring covered with a silicone-rubber tube (sealed at both ends), occasionally leaked saltwater. Investigation revealed that the radios were subjected to much rougher treatment during operational use than was anticipated originally. As a result, the silicone-rubber covering was punctured and torn, allowing saltwater to leak in and ruin the antenna. When the flotation bags were put into use, the antenna situation was improved to some extent because the bag provided protection for the antenna. To ensure reliability, however, it was necessary to find a tougher covering for the antenna than the silicone rubber. After investigating several different materials and methods of application, Tygon tubing was selected.

4. Although no failures occurred during mission operations, a large number of transmitter and receiver failures (22 of 90 radios) were discovered during bench checkout, in the field, and at JSC. Failure analysis revealed that two crystals were coming loose because the 90-ohm matching coaxial cable (which had a fairly large diameter for the space available) was putting pressure on the crystals. Because an antenna modification was necessary, the 90-ohm coaxial cable was replaced with a 50-ohm coaxial cable that had a much smaller diameter, the 90-ohm matching network was replaced with a 50-ohm matching network, and the antennas were trimmed so that they would have an impedance of approximately 50 ohms at 282.8 and 296.8 MHz instead of 90 ohms.

CONCLUDING REMARKS

Although certain problems with the Apollo swimmer radio were experienced, no failures occurred during mission operations, and both the Apollo survival radio and the Apollo swimmer radio have provided satisfactory results. After the minor modifications required for the swimmer radio were incorporated, this radio was trouble free. Both types of radios have proved to be more than capable of performing the jobs for which they were intended.

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