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NRL LARK-WASP GUIDANCE PROGRAM

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NRL LARK-WASP GUIDANCE PROGRAM

by

William C. Hodgson

April 1947

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A-156R-S

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ABSTRACT

The status, findings, and projected activities of Radio Division III, NRL, in its research and development of a missile-control receiver and surface radar for Wasp guidance of the Lark Missile are summarized. Applied research projects which are discussed include missile launching and capture problems, attenuation of radar signal by jet exhaust, Wasp transmission bandwidth studies, the NRL Wasp Simulator, optimum beam crossover level, related radar research, and a modified Wasp control system.

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NRL LARK - WASP GUIDANCE PROGRAM

I INTRODUCTION

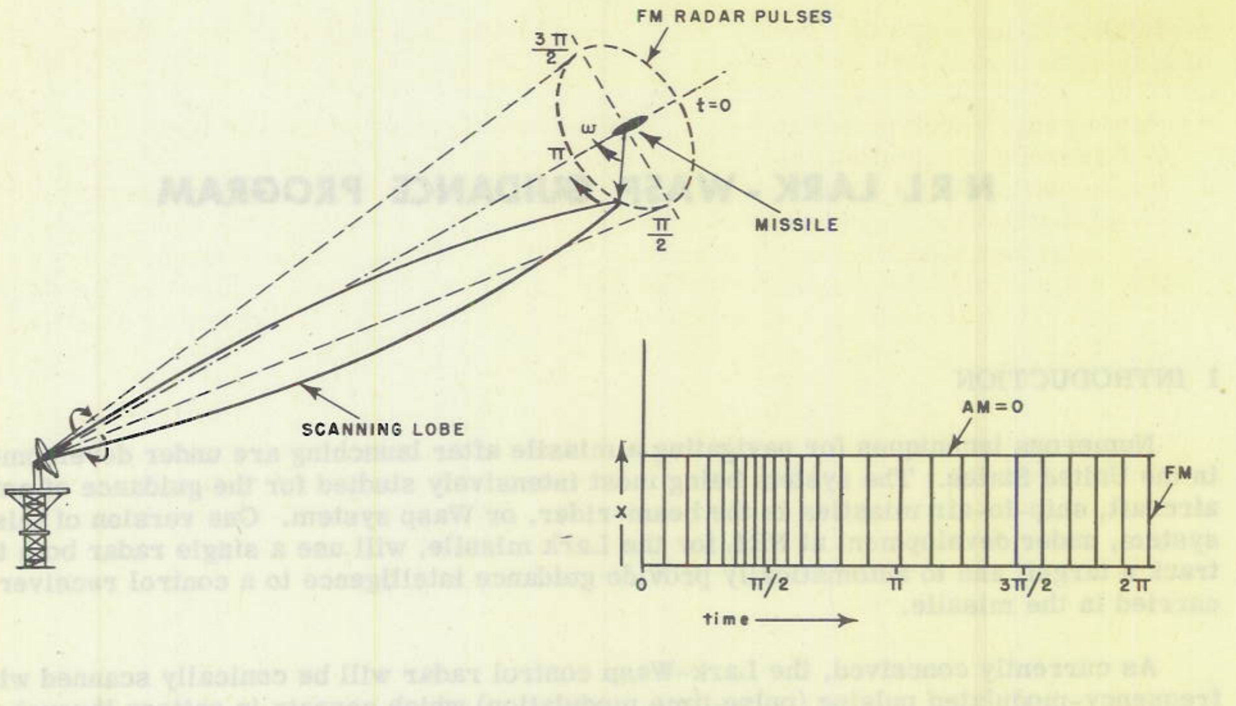
Numerous techniques for navigating a missile after launching are under development in the United States. The system being most intensively studied for the guidance of anti-aircraft, ship-to-air missiles is the beam-rider, or Wasp system. One version of this system, under development at NRL for the Lark missile, will use a single radar both to track a target, and to automatically provide guidance intelligence to a control receiver carried in the missile.

As currently conceived, the Lark-Wasp control radar will be conically scanned with frequency-modulated pulsing (pulse time modulation) which repeats in pattern through each scan cycle. Guidance intelligence needed for the return of the missile to a course along the beam requires measurement at the missile of both amplitude and angle of displacement. Error amplitude (distance from beam axis) is determined by measurement of the received lobe amplitude modulation. Amplitude modulation is a linear function, within limits, of displacement distance. Beam pulse-repetition frequency modulation provides a reference signal for the measurement of angular displacement of the missile from a zero reference. The translation of these measurements into up-down, left-right, and rate orders to servos which operate control surfaces will require also a true vertical reference in the missile. The receiver's indication of a position error in amplitude and angle must be independent of radar-to-missile range. Reliable AGC circuits which can maintain signal output as a function of error are thus required. Figure 1 illustrates the Wasp system for automatic generation of error signals.

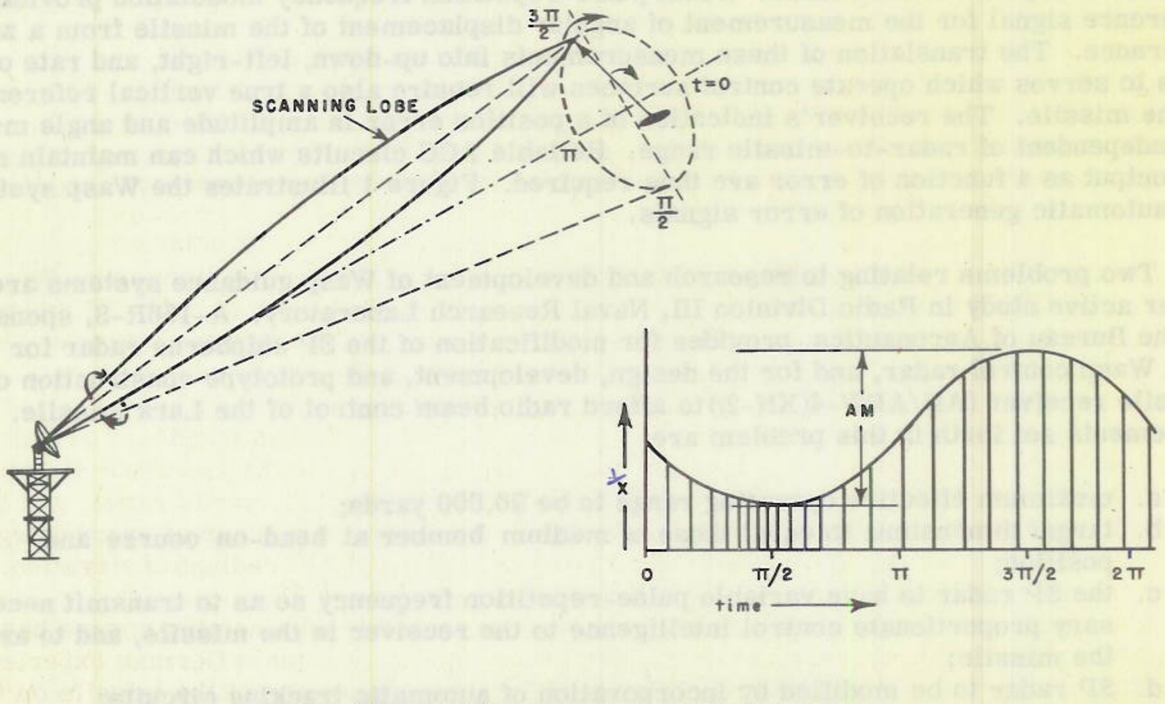
Two problems relating to research and development of Wasp guidance systems are under active study in Radio Division III, Naval Research Laboratory. A-156R-S, sponsored by the Bureau of Aeronautics, provides for modification of the SP shipborne radar for use as a Wasp control radar, and for the design, development, and prototype construction of a missile receiver (AN/APW-4(XN-2)) to afford radio beam control of the Lark missile. Requirements set forth in this problem are:

a. maximum effective operating range to be 90,000 yards;
b. target dimensions to equal those of medium bomber at head-on course and position;
c. the SP radar to have variable pulse-repetition frequency so as to transmit necessary proportionate control intelligence to the receiver in the missile, and to arm the missile;
d. SP radar to be modified by incorporation of automatic tracking circuits;
e. the missile receiver, AN/APW-4(XN-2), to be approximately as indicated in NAVAER-EP-324 (Mod. 1); and
f. the minimum range at which the equipment can take control to be dictated by minimum range capabilities of the missile receiver, but should be 200 yards or less.

O(A)125R-S, sponsored by the Bureau of Ordnance, provides for research and development of automatic guided-missile remote-control systems signaled by frequency



a. Missile Following Beam Axis



b. Missile Displaced from Beam Axis

ω_1 = angular frequency of scan

→ = received energy vector

Figure 1. The Effect of Displacement upon the Received Energy Vector

modulation of the lobes of a radar beam. This problem includes the development and test of a system to include:

a. a radar receiver suitable for use in a Wasp-controlled guided missile, for maintenance of missile flight along the axis of the radar beam;
b. modification of a fire-control radar system to transmit signals required by the receiver for maintenance of missile flight along the axis of the radar beam; and
c. a further modification, if necessary, of a fire-control radar system to use a single antenna system for the location of and the guidance of the missile to the target, with introduction of lead angle which shall put the missile on a collision course.

The overall problem of developing and producing equipment suitable for use as a Wasp guidance system for guided missiles can be broadly separated into two major areas: supporting research studies; and design, construction, and test. Supporting investigations and equipment design are complementary, and are developed concurrently. This report proposes to summarize the findings and status of both.

II RESEARCH STUDIES (GENERAL)

There have been numerous instances of successful remote guidance of aircraft and drones by means of radio link, but no one has yet successfully applied the Wasp guidance system in a powered missile. Guidance of a missile requires, first, that the missile be directed into the beam, and, second, that positioning signals be delivered to the missile's receiver, from a remote position. The positioning signals must be of such a nature that they can be effectively used by the receiver to produce error signals as functions of both angle and amplitude of displacement from the beam axis.

Missile Launching and Capture Studies

Preliminary studies indicate that the problem of directing a missile into the control radar beam and effecting its "capture" by the beam is a difficult one. A shipborne radar that is tracking an aircraft target will project into space not one, but many control lines which can be followed by a Wasp-controlled missile. Multiple control lines occur because of side lobes and surface reflection of the radar beam. The number of control lines is a function principally of radar antenna-elevation angle. Elevation angle is determined by target range and altitude.

An initial study of this problem by W. S. Ament, NRL, indicates that there are about 50 crossovers below a missile elevation angle of $\theta = 2.6^\circ$; that there are about 41 crossovers when the target being tracked is flying at 100 feet and 10,000 yards range; and that nulls caused by interference of direct and sea-reflected rays will occur at every integral multiple of 0.0185 radians, or there are about 30 nulls in the first 0.55 radians of elevation.

Each alternate control line will tend to direct the missile on a homing course back toward the origin of the control beam. This phenomenon may explain German experience in field tests of Wasp-controlled missiles wherein apparent homing of the missile on the control radar caused fatalities to some of the testing crew and discouraged further exploration of Wasp as a missile-guidance system. Studies of the multiple control line problem are being continued.

The existence of more than one control beam complicates the missile launching and capture problem, but it is not the only consideration of major importance. The study of the general launching and capture problem that has been undertaken will consider maneuverable and stationary launching platforms, and techniques for capturing the missile in the main control beam. Findings of this study will be reported in detail at a later date.

Attenuation by Jet Exhaust

All ship-to-air guided missiles under development will use jet propulsion. Jet motors introduce between the missile antennae and the control radar a mass of hot, ionized gas having inconstant volume, temperature, ionization, impurity content, and motion. It is anticipated that jet exhaust may seriously modify the radar guiding beam by its attenuating effects. Inconstancy of attenuation will, moreover, modulate signals passing through the jet exhaust. This problem has been considered, and at least superficially studied, by several research agencies. Measurements of attenuation per meter of flame have been taken in tests of various kinds of flames, and the frequencies which predominate in the flame have been recorded. Modulation of the control signal by the propelling flame at scan frequency, or within the usable bandwidth each side of scan frequency will cause the transmission of false intelligence to the receiver.

This problem could be so serious as to require reorientation of the currently conceived Wasp control program. It is, in any event, of sufficient importance to require thorough analysis and study. A preliminary survey has indicated the following general conclusions:

a. Flame from a given type of jet motor and fuel will produce attenuation effects unlike those developed by a different type of motor or fuel. The exhaust flame of the specific missile for which Wasp guidance equipment is being developed should therefore be studied.
b. Attenuation and modulation will vary with altitude, speed, thrust, exhaust-throat configuration, fuel pressure, and intermittence of motor operation. Dynamic flight tests should be more valid than ground tests for a given propulsion system and airframe.
c. Optimum geometry of missile antennae with respect to the flame and beam source will be an important determination.

Initial NRL studies of flame attenuation included tests using a 300-pound-thrust acid-aniline motor (similar to Lark). The jet from this motor was about six feet long and six inches in diameter. S-band signal attenuation through the flame averaged more than 6 db per meter, with spurt values ranging from 12 to 30 db per meter. Modulation frequencies of large amplitude were broadly distributed at about 180 cycles per second. A second frequency band at lower amplitude, possibly due to microphonics, was found in the region of 2,000 cps.

The addition of small amounts of metallic salts to the jet fuel greatly increased attenuation. A concentration of 0.014 moles/liter of sodium sulphate in the acid resulted in an average attenuation of 12 db per meter.

Flame-attenuation studies are being actively continued. A mobile field unit is under construction for use at Reaction Motors, Inc., Dover, New Jersey, in NRL studies of reflection, refraction, absorption, destructive interference, and incidental amplitude modulation. Initial tests will use the Lark acid-aniline jet motors, and measurements will be taken of jet attenuation of incident S-band radiation. A sixty-watt S-band CW transmitter has been completed, multiple detection units are substantially complete, and spectral radiation-detection apparatus is well under way. Future dynamic flight-test measurements of the Lark motor are under consideration.

Wasp Transmission Bandwidth Studies

The Wasp-controlled missile in flight will represent a closed-loop servo system. Input reference signals are amplitude modulation, frequency modulation, and noise. These are detected in the missile receiver, and are modified by position and rate follow-up or feedback in the servo loop.

Input noise can be minimized by limiting the servo input band pass to those frequencies required by the missile for the maintenance of flight along the radar beam within the tolerable error. A determination of transmission bandwidth requirements is therefore important. This determination is, in fact, essential in any economic and intelligent design of the control components of the Lark-Wasp system.

In tactical applications of the Wasp guidance system, angular movement of the control radar beam will be a function of target motion and range. The missile should fly along the axis of the moving beam and follow a line-of-sight course between the radar source and the target. Angular turning rates required of the missile to stay in the beam will be determined largely by target course and initial angle of fire.

It has been found that the frequency spectra associated with required missile turning rates can be determined mathematically. Approach, circular, and pass target courses have been considered and the associated frequency spectra have been computed and graphed. In addition, the frequency spectrum associated with missile entry into the beam at twice the beam's angular velocity has been computed and graphed.

The spectra associated with tactical target courses will serve to determine the frequency-response requirements of the control system as a whole. Wasp mid-course guidance requires delivery of the missile to a region in space determined by its homing, turning radius, and relative-speed capabilities. It is necessary to pass only those frequencies to the servo loop that are required to locate the missile properly for end-course guidance. If the transmission band is limited to those frequencies, the noise which results from flame attenuation, the atmosphere, radar scan rate, and the like, can be minimized. A detailed report covering this study will be issued shortly.

Wasp Simulator

The design of complex control equipment can be materially simplified if the required performance characteristics of the system and system elements are predetermined in some detail. Frequency-spectrum analysis, described in Part 3 above, will serve to determine some of the required performance characteristics and parameters of a Wasp-controlled missile. The Wasp Simulator under development should provide both a means for determining certain Wasp component specification requirements, and a device for pre-flight test of control components and systems designed and constructed.

It is both impractical and uneconomic to confine the measurement of performance and the determination of required parameters for a guided-missile control system principally to test-vehicle firings. In addition to the prohibitive cost of a test-firing cut-and-try approach, activities applying this technique have found it to be extremely difficult to isolate a single problem element for analysis by controlling all other significant performance variables. It is, for example, impossible to measure the missile's response to a particular control order unless such related variables as noise, crosstalk, inconstant thrust, airframe and response dissimilarities between missiles fired are controlled or quantitatively known. The Simulator will isolate control component elements for quantitative and qualitative analysis, and will serve to determine overall parameter requirements for a particular control system and missile.

This device will simulate on the ground the flight performance of a Wasp-controlled missile. It is essentially an analog computer designed to generate and plot relative courses of target and missile. Equivalent circuits and components are provided to simulate the major component assembly groups of a typical Wasp-controlled missile, and the motion of a pass-course target. Relative trajectories of target and missile will be plotted in scale on a one-to-one time base.

A unique characteristic of this simulator is its synthetic reproduction of missile aerodynamic airframe responses. For a given missile, such as Lark, wind-tunnel findings, aerodynamic computation, and flight-test data should establish certain predictable airframe responses. These will be applied in the design of electronic networks and servos that will reproduce, in their output circuits, values equivalent to Lark aerodynamic airframe responses. The need for step-by-step solution of complex aerodynamic equations in an elaborate computer may thereby be obviated. The simulator will thus apply aerodynamic responses, as determined elsewhere for a specific airframe, to the generation of relative missile trajectories, and to the measurement of control component performance.

Design and construction of the simulator is progressing rapidly. A prototype should be completed and in operation by summer of 1947.

Determination of Optimum Lobe Crossover Point for Wasp Radar

The Lark-Wasp control radar will perform the dual functions of missile guidance and target tracking. Standard radar uses pulse reflection from a target to measure target angle, range, and rate. In such an application the radar beam travels twice the target range. Missile guidance is to be effected by radar transmission over a one-way path from the ground-control radar to the missile receiver.

The high lobe crossover point for SP radar and its relatively narrow (3.5°) beam width were selected originally to give maximum range sensitivity and tracking capability. Application of the SP, or any other standard radar, to Wasp control requires analysis to determine optimum beam width and crossover point. In general terms, as the crossover point is raised and the beam narrowed, range capacity is increased and target acquisition capabilities reduced. In the one-way missile-guidance application, modulation amplitude is a function of both error amplitude and beam crossover level.

The two principal requirements of Wasp radar transmission are automatic target tracking over a two-way beam path, and automatic missile guidance over a one-way path. A determination of the various parameters affecting these two requirements has been made, and a mathematical analysis of them will be undertaken to calculate optimum crossover point for the Wasp radar beam. This point will be a compromise that should provide optimum signal-to-noise ratio, modulation amplitude, and linearity of error signals for both tracking and guidance. A report covering this study will be issued.

Modified Wasp Control Systems

Trajectory studies and analyses indicate that it is desirable to utilize radar beam-riding systems for mid-course guidance only. The final phase of guidance to the target can best be accomplished by a target seeker or homing device. If a device could be so designed as to use some of the components of the beam-riding receiver for homing, then such an integrated system would offer manifold advantages.

The maximum range expected for homing on radar target illumination transmitted from the missile is two to three miles. It will be necessary, therefore, for Wasp mid-course guidance to position the missile in the base of a relatively small cone at two- to three-miles range from the target, and to cause its antenna to be pointed in the direction of the target within relatively narrow limits. The size of the cone base and the tolerable pointing error are extended as the homing range is increased. It is therefore desirable to extend the homing range as far as possible.

It is not practical to build high-power radar transmitting equipment into the missile itself. The maximum homing range on a ground illuminated target, however, may be greater than the maximum range of a self-contained homing radar. Consideration is therefore being given to systems in which the missile homes on reflections received from the illumination of the target by high-power radar transmission from ship or aircraft. If such a system is practicable, the missile-radar homing transmitter would be eliminated; components of the receiver would be used both for one-way Wasp guidance error-signal generation and for homing; and a collision (constant-bearing) course could be followed by the missile over a greater portion of its flight path. Extended front-end guidance would, moreover, simplify the problem of flame attenuation of the beam.

It is not anticipated that passive homing will take the place of direct beam guidance, but rather that the homing period may be extended, and the necessity for certain missile components eliminated. It is planned to design, construct, and test at NRL a two-purpose missile receiver to be used for both front- and rear-end guidance-signal generation.

Related Radar Research

A prototype radar system employing high-speed electronic lobing was recently completed and successfully demonstrated at the Naval Research Laboratory. The system can be applied as an automatic-tracking radar with accuracy greater than has been achieved with either optical tracking or with other radar-tracking systems. Its outstanding feature is the inclusion of a new electronic lobing technique capable of aperiodic operation and of lobing rates as much as ten times those previously possible with conventional scanning or lobing methods. Electronic lobing is accomplished at radio frequencies with NRL gas attenuator tubes. This radar system has probable future application in Wasp and other missile-guidance techniques.

A simultaneous-lobe-comparison radar system has also been developed and successfully demonstrated at NRL. Application of this system to missile guidance and control is in a study stage at the present time. It is quite conceivable that the passive-homing problem can be simplified by application of simultaneous lobe comparison in the missile's homing-radar receiver.

III DESIGN, DEVELOPMENT, AND TEST OF WASP CONTROL EQUIPMENT FOR THE LARK MISSILE

General

Investigations leading to the development, design, construction, and test of Wasp guidance equipment are covered generally by Problem 0(A)125R-S. The delivery of specific equipment for Wasp guidance of Lark is covered by Problem A-156R-S. Equipment to be delivered under this problem includes a prototype missile receiver AN/APW-4(XN-2) as specified in NAVAER-EP-324 (Mod. 1), and a ground Wasp control radar to consist of an SP radar as modified for Wasp guidance.

Lark Receiver

Specifications for this receiver provide in summary that it shall deliver signals to the Lark "automatic pilot" (Flight-Control Assembly manufactured by Raytheon) such that the missile will be guided along a radar beam to a point where, at two miles or less range, the target will be presented within the cone of the homing head. Maximum range is set at 90,000 yards. Proportional-control d-c error voltages as functions of both amplitude and direction of error are required. Principal detail specification requirements for the receiver are set forth below:

a. Frequency shall be at Sy band--2600-2700 megacycles (adjacent to type-SP microwave shipborne radars).
b. Receiver output per unit error shall be essentially flat from 200 to 90,000 yards range.
c. Maximum weight shall be 20 pounds, not including batteries and radome.
d. Maximum power available to receiver shall be 50 watts at 28 volts for a period of 40 minutes.
e. The receiver shall be capable of operating for 25 hours at altitudes between 0 and 40,000 feet, and in temperatures between -40°C and 50°C. It shall tolerate accelerations to 15 g, and operate stably at input voltages varying between 24.5 volts and 28 volts.
f. Receiver size, not including r-f amplifier and first converter, shall not exceed $9\frac{1}{2}$ in. x 8 in. x 5 in.
g. Radiation: horizontal and vertical maximum beam width to be 30°; high front-to-back ratio.
h. Antennae: one antenna to be polyrod 18 in. long, tapered from 1 in. for wing-tip mounting; a second to be end-fire array type similar to A8-68/APG-5, enclosed for wing-tip mounting.

The design of a receiver capable of dependably producing amplitude- and angle-error signals requires that the receiver have stable references against which error signals can be generated and measured. Two base references to be generated by the surface radar are presupposed for the system. These are pulse-frequency modulation for angle reference, and amplitude modulation for measurement of lateral displacement. Pulse-frequency modulation originates at the radar transmitter. Signal amplitude modulation is a function of displacement of the missile from beam crossover. Vertical reference is taken from a missile vertical to be maintained by the automatic pilot. ACG maintains the receiver output independent of range.

A number of receiver circuits have been designed and subjected to preliminary test at NRL. The problem most difficult of solution is maintenance of a relatively constant input-signal strength at the receiver through the transmitter-to-receiver range limits of 200 to 90,000 yards. Variables, in addition to range, that make the constant-signal problem a serious one include excessive amplitude modulation, normal fading, expected flame-attenuation effects, and input variation caused by changes in antenna aspect angle. Additional problems are: receiver detection, and maintenance of the pulse-repetition-rate reference despite signal fading; minimization of microphonics in the receiver, and of frequency drift; conversion of angular error to lateral error; cross-talk; and demodulation of error and reference voltages.

In this development, straight crystal video was first applied, but was found to create excessive harmonics and microphonics. Microphonics were minimized by substituting a tuned (500-kc) amplifier, but this system lacked sufficient sensitivity. The third and current version is a superheterodyne circuit using a klystron oscillator. Bandwidth is 10 to 20 megacycles. This relatively compact system (5 in. x 8 in. x 9 in.) has been effectively used in field flight tests.

The missile receiver has been flight tested as detailed in another section of this report, and the modifications indicated as desirable by the tests are now being incorporated.

Stability in the angular-error reference circuits will be maintained by including a "memory" circuit as a means of continuity to carry the incoming FM signal through null periods. The "memory" circuit has demonstrated good performance in laboratory tests. It will be test flown in the near future.

A detailed report outlining the development of the AN/APW-4(XN-2) receiver in Radio Division III, NRL, will be issued at a later date.

Modified SP-1 Radar for Lark-Wasp

Problem A-156R-S, (BuAer), provides that "modifications to the SP shipborne radar shall include complete electronic systems engineering for operation with the radar beam control receiver to be incorporated in the Lark missile." Problem 0(A)126R-C, (BuAer, BuOrd), provides that "a fire-control radar shall be modified so that it will generate and transmit such signals, modulated differently in different lobes, as are necessary to guide a missile to the center of the radar beam. Further, the modification, if necessary, of a fire-control radar system that will use an antenna system to locate the target, with introduction of lead angle which shall put the missile on a collision course."

There are two principal versions of SP radar: the SP shipborne radar, and the SP 1-M ground radar. These two systems differ as follows: SP (shipborne) uses an 8-foot parabolic reflector with three-axis mount, and has level and cross-level stabilization provided by a Stable Element Mk 8; the SP 1-M uses a 6-foot dish with two-axis mount and, as a portable ground radar, requires no stable element. Early models of both systems use a spark-gap modulator, and have maximum power of about 0.75 megawatts, a 3.5° beam width, and lobe crossover at about 0.5 db down.

In order to provide equipment for both shipborne and ground-test work, it was decided to modify the two systems (SP and SP 1-M) for use as Lark-Wasp control radar systems. The principal required modifications include design and incorporation of

a. pulse-time modulation circuits to replace the spark-gap modulator;
b. an automatic gain control system;
c. automatic tracking circuits in all coordinates, with double-gated automatic range circuits for the SP 1-M;
d. effectively equalized servo systems for antenna main drive in train and elevation, and for automatic hand-crank positioning;
e. redesign, to lower lobe crossover to an optimum point for the combined missile-guiding and tracking functions as determined by pattern analysis (see Section 1, part a); and
f. design and construction of a field-modification kit to permit incorporation of the above modifications into existing SP and SP 1-M radar systems.

The spark-gap modulator has been replaced by a hydrogen-thyratron, and the pulse frequency-modulation circuits are completed.

The new automatic-gain-control system has been completed. Tests show good response through about seven cycles per second, and effective rejection filtering of the 24 cps SP scan rate.

Automatic-tracking circuits are completely designed, but will not be applied and tested until the antenna-drive and hand-crank-positioning servo systems (also completely designed) are installed.

Lark-Wasp Test Program

The technical evaluation program for Wasp guidance equipment developed at NRL includes supporting investigations and laboratory, field, and flight tests of control systems and system components. Such supporting investigations as the Wasp Simulator, flame-attenuation studies, multiple-control-line studies, determination of optimum radar-lobe crossover point, Wasp frequency-spectrum analyses, and related projects are discussed in Section I of this report. Routine laboratory-test procedures and findings are believed to be of lesser general interest than the field and flight test program. This section will therefore detail only the latter program.

Technical evaluation of the Wasp control radar and receiver developed for Lark has as its primary objective the development of a system which has reasonably predictable performance when applied operationally. It is considered more economic to delay installation and test shooting of the control receiver in the Lark missile until there is a reasonable certainty of the successful operation of the system.

Laboratory component and system tests are followed by ground and flight testing of equipment developed. This program has required field installation of the modified SP Wasp control radar; the procurement and instrumentation of aircraft for receiver flight-test and radar-pattern analysis; and ground instrumentation for tracking, control transmitter measurements, and air-to-ground two-way communication.

a. Wasp Control Transmitter

An SP radar as modified for the transmission of Wasp control signals has been operated for some months. This installation is equipped with the pulse repetition frequency modulator, and will include other Wasp radar modifications, described in Part 3 above, as these are completed. It has been used as the control-signal source for Wasp-receiver bench and flight tests. Range dials and photographic equipment for range recording have been installed.

b. Receiver Flight Tests

In initial flight tests, the AN/APW-4(XN-1) was installed in an SNB aircraft with receiver outputs fed to left-right and up-down indicating meters. The pilot acted as a servo between meter error indication and aircraft reorientation and flew the plane for minimum-error indication. These initial tests showed that the receiver would accurately indicate position error in respect to beam crossover for short periods. Intermittance of operation was believed due to an instability of the displacement-angle reference circuits which resulted from FM nulls caused by over-modulation and fading. Bench tests indicate that this instability has been corrected in the most recent receiver design. The modified receiver will be flight tested in the near future.

c. Aircraft Instrumentation

It is planned to couple the receiver via a "controller" to a type P-1 auto-pilot for automatic flight along the radar beam. Toward this end, a P-1 auto-pilot and "controller" have been installed in an SNB aircraft. Frequency-response characteristics of both have been determined. The "controller" will translate receiver error signal into auto-pilot orders.

Photographic equipment has been designed for the photo-recording in flight of receiver output-meter indications.

d. Ground-Tracking Instrumentation

Photographic tracking of the aircraft will be effected from the ground by the use of 16 mm motion-picture cameras with telephoto lenses. The normal maximum photographic range in the Washington area (10,000 yards) is insufficient for the tracking requirements of these tests. It has been demonstrated that a 500-watt landing light on the aircraft, pointed approximately toward the camera, can extend the maximum photographic range to approximately 54,000 yards when color film and a 17-in. telephoto lens are used. A number of light sources and film types were tested, but no other combination resulted in so great an effective range.

Range data from the SP radar, receiver output-meter indicators, and ground tracking data will be interpreted together to determine how accurately the receiver indicates position error.

e. Forthcoming Flight Tests

When receiver performance is demonstrated to be consistently satisfactory in flight, a complete investigation of all parameters will be made with the objective of effecting the optimum design of a prototype receiver for the Lark missile. An analysis of the frequency-response characteristics of the receiver, controller, auto-pilot and aircraft should provide the data required to equalize these four components for operation as a coordinated system. With the completion of this analysis and resulting equalization, an attempt will be made to fly the aircraft along the beam by remote control, but with an aircraft pilot acting as stand-by.

Upon successful completion of the above tests, it is planned to fly the SNB aircraft automatically along a radar beam which will be displaced at programmed rates equivalent to those required for the tracking of targets following various approach and pass courses. These tests will serve to determine control system and airframe response in tactical applications of Wasp control.

Other tests relating operational Lark-Wasp guidance components to the supporting investigations (flame attenuation, multiple control lines, etc.) are being planned, and will be outlined in detail in later reports.

There is now in preparation at the request of BuAer an NRL recommended overall test program for the Lark missile. This program will include tests of both mid-course and homing systems being developed for guidance of the Lark missile.

IV ACKNOWLEDGMENTS

Most of the Sections and many of the personnel of Radio Division III have contributed to the program and progress outlined. Engineers of other divisions, notably Radio Division I, have materially assisted in the flame-attenuation and multiple-control-line studies. The writer has had primarily an editorial function in the preparation of this report. References from which material was taken follow.

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