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DEVELOPMENT OF THE RADAR BEACON AN/DPN-3 (XB-1) FOR USE WITH THE LARK MISSILE

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DEVELOPMENT OF THE RADAR BEACON AN/DPN-3 (XB-1) FOR USE WITH THE LARK MISSILE

Charles R. Ahern

July 20, 1948

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Approved by:

Mr. H. L. Flowers, Head, Command and Report Links Section
Dr. R. M. Page, Superintendent, Radio Division III

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ABSTRACT

The Radar Beacon AN/DPN-3(XB-1) is an ultra-small S-band beacon especially designed to provide range extension and thus permit the tracking of the KAY-1 and KAQ-1 missiles to greater ranges than permitted by radar reflection. The beacon weighs 3 pounds and 10 ounces, less batteries. Present battery weight is 4 pounds for 30-minute operation. The beacon is packaged in three separate units and the batteries in an additional three units. The transmitter or receiver can be used with other equipments to avoid excessive duplication of equipment within the missile. The beacon has been tracked to a range of 208,000 yards using a modified radar SCR-584 and is designed to operate with the radars SP, SP-1M, or the SCR-584, although its operation is not restricted to these equipments. The receiver sensitivity is greater than 5×10^{-8} watts and the transmitter pulse power output is greater than 75 watts.

PROBLEM STATUS

This development completes one phase of the problem. Work will continue toward improvements for this and similar equipments as a part of the long range plans of this activity.

AUTHORIZATION

NRL Problem No. R05-16D.

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DEVELOPMENT OF THE RADAR BEACON AN/DPN-3(XB-1) FOR USE WITH THE LARK MISSILE

INTRODUCTION

When radar tracking and calculations of the reflection cross section of the XSAM-2 and XSAM-4 missiles showed that the missiles could not be tracked by radar echo to the range required for the development of the missile guidance equipment, the development of the Radar Beacon AN/DPN-3(XB-1) was undertaken in April 1947. This beacon was to serve as an instrument to provide tracking range extension when used with the radar equipments SP, SP-1M, or SCR-584. Of course the use of the beacon provides the obvious advantages of freedom from ground or sea clutter and, in addition, eliminates the possibility of tracking the launching boosters instead of the missile at the time of booster separation.

Because of the stringent space requirements within the missile, it was decided to employ subminiature tubes wherever possible and to adjust the form factor of the components of the beacon so that they could be installed within the forward wings of the missiles. Therefore, the transmitter and receiver were packaged separately. This also permits their use with other equipments. Thus another receiver within the missile could be employed to trigger the transmitter, or the receiver could be used to trigger some existing transmitter thus avoiding excessive duplication of equipment in the missile.

CHARACTERISTICS OF THE BEACON

The receiver is of the crystal-video type and has a sensitivity in excess of 5×10^{-8} watts. The transmitter tube is a type 2C40 and transmits 0.6-microseconds pulses of greater than 75 watts peak. By selecting tubes it is possible to maintain the transmitter power output at 250 to 300 watts peak. The transmitter generates single pulses only, with no provision for range coding. Figure 1 shows the beacon with interconnections between the various units. The weight of the beacon is three pounds and ten ounces, less batteries. The total weight including batteries is seven pounds, ten ounces.

RECEIVING SYSTEM

The receiving system consists of the following:

a) Receiving antenna

b) RF transmission line

c) Detector-Filter cavity - TN-144(XB-1)/DPN-3

d) Crystal video receiver - R-255(XB-1)/DPN-3

e) Receiver plate-bias battery pack - BA262(XB-1)/U

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The RF transmission line employed is either RG-9/U or RG-5/U with type "N" connectors. The RG-9/U cable is preferred where space permits.

Experience with the tracking of airborne beacons with automatic tracking radars has indicated that some means must be employed to keep other radars in the area from interfering with the automatic tracking radar-beacon operation. The interference arises from the fact that after the beacon has been interrogated it is "dead" for a certain length of time before the circuits have recovered sufficiently so that it can be interrogated again. Therefore, if a pulse from any interfering radar reaches the beacon just before the pulse from the tracking radar, the tracking radar will not receive a reply from the beacon. This can cause serious interference with the tracking radar or complete loss of the beacon by the tracking radar. Several methods have been employed to avoid this difficulty, and among these are RF filters and interrogation coding. The AN/DPN-3 employs an RF filter to reduce the RF passband over which the receiver is sensitive.

The filter cavity is a three-quarter-wave coaxial cavity which has a crystal holder built into the output loop as shown in Figure 2. The cavity is tuned by adjusting the length of the center post and is tuneable over the range of 2650 Mc to 2950 Mc. The loops coupling into and out of the cavity are adjusted in size so that the loaded Q of the cavity is approximately 560, which corresponds to a half-power bandwidth of 5 Mc. The unloaded Q is kept as high as possible to reduce the cavity losses. The output of the cavity is connected to the crystal video receiver by means of a short length of RG-58/U cable. In the event that it is desirable for the beacon to reply to any interrogation in the RF band, a broadband crystal holder having a bandwidth of 100-300 Mc may be used in place of filter cavity.

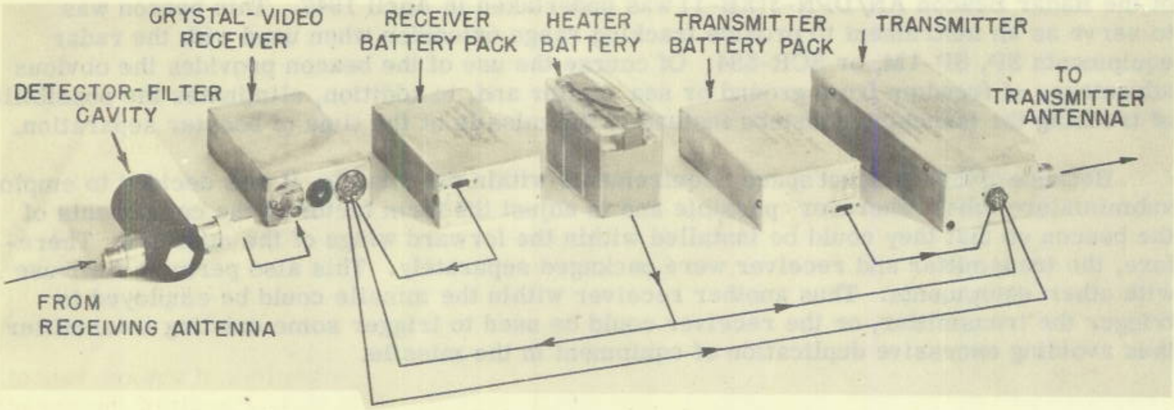

Fig. 1 - AN/DPN-3 (XB-1) Showing connections between units

CRYSTAL VIDEO RECEIVER

The output of the detector-filter cavity is in the form of short video pulses which are applied to the input of the crystal video receiver. This receiver (Figure 3) consists of a video amplifier, grasscutter, limiter, driver, and blocking oscillator. The video amplifier consists of two inverse feedback pairs coupled by a short time constant coupling to a fifth stage. The frequency response of the video amplifier is shown in Figure 4.

The video amplifier has a gain of about 70 db. The sixth or "grasscutter" stage is a cathode biased amplifier which permits adjustment of the threshold of operation.

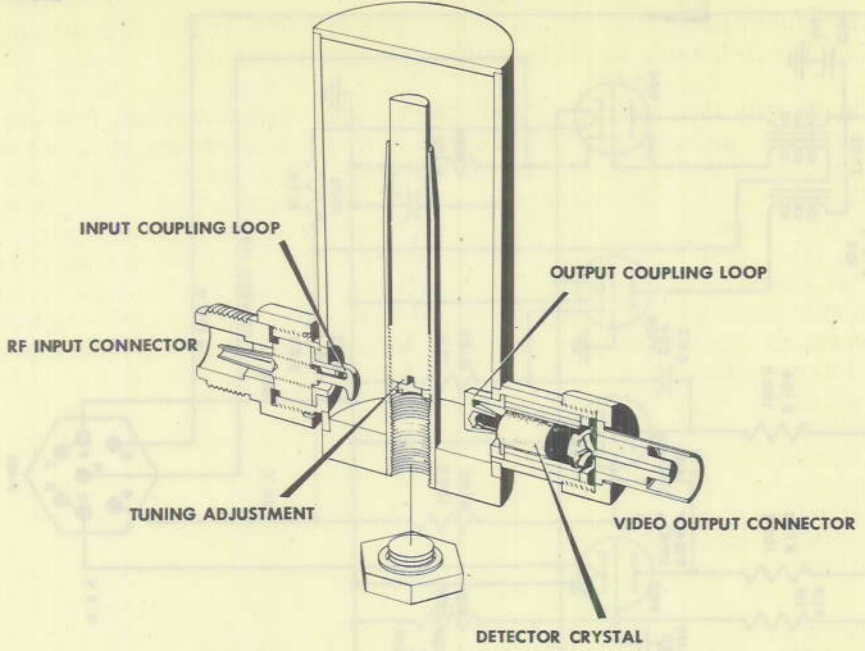

Fig. 2 - Detector filter cavity

One of the performance requirements of the beacon is that the variation of internal delay be held to a minimum. The internal delay of such a beacon can be considered to be of two parts: a fixed delay which can be compensated for at the ground station, and a variable delay due to change in signal strength. The overall fixed delay of the AN/DPN-3 is of the order of .85 microsecond. Figure 5 shows the reduction of the variation of beacon receiver delay as a function of input signal for the receiver when the blocking oscillator is driven by V108 instead of V106.

The grid of the seventh stage is connected to B+ to reduce the effect of any overshoot on the negative signal applied to the grid. The time constant of the plate circuit of the seventh stage is such as to provide the output with a nearly constant slope with change of amplitude of the input signal. This output, amplified by the eighth stage, drives the blocking oscillator. This results in a reduction of the variation of internal delay with signal strength. In order to reduce the variation of internal delay of the receiver with battery voltage, the bias battery is loaded by R-127 and R-128 to provide compensation for the variation of internal delay with plate and heater battery voltage changes as shown in Figure 6. (The abscissa is linear with time and actual supply voltages are shown.)

The output of the crystal video receiver is used to trigger the transmitter. The use of a coaxial cable to transmit the positive pulse from the grid of V-110 to the transmitter located several feet away within the missile was impractical because the poor impedance match was found to upset the operation of the blocking oscillator. Therefore a low impedance output was employed by taking the current pulse of the blocking oscillator across R-129. This provides a positive pulse, as shown in Figure 7, of 20 to 30 volts amplitude depending upon the plate battery voltage.

The receiver is constructed upon a chassis of polystyrene. Its construction is unique because the leads of the components were employed as terminal lugs and the use of insulated wire was practically eliminated. This style of construction was employed with a view to

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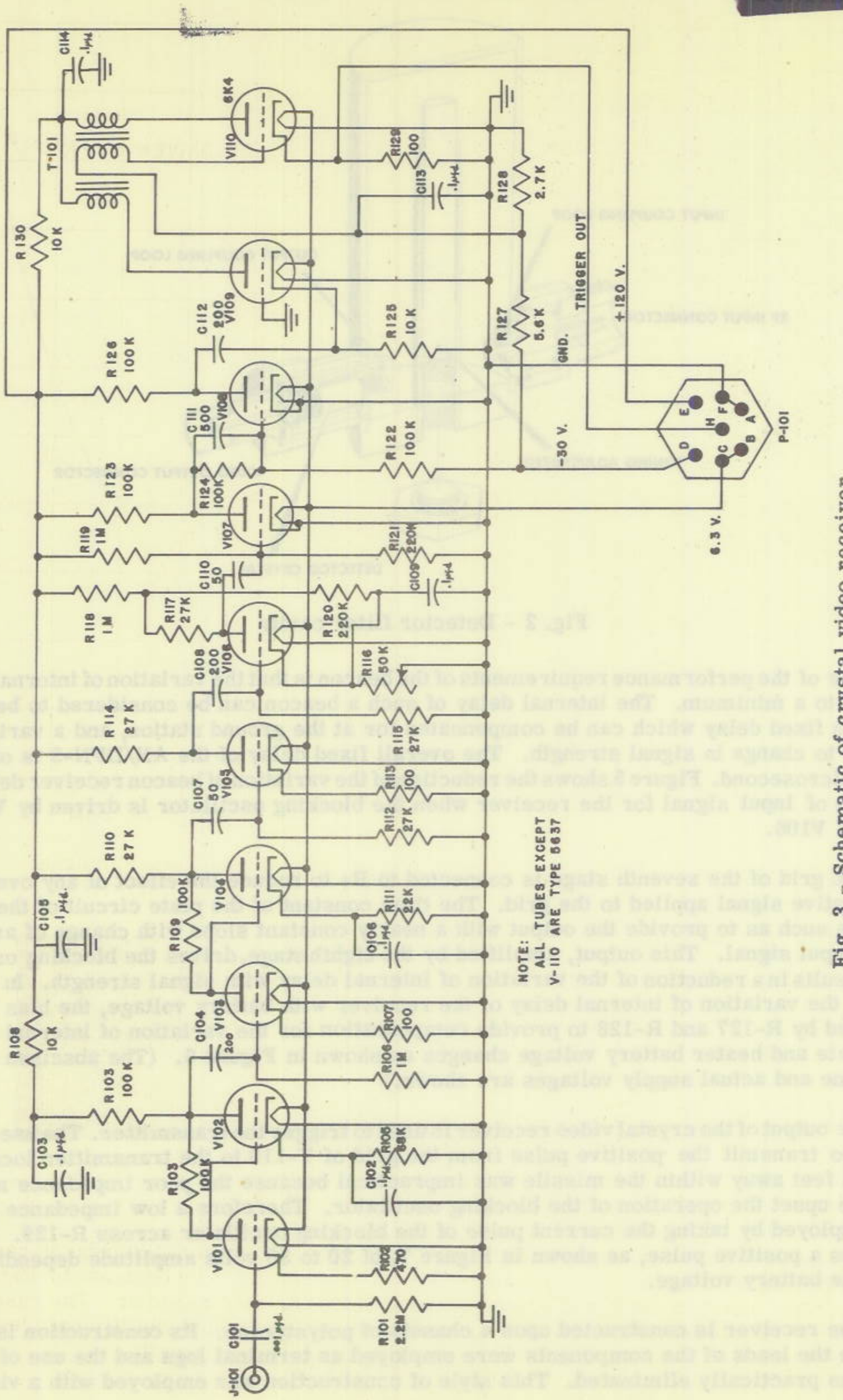

Fig. 3 - Schematic of crystal video receiver

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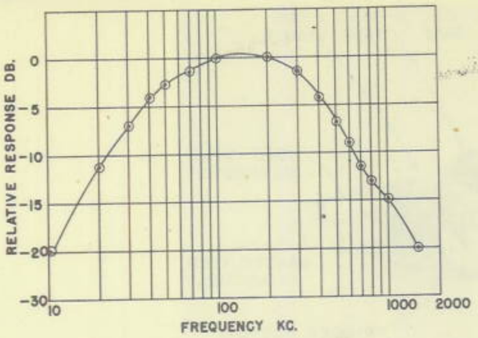

Fig. 4 - Frequency response of receiver video amplifier

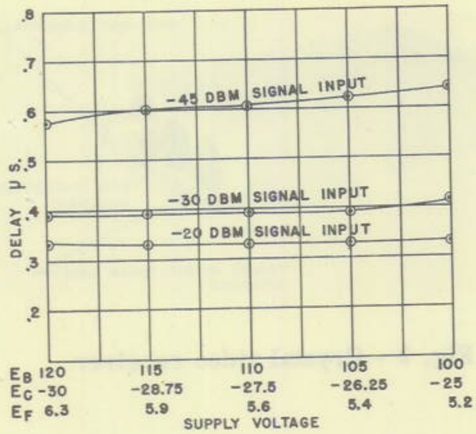

Fig. 6 - Receiver internal delay vs battery voltage

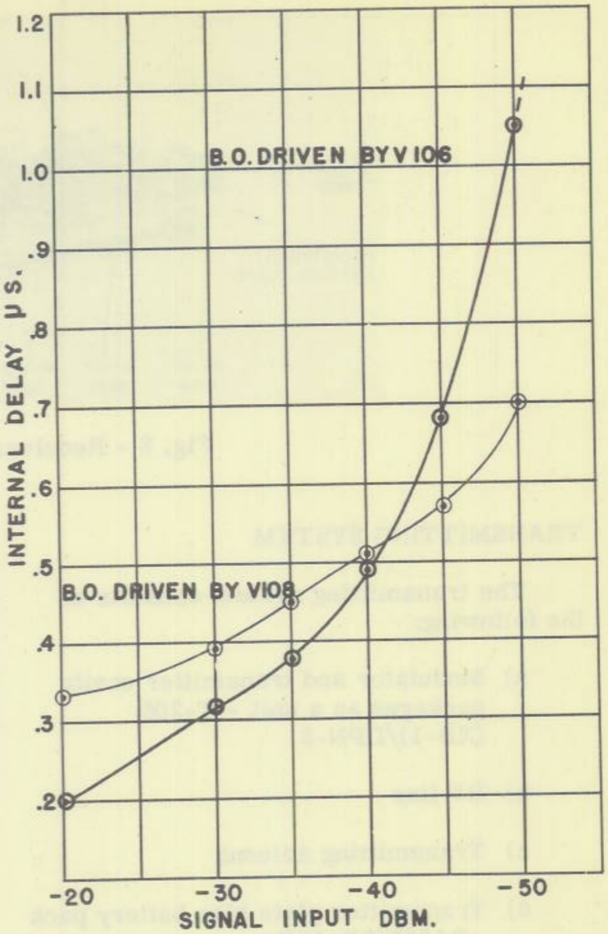

Fig. 5 - Receiver internal vs input signal

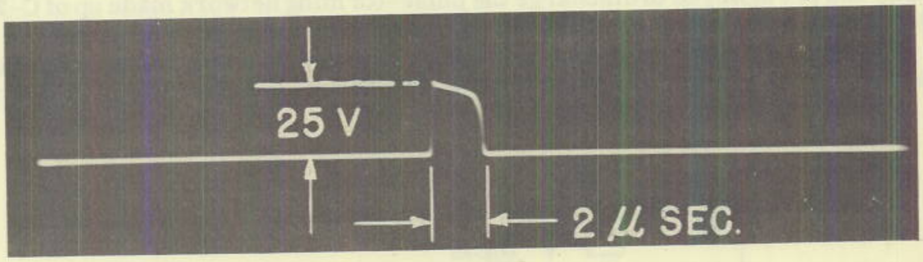

Fig. 7 - Receiver output pulse

potting the receiver in a casting resin. Both the National Bureau of Standards casting resin and Paraplex P-13 made by the Resinous Products Company have been used. Figure 8 shows the receiver before casting and Figure 9 shows the completed receiver. The case is cadmium-plated thin sheet steel. The receiver weighs one pound and it measures 2-7/8 inches in width, 1-1/8 inches in thickness, and 4-7/8 inches in length.

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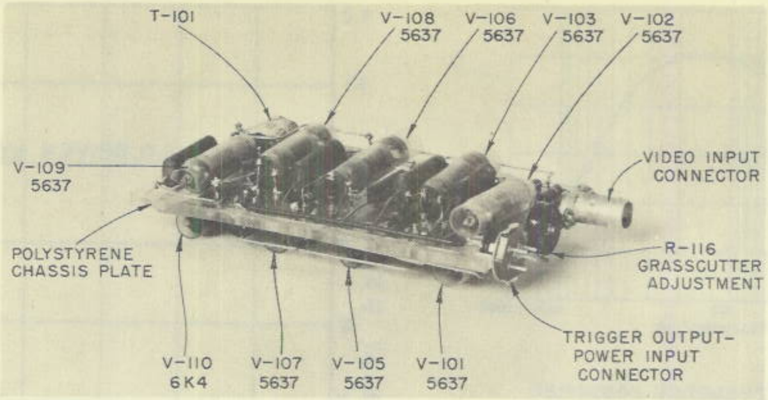

Fig. 8 - Receiver before casting

TRANSMITTING SYSTEM

The transmitting system consists of the following:

a) Modulator and transmitter cavity packages as a unit - T-206 (XB-1)/DPN-3

b) RF line

c) Transmitting antenna

d) Transmitter plate bias battery pack -BA263(XB-1)/U

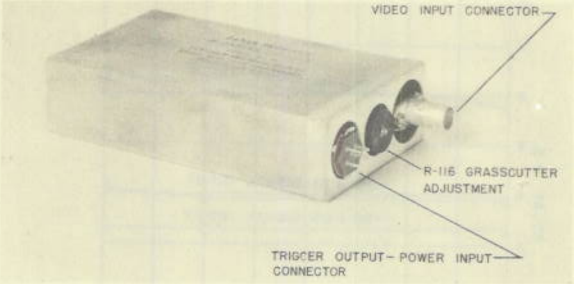

Fig. 9 - Crystal video receiver

The modulator employed in the transmitter is of the gas-tube pulse-forming-network type and a schematic of the transmitter is shown in Figure 10. This gas-tube, V-201, is a type 2D21 and is employed to discharge the pulse-forming network made up of C-201, C-202 and L-202 through the primary of the output pulse transformer. To permit the use of lower voltage batteries, the pulse-forming network is charged between pulses by means of a dc resonance charging system which includes L-201 and V-202. The use of V-202 as a hold-off

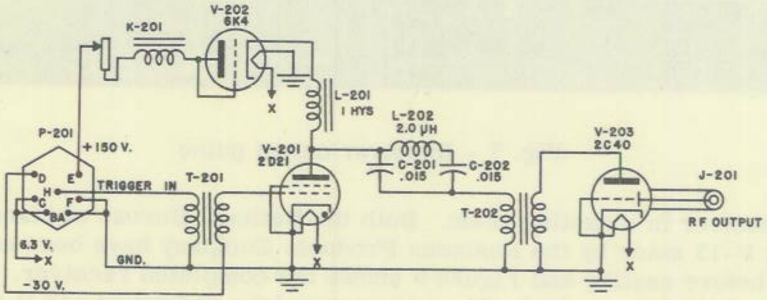

Fig. 10 - Schematic of transmitter

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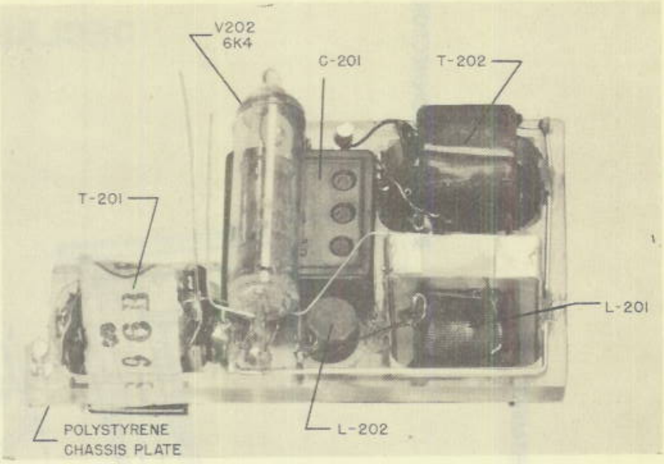

Fig. 11 - Modulator before casting

diode avoids the dependence of power output upon pulse rate and permits the pulse-forming network to be held at nearly twice the plate battery voltage. The overload relay K-201 is employed as a safety device to open the plate supply lead in the event the grid of the 2D21 should lose control. This happens when the beacon is overinterrogated so that the 2D21 deionization time is longer than the time between successive pulses. If this occurs and the gas tube continues to conduct, the current through the relay coil would be sufficient to open the relay contacts thus removing the voltage on the plate of the tube and permitting the grid to regain control. The gas tube is biased at -30 volts and is triggered by the output of the receiver through the step-up pulse transformer T-201. The use of a pulse of large amplitude from the pulse transformer to trigger the 2D21 seems to avoid the change of internal delay with different tubes. The modulator is constructed in a manner similar to the receiver, i. e., the components are mounted upon a polystyrene plate which is placed in a sheet-steel container and the casting resin added. Figure 11 shows the modulator before casting and Figure 12 shows the completed modulator unit. The transmitter tube V-203 (Figure 10) is a 2C40 planar grid triode. The transmitter cavity is of the conventional reentrant design as shown in Figure 13. There is one significant change in the cavity design, namely, the output connector. This has been redesigned to provide a smooth output coupling adjustment and to avoid the use of flexible cable within the transmitter unit.

The transmitter tuning mechanism has been redesigned to permit tuning of the transmitter from the socket end of the cavity. The transmitter tube is plate pulsed as shown in the schematic diagram, Figure 10. The waveform of the pulse is shown in Figure 14. No attempt was made to improve the pulse shape but rather the spectrum of the output RF pulse was used as the criterion of performance. A typical spectrum is shown in Figure 15. Selection of 2C40s permits the peak power output of the transmitter to be 250 to 300 watts.

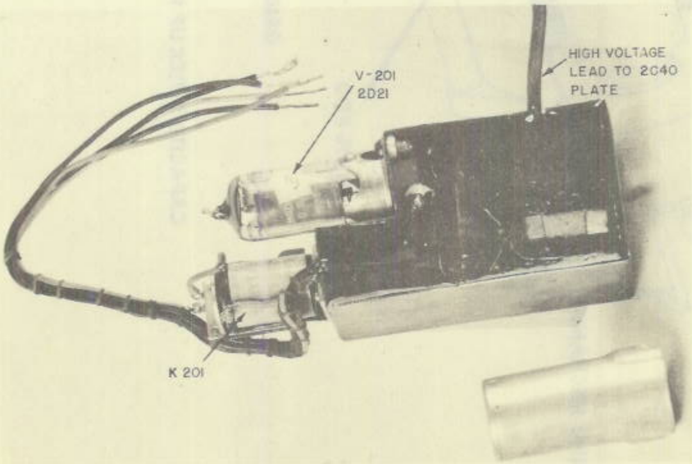

Fig. 12 - Modulator

The transmitter unit (Figure 16) is packaged in a light-weight steel case which is not pressurized since it is not expected that the unit be operated above 25,000 feet. The complete transmitter unit weighs two pounds and one ounce.

POWER SUPPLY SYSTEM

The power supply system employed in the AN/DPN-3(XB-1)

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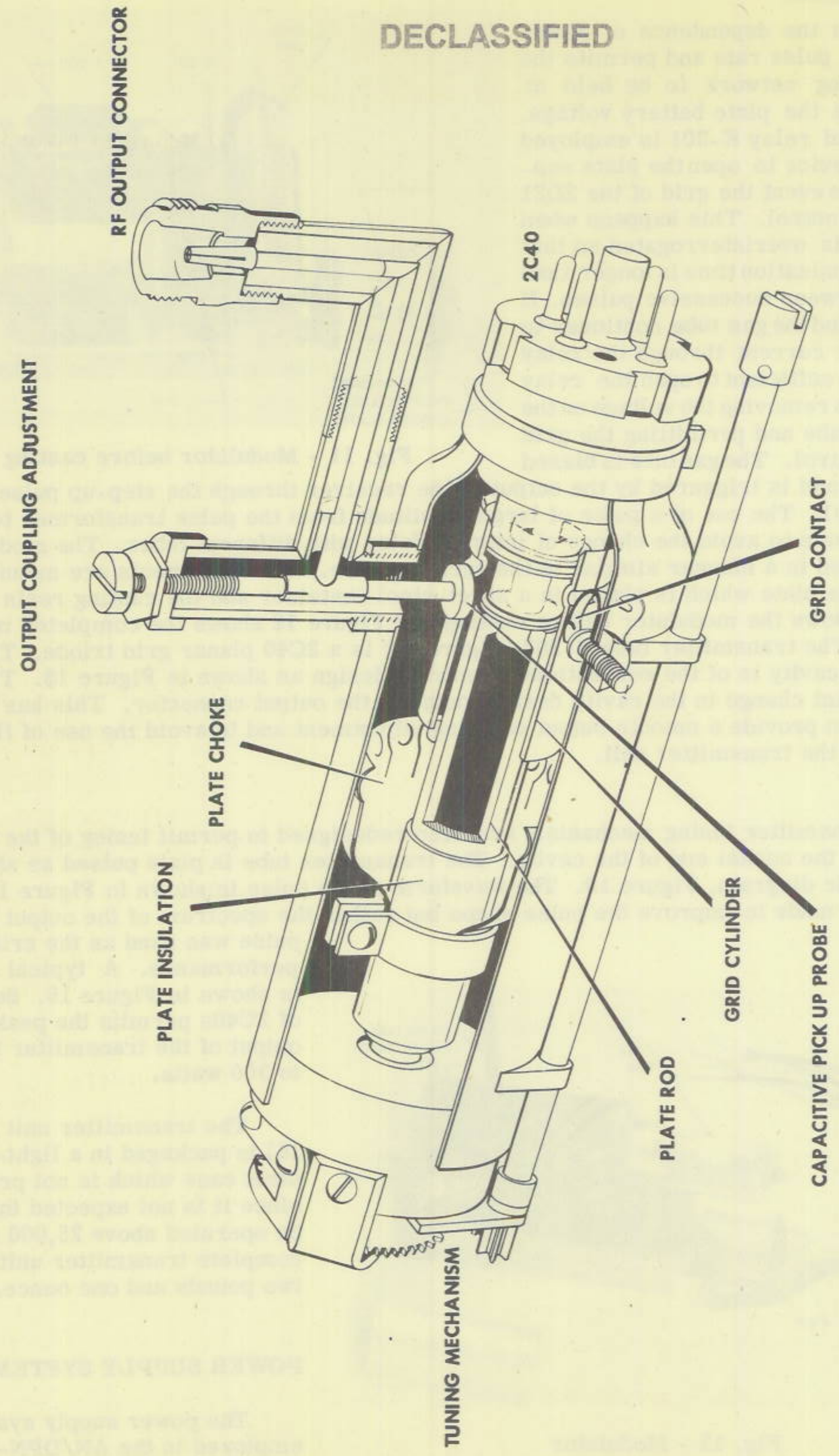


Fig. 13 - Transmitter cavity

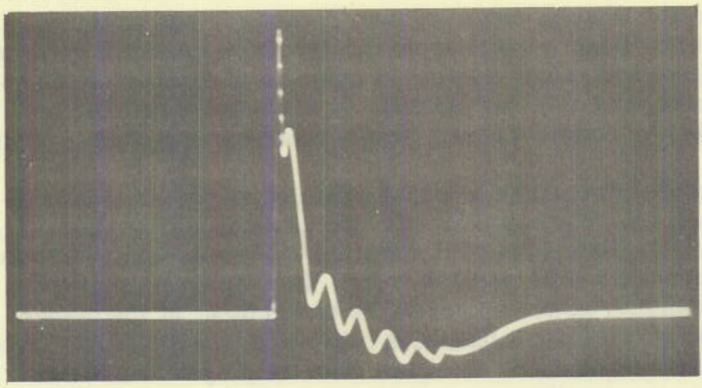
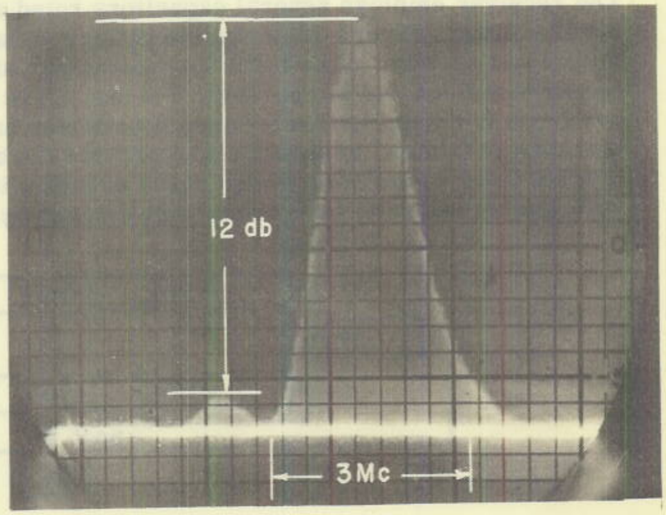


Fig. 14 - Transmitter plate pulse

Fig. 15 - Spectrum of RF output pulse



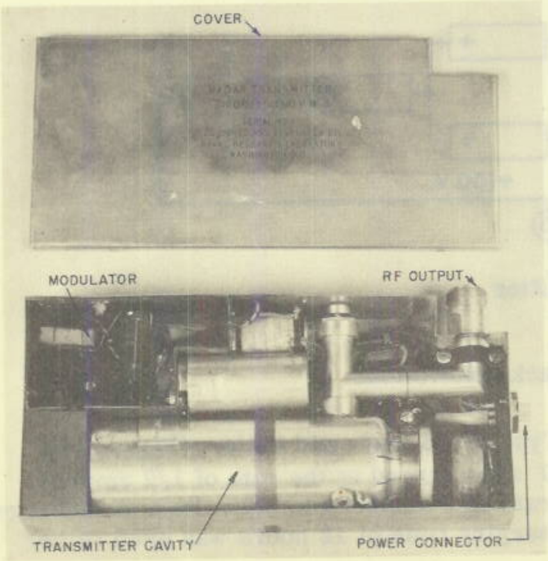
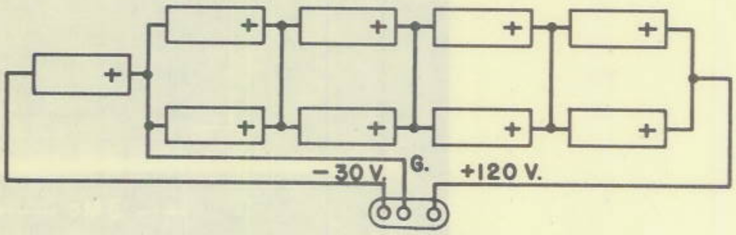


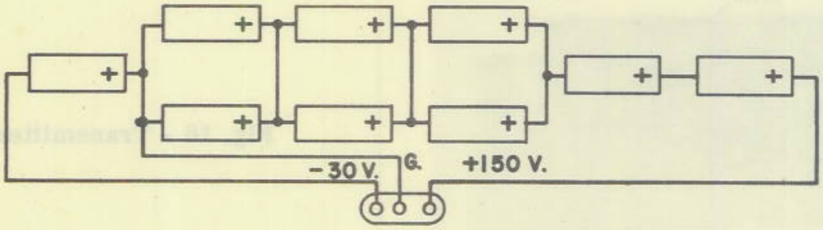
Fig. 16 - Transmitter

beacon is completely separate from the missile power system because it was expected that the beacon would not be used in the Lark missile after the development of the guidance equipment has been completed. The power supply system is made up of a receiver plate-bias pack, transmitter plate-bias pack, and a heater battery. It is expected that for installation in other missiles, a central or common power supply could be employed if desired.

The transmitter and receiver plate-bias packs are each made up of nine 30-volt batteries of the Eveready Type 413 or 413E. The batteries are connected in series-parallel, as shown in Figure 17. The transmitter plate-bias pack supplies +150 volts and -30 volts. The receiver plate-bias pack supplies +120 volts and -30 volts. The transmitter uses a 150-volt supply to take advantage of higher power output of the transmitter at the higher voltage. Because of the limited number of 30-volt batteries allowed by the available space, the transmitter battery series-parallel connections as shown were employed to maintain the overall internal resistance as low as possible consistent with the voltage obtained. The receiver employs several capacitors rated at 150 volts and therefore must operate at a lower voltage. Figure 18 shows the battery voltage as a function of time for both transmitter and receiver plate batteries operating under actual load conditions. The transmitter requires 4-5 ma and the receiver 7-8 ma. Care must be taken to insure that the batteries are fresh from production because if batteries have been stored an appreciable time, the increase of internal resistance will prevent the batteries delivering the required power. Of course, in an installation where space permits, it would be desirable to use either batteries with greater capacity or a common power supply.



Receiver



Transmitter

Fig. 17 - Battery pack connections

The heater battery employed is a Willard Type NT-6 lead-acid battery (Figure 19). The NT-6 is filled with sulfuric acid sp g 1,400 and charged at the rate of 1/2 ampere for 18 hours, then cycled by discharging at the rate of 3 amperes to 6.0 volts and recharged at 1/2 ampere for 18 hours. (For this work, charging time of 18 hours was used rather than that indicated on the battery.)

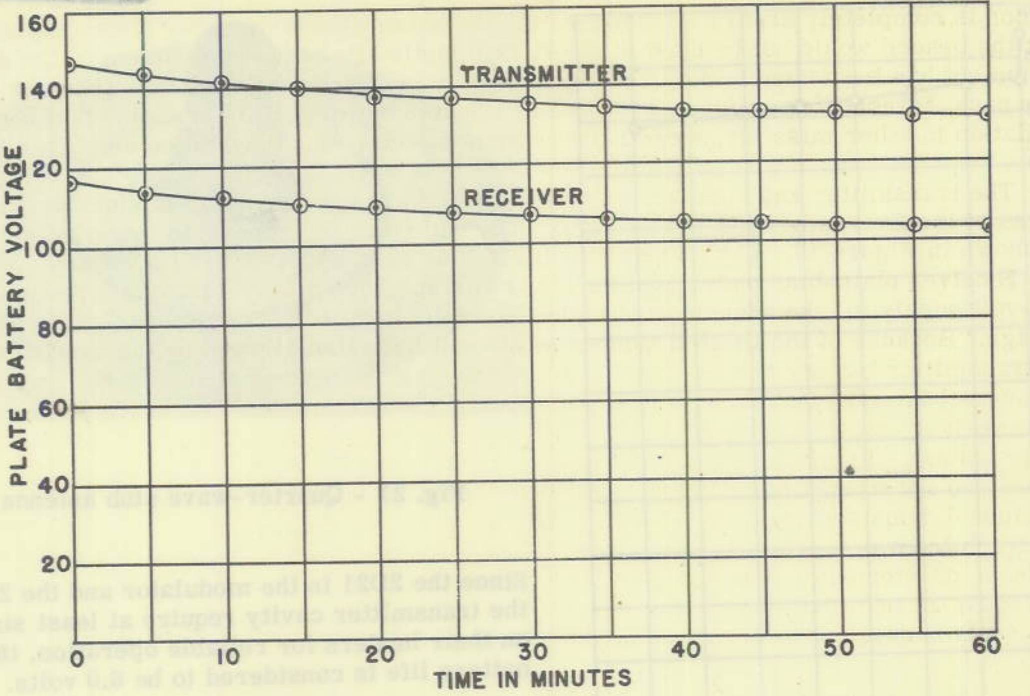


Fig. 18 - Battery pack discharge curves

If discharged within a short time it will deliver three amperes for about 25-30 minutes before the terminal voltage falls below 6.0 volts (Figure 20).

Fig. 19 - Heater battery-Willard type WT-6

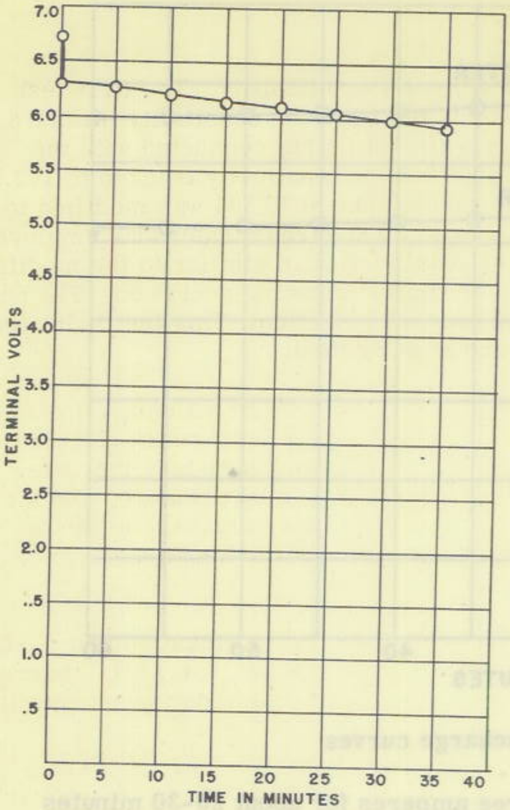


Fig. 20 - Discharge curve for heater battery

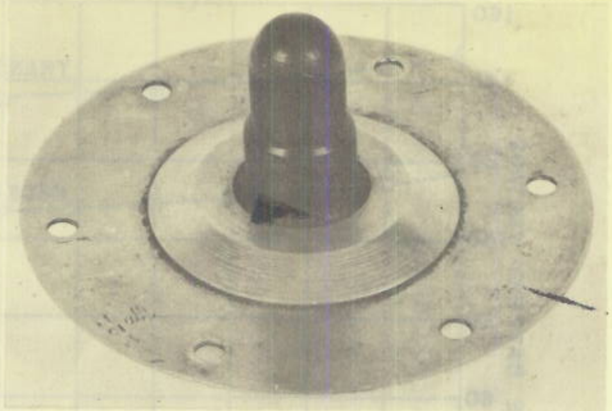


Fig. 21 - Quarter-wave stub antenna

Since the 2D21 in the modulator and the 2C40 in the transmitter cavity require at least six volts on their heaters for reliable operation, the end of battery life is considered to be 6.0 volts.

ANTENNA SYSTEM

The antenna system consists of two usually identical antennas, one for receiving and one for transmitting. In general, beacon antenna installations on guided missiles cannot use antennas of a "universal" type, but must employ antennas suited to the individual missile. The factors to be considered are radiation pattern required, allowable drag, and physical construction of the missile. The radiation pattern requirement is determined by the flight characteristics of the missile and the aspect of the missile as viewed by the tracking radar. The allowable drag may be so small as to require "zero drag" antennas built within the airframe of the missile. For similar missiles such as the XSAM-2 and the XSAM-4, the difference of construction of the airframe requires that the antennas be quite different in construction and installation, therefore the AN/DPN-3 (XB-1) will not be supplied with antennas but will operate satisfactorily with any antenna matched to a 50-ohm line to an SWR of better than two over the operating range of 2650 to 2950 Mc.

The antennas employed with the XSAM-2 will be "Polyrods" or dielectric antennas built into the wing tip and having vertical polarization. Those employed with the XSAM-4 will be built into a vertical wing flap and will be made up to two dipoles covered by a plastic "radome" which serves as the surface of the wing flap. The polarization is vertical.

For aircraft test flights the antennas employed were quarter-wave stubs mounted on the belly of an F8F aircraft. These antennas are vertically polarized and provide omnidirectional azimuth coverage. Figure 21 shows one of the quarter-wave stub antennas.

TESTS

The beacon has undergone several tests to determine its suitability. The first test was to determine the validity of the transmitter output and receiver sensitivity measurements. The AN/DPN-3 was installed in an F8F aircraft and flights conducted with the beacon operating with the SCR-584 radar. The beacon was automatically tracked to 192,000 yards and was manually tracked an additional 8000 yards. The SCR-584 was modified to extend the range of automatic tracking from 32,000 to 192,000 yards. The radar employed an "H" plane antenna with a six-foot reflector. The modification is similar to the modification kit MC-627 which adapts the SCR-584 to close control bombing operation. The beacon used quarter-wave stub antennas, indicated in the preceding section. This test indicated that the beacon had adequate receiver sensitivity and power output.

The second test, conducted with the assistance of the Shock and Vibration Section at NRL, subjected the beacon to a series of vibration and acceleration tests which included acceleration tests up to 50 g in three planes. The beacon performed satisfactorily after each test. Performance during the test was measured where the setup permitted and the beacon was found to operate in a satisfactory manner. It was found necessary to modify the transmitter cavity output probe to prevent a frequency shift during the high acceleration of 45-50g.

The beacon, not including batteries, is expected to have a life of at least 50 hours. One production beacon has operated for 100 hours of intermittent operation, i. e., 8 1/2 hours on 15 1/2 hours off; this was then followed by an additional 50-60 hours of continuous operation.

PLANS FOR THE FUTURE

The development of the AN/DPN-3 has been a "crash" program in that the equipment was to fulfill a particular need and the time permitted for development was limited to six months. For these reasons compromises were made which would not have been acceptable if the time for the development had been more liberal. Plans are under way for several improvements to make the beacon more suitable as an operational equipment.

A considerable saving in weight of the overall beacon by the use of light-weight sea-water batteries can be obtained. It is expected that suitable batteries for 30-minute life can be produced. For use with a complete beacon, the total battery weight would be approximately 1.06 pounds thus resulting in a saving of nearly 3 pounds in the battery weight. The only difficulty arising from the use of these batteries is the fact that once the electrolyte has been added, the batteries must be used within a few minutes. This is not believed to be a serious handicap in view of the indefinite shelf life of the sea-water batteries. Of course, where an installation will permit, any of the standard types of power supply such as dynamotor, 400-800 cycle AC, vibrator, etc., could be used.

The transmitter unit should be pressurized to provide reliable operation under conditions of high humidity and at altitudes in excess of 25,000 feet. Drawings for such a housing are being prepared to provide a container. The pressurized housing will, of course, increase the overall size and weight of the transmitter unit.

The advent of new tubes for the beacon transmitter offers a hope for a transmitter greatly reduced in size. Such tubes as the RCA type A2302 and the A2317 are being investigated to provide a much smaller oscillator with reduced power input for the same or greater power output. The heater power requirement for these newer tubes is very modest being of the order of one watt.

To simplify the design of the AN/DPN-3, the entire problem of coding has been avoided. It is desirable to increase the security of the receiver system by the use of a coded interrogation. Decoder systems in the receiver could be made to respond to multiple pulses variations in pulse width, or a combination thereof. The transmitter could be made to reply in code by use of additional pulses and thus insure proper indentification. This of course would result in a different modulator design and possibly a different transmitter cavity design.

It is possible to use the receiver and transmitter as portions of links to convey intelligence to and from the missile. Thus the receiver could also act as a command receiver and the transmitter also act as a telemetering transmitter. Long range plans are under way to study such a system.

ACKNOWLEDGMENTS

The author is grateful to the following for their part in the development of this beacon: Mr. C. A. Kennedy and Mr. J. M. Ryan of the Command and Report Links Section for their fine work in aiding the development of the receiver and transmitter; Mr. P. J. Franklin and Mr. Weinberg of the Bureau of Standards and Dr. M. A. Elliot, Mr. T. D. Callinan, Mr. R. J. Violette, and Mr. J. J. Kane of the Chemistry Division of NRL for their assistance with the potting of the various units; Mr. C. J. Bastien, Mr. G. W. Dorr, and Mr. P. F. Delisi of the Shock and Vibration Section of NRL and to Mr. Sullivan of the Naval Ordnance Laboratory for their assistance in vibration and acceleration tests of the beacon; and to Mr. G. Wilcox and Mr. V. Johnson of the Electricity Division for their assistance in making altitude tests of the beacon.

The design of the receiver filter cavity was made by Bernard Rices Sons, Inc. of New York.

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