IRIG Document Number **106-59**

IRIG SYSTEM STANDARDS FOR C-BAND (5 CM) INSTRUMENTATION RADARS AND BEACONS

Inter-Range Instrumentation Group
Of The
RANGE COMMANDERS' CONFERENCE

Air Force Flight Test Center
Air Proving Ground Center
Atlantic Missile Range
Naval Ordnance Test Station
Pacific Missile Range
White Sands Missile Range

IRIG DOCUMENT NO. 106-59

IRIG SYSTEM STANDARDS

FOR C-BAND (5 CM)

INSTRUMENTATION RADARS AND BEACONS

Prepared by

Electronic Trajectory Measurements Working Group
of the
Inter-Range Instrumentation Group

Document Approved March 1960

This document was reissued July 1961.
Additional copies may be obtained from:

U. S. Department of Commerce
Office of Technical Services
Washington 25, D. C.

or

Armed Services Technical Information Agency
Arlington Hall Station, Arlington 12, Virginia

ACKNOWLEDGEMENT

These System Standards were prepared by the Beacon Committee of the Electronic Trajectory Measurements Working Group of the Inter-Range Instrumentation Group of the Range Commanders' Conference.

BEACON COMMITTEE

Beuhring W. Pike, Code 3101-2.2, PMR, Member (Chairman)

C. H. Wehmeyer, Code 3271.1, PMR, Member (Alternate)

F. J. Clark, Code MTLDR, AMR, Member[1]

H. H. Hufnagle, Code PGNDE, APGC, Member[2]

R. E. Boyer, Code 3067, NOTS, Member[3]

P. L. White, Code SIGWS-RA-3, WSMR, Member

The Beacon Committee was assisted from time to time by:

L. F. O'Kelley, RCA, AMR, (Associate Member)[4]

T. L. Pace, Division 5221, Sandia Corp., Albuquerque, N. M. (Assoc. Member)

M. R. Paglee, RCA, Moorestown, N. J. (Guest)

G. H. Nibbe, Canoga Div. of Underwood Corp., Van Nuys, Calif. (Guest)

Peter Maresca, Army Signal R&D Laboratory, Ft. Monmouth, N. J. (Guest)

W. J. Flynn, Army Signal R&D Laboratory, Ft. Monmouth, N. J. (Guest)

---

(1) Former AMR member: H. C. Wilson, Code MTLDR

(2) Former APGC member: B. L. Stoffel (now with Cubic Corp.)

(3) Former NOTS member: W. D. Caffery (now Code 5009)

(4) Now with Radiation, Inc.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

FOREWORD

C-Band instrumentation radars are a major factor in range instrumentation today. The ranges AMR, PMR, WSMR, and APGC each has AN/FPS-16 radars and PMR has also AN/MPS-26 (XN-1) radars. In addition, NASA has FPS-16's at Langley Field (Wallops Island) and Bermuda; the U. S. Army has them at Ft. Huachuca Proving Ground, Arizona and the United Kingdom has them at Woomera, Australia. Plans for the future call for the production of additional FPS-16s, some of which will be trailer mounted versions and some for ship mounting. Plans also call for various modification kits to capitalize on the growth potential of the FPS-16 radars.

These system standards are an "IRIG Recommendation" primarily for the purpose of establishing and preserving compatibility between C-Band range instrumentation radars* and C-Band instrumentation beacons* of the present and the foreseeable future. In this document "C-Band" means the range 5,400 to 5,900 mc/sec. (5.1 to 5.6 cm).

The second purpose of this document is to make available, in condensed form, data on the nominal characteristics of C-Band instrumentation radars AN/FPS-16 and AN/MPS-26 (XN-1).** The third purpose is to list some potential improvements for these radars, some of which improvements are necessary for optimum operations with beacons. The fourth purpose is to list in brief the principal modern C-Band beacons. The final purpose is to provide a bibliography.

The goals are to have all C-Band instrumentation radars so that any test range utilizing such radars can accommodate any beacon that meets these standards and to have all C-Band beacons meet these standards. It is not the aim of these standards to require all beacons to use the same pulse coding system and the same spot frequencies but rather to establish an envelope of codes and an envelope of frequencies that all test ranges can cover completely. In this way the aims can be met and yet the interference-free traffic capacity will be larger than if only one system of codes and spot frequencies were used.

The standards are not intended to limit the development of radar and beacon improvements. This is particularly so in the future area of extremely long range beacon tracking, where entirely different techniques may become necessary. It is intended that such new developments be coordinated through all users of these radars, and new standards issued accordingly.

- -

*Where the term RADAR is used without qualification, pulse radar is meant. Herein, a BEACON is a pulse radar transponder, a pulse radar responder. For additional definitions, see Appendix A. The best general reference on Instrumentation Radars is "Final Report, Instrumentation Radar AN/FPS-16 (XN-2)" by RCA. The best general reference on radar beacons is Vol. 3 of MIT Radiation Laboratory series, titled "Radar Beacons", edited by A. Roberts, published by McGraw-Hill, 1947. For referencessee Appendix D of these standards.
**The suffix (X--) indicates "Experimental Model". It should be noted that there were three experimental models of AN/FPS-16. These were (XN-1) with an X-Band Transmitter and a lens antenna, (XN-1) with a C-Band transmitter and reflector, and (XN-2), the production prototype. The trailer mounted version of the AN/FPS-16 probably will be named AN/MPS-25.

These standards are based on the known characteristics of existing instrumentation radars AN/FPS-16 and AN/MPS-26 (XN-1) and on the assumption that certain necessary additions and modifications to the radars will be made (and that future AN/FPS-16 and AN/MPS-26 type radars will incorporate these new features). The manufacturers of these radars reviewed a draft version of these standards and their comments were taken into account.

These standards have been made to accommodate (with a few unavoidable minor exceptions) existing U. S. Army short-range beacons AN/DPN-42 and AN/DPN-31 and the medium range beacon AN/DPN-48. The U. S. Army long-range beacon AN/DPN-50 (under development by Stromberg-Carlson) is expected to meet these standards completely except for the minor point that the beacon will be made so that it triggers on the trailing rather than the leading edge of the triggering pulse. See Part III, Note (25).

The U. S. Air Force long-range beacon AN/DPN-54 (under development by Motorola) differs from the above-mentioned beacons principally in the use of longer pulses, wider pulse spacings, fewer pulses, and in the method of pulse modulation for command control. These differences are principally for the purpose of increasing range by increasing pulse duration (thereby increasing pulse energy) and by decreasing bandwidth (thereby increasing sensitivity, but decreasing information capacity). Although these are significant differences, this beacon is expected to meet these standards completely.

All of the above beacons are designed primarily for one-shot use in missiles rather than for use in aircraft.

The U. S. Navy long-range beacon (BUAER Preliminary Specification XAV-28) is under development (by Canoga). It is expected that this beacon will meet these standards and that it will be similar to AN/DPN-50 or AN/DPN-54 (except that it will be primarily for aircraft instead of primarily for missiles and it may have interchangeable RF Heads to cover S and X Bands in addition to C-Band).

These standards have been made to accommodate the existing C-Band instrumentation radars (as originally manufactured) to the greatest practical degree.* However, the radars alone are not completely compatible with all existing beacons nor with the current state of the beacon art. Where there was a conflict, the standards were based on the philosophy that any necessary complexity should not be in the beacon if it is possible to put the complexity in the radar instead. For one example, it is expected that the frequency stability of a radar's tunable magnetron may be such that it will be necessary to add an automatic frequency control in order to stay within a practical beacon's pass-band. For another example, it is known that, because of unavoidable modulator pulse transformer limitations, the AN/FPS-16 radars will not be able to space the fifth 0.25 microsecond pulse as close as the desired 1 microsecond after the fourth pulse (and none

---

*These standards do not cover AFMTC Mod-III C-Band Instrumentation Radars since they are no longer in use at the IRIG ranges. It is recommended that present users of these radars modify them (if necessary) to meet the standards so that they will be able to use beacons designed to meet these standards.

of the pulses can be spaced as close as the design goal of 0.50 microsecond). It is expected that, for the same reason, the 0.25 microsecond pulses may not have the desired shape and pulse-to-pulse frequency stability. Therefore, it is expected that it will be necessary to improve the modulator of the tunable magnetron. This improvement probably will be possible by removing the 1 to 1 pulse transformer and replacing it with a direct drive circuit or by developing an improved transformer. If the tunable power of a radar is increased by adding a modification kit, the above improvements must be incorporated in the kit.

These standards do not cover the pulse-modulation aspects of radar/beacon type command-control systems except to specify the maximum number of pulses and the time modulation limits. In other words, these standards do not specify the frequency and wave shape of pulse modulation control signals. At some later date the standards may be amended to include these items. Meanwhile, plans to use radar/beacon command systems should be coordinated with the test range or ranges involved. It is however, a recommendation of these standards that future beacons have the command control equipment in a separate removable unit to minimize the size of the beacon when used for applications not requiring command-control. It is therefore recommended that the only command-control output of the beacon be the required video pulses. In this way the same beacon could be used in systems utilizing different kinds of modulating signals.

The present C-Band Radars, as delivered, are not equipped with Multiple-Trigger Generators (Encoders) for using coded beacons; so far as is known, a trigger generator that meets these standards has never been developed. Therefore these standards will also serve as a guide for the development of such devices.

These standards do not cover the format of the real-time digital data of the radars. At some future date, IRIG may publish a standard to facilitate real-time exchange of data between the ranges.

Additional copies of these standards may be obtained from IRIG Secretary, White Sands Missile Range, New Mexico; (or from the Armed Services Technical Information Agency, Document Service Center, Arlington 12, Virginia).

For detailed specifications on beacons refer to Inter-Range Instrumentation Group "Electronic Trajectory Systems Catalog", Vols. II, IIA and IIB. Volume IIB is classified CONFIDENTIAL. These volumes may be obtained from the IRIG Secretariat, White Sands Missile Range, New Mexico, (or through ASTIA when the original printing is exhausted). Volume I and Volume IA of this catalog will cover Electronic Systems for measuring trajectories and will include some data on instrumentation radars. This volume should be available early in 1960. The final volume will cover electronic miss-distance measuring systems. Availability of this volume is indefinite.

Errors found in these System Standards (or suggestions for improving future issues) should be brought to the attention of IRIG Secretariat, White Sands Missile Range, New Mexico, for relay to the proper person.

Following the original printing of this document, the Department of Defense indorsed the objectives and intent of 106-59 and addressed a memorandum to the Assistant Secretaries of the Army, Navy, and Air Force which is quoted in part as follows:

> "It is requested that you insure that these standards are adhered to by all agencies concerned with the development and design of C-Band instrumentation radars and beacons to be employed by the Ranges or by vehicles to be tested on the Ranges. As new developments and techniques become available, it is requested that the Ranges and Range Users take cognizance of that fact and insure that the standards are appropriately modified to insure continuing compatibility between ground and airborne equipment and between the several Ranges."

NOTES:

1. This document will be reviewed for revision one year after date of publication.
2. Permission to publish data on system characteristics of AN/FPS-16 and AN/MPS-26 (XN-1) radars was granted by BUAER letter Aer-AV-4322/51, of 6 May 1959, to PMR.

INTRODUCTION

These System Standards are presented in two major parts. Part I is for the radar-to-beacon link (the "interrogation" link). Part II is for the beacon-to-radar link (the "response" link). Each part is divided into topics, such as "Frequency Range". Under each topic, both the radar and the beacon are treated; with the transmitter being treated first and the receiver next. In some instances, explanatory remarks are included in Part III in the form of numbered footnotes.

In addition to the basic System Standards, appendices are included. Appendix A lists data on the nominal characteristics of AN/FPS-16 and AN/MPS-26(XN-1) radars as they were originally produced. Some planned future modifications of the radars are mentioned in the footnotes of this appendix. Appendix B lists recommended and potential modifications to the radars. Appendix C lists miscellaneous recommendations concerning beacon systems. Appendix D is a list of references and Appendix E describes briefly some typical modern C-Band beacons.

Herein, references to the page numbers of this document will be found only in the Table of Contents. All other similar numbers referred to in the body of this publication apply to items, sections, or paragraphs and not to page numbers.

This document has been configured so that it can be filed with the loose-leaf sheets of the AN/FPS-16 Instruction Manual.

Note: Within the limits of authority of this document, "shall" items are "mandatory" items, and "should" items are "strongly recommended" items.

PART I

INTERROGATION LINK
(Radars to Beacon)

1.1 FREQUENCY RANGE:[1]

A. Radar's Transmitter: Shall be tunable to any frequency within 5,400 to 5,900 mc/sec. (mc/s means "million cycles per second"; sometimes written "mcps", or even "mcs" for short.)

B. Beacon's Receiver: Shall be tunable to any frequency within 5,400 to 5,900 mc/sec.

1.2. FREQUENCY INACCURACY (ABSOLUTE):[2][1]

A. Radar's Transmitter: Shall hold ±2.0 mc/sec or less at all times (any and all pulses).

B. Beacon's Receiver: Shall hold ±2.0 mc/sec or less at all times.

1.3 FREQUENCY JITTER:

A. The pulses of a single interrogating pulse-group shall not differ in frequency by more than 0.2 mc/sec.

1.4 FREQUENCY OFFSET:

A. It is not required that the radar's transmitter operate on a frequency less than 25 mc/sec away from the receiving frequency of the radar's beacon receiver.[3]

1.5 FREQUENCY SPECTRUM:

A. Radar's Transmitter: The RF pulse spectrum shall not be wider, between -6 db points, than 2.0/pulse width. For example, for 0.25 μs pulses, the width shall not exceed 8 mc/sec.

B. Beacon's Receiver: See 1.10 (RF Bandwidth).

1.6 LOCAL OSCILLATOR FREQUENCY:

A. The beacon's L.O. normally should be lower in frequency than the radar's transmitter frequency. It is desirable that the L.O. be capable of operating on either side of the radar's frequency. For crystal-video beacons, ignore all references to beacon's L.O.

---

[1]For footnotes, see PART III.

1.7 INTERFERENCE RADIATION:

A. Both the transmitter and the receiver shall meet the latest issue of Military Specifications MIL-I-006181 and MIL-E-16400 (SHIPS), as applicable, except as specified herein.

B. Radiated power at frequencies outside of 5,400 to 5,900 mc/sec should be at least 60 db less than the C-Band fundamental, except for the theoretically expected harmonics of the C-Band R.F. pulse.

C. Local Oscillator C-W energy delivered to the antenna should be less than -40 dbm.

1.8. IMAGE FREQUENCY REJECTION:

A. The beacon's receiver should have at least 60 db of image frequency rejection.(5)

1.9. INTERFERENCE SUSCEPTIBILITY:

A. The beacon's receiver (exclusive of any decoder) should have at least 60 db of rejection of CW or pulse signals at frequencies outside of 5,400 to 5,900 mc/sec, except as qualified by the theoretical receiver pass-band specified in 1.10 herein.(5)

1.10. BANDWIDTH:(17)

A. Radar's Transmitter: See 1.5 (Frequency Spectrum).

B. Beacon's Receiver: (a). It usually is not practical to use signal-actuated AFC in a beacon's receiver (especially so for chain-radar operations). Therefore, the RF pass-band of the receiver must be wide enough to accommodate not only all the desired side frequencies of the R.F. pulse spectrum, but also the frequency error of the radar's transmitter plus the frequency error of the beacon's receiver plus any doppler frequency shift (which usually is negligible). (b). Since a beacon triggers somewhere on the leading edge of a video pulse and since a variation in the triggering point produces an error in the measurement of range, a very rapid rise of the video pulse is highly desirable. This requires a wide video pass-band and a correspondingly wide RF. pass-band. For a video rise time R_V, the video pass-band must be at least $(0.35/R_V)$ cycles/sec. wide at the -3 db points, and the RF pass-band must be about twice that, or $(0.70/R_V)$ cycles/sec. (6), (7). Therefore, for a rise time of 0.05 μs (about 10 yards), the RF bandwith must be 14 mc/sec. To this must be added the radar's transmitter frequency error of ± 2 mc/sec. (See 1.2.) and the beacon's receiver frequency error of ± 2 mc/sec. (See 1.2.). This results in a beacon receiver RF pass-band requirement of 22 mc/sec. between -3 db points. For a beacon having lower range accuracy requirements, a narrower pass-band is suitable, but the frequency errors set a lower limit. (c). Recommended compromise bandwidths for an average beacon are 15 mc/sec. for the RF and at least 3.5 mc/sec. for the video. A wider video pass-band, such as 7 mc/sec. or more, is highly desirable.(8) (d). For maximum rejection of noise and interfering signals, the RF pass-band should have steep skirts. However, the steeper the skirts, the longer the pulse rise time, the greater the pulse overshoot, and the greater the receiver complexity. Therefore, the RF pass-band skirts ordinarily should be optimum for the gain times band-width required and additional selectivity should be obtained by multiple-pulse interrogation coding. However, it is recommended that the beacon's receiver RF pass-band be no wider than 60 mc/sec. between the -60 db points. See note (17) regarding "Pulse Bandwidth". The pass-band should be symmetrical.

1.11 RF CHANNELS:

A. Radar's Transmitter: A tunable transmitter is highly desirable for all beacon operations and is mandatory for chain-radar beacon operations. The presently available tunable magnetrons cover only 5,450 to 5,825 mc/sec. and the present high-power fixed tune magnetrons (for skin-tracking) are at 5,480 mc/sec. ± 30 mc/sec. Therefore, until high-power tunable transmitters that cover the whole 5,400 to 5,900 mc/sec. band are available, skin-tracking-only radars should be within 5,450 to 5,510 mc/sec. and beacon-tracking radars within 5,510 to 5,825 mc/sec. It is recommended that frequency assignments for beacon-tracking radar transmitters normally be spaced about 80 mc/sec. (except, of course, radars of a given chain must all be on the same frequency).

B. Beacon's Receiver: The beacon's receiver must be tuned to the frequency assigned to the radar's transmitter; it is recommended that the L.O. ordinarily be set below the radar's frequency. For minimum rise-time jitter and for maximum image rejection, a high IF should be used. An IF of at least 60 mc/sec. is recommended. If an adequate pre-selector cannot be provided, the RF channel assignments should be such that no radar frequency is near the image frequency of a beacon.

C. Two-Way Channels: See PART II; 2.11.

1.12. POLARIZATION:

A. Radar: It is desirable for the radar to have pushbutton selection of four polarizations: Linear Horizontal, Linear "Vertical", Right-Circular, and Left-Circular. If only one linear polarization is available, the electric vector shall be linearly polarized with "vertical" orientation.(9) If only one sense of circular polarization is available, it shall be Right-Handed, by IRE definition.(10) A rotating linear polarization such as is produced by a rotating dipole shall not be used.

B. Beacon: Polarization shall be optimum for the radar polarization used. Normally the polarization should be linear and "vertical", or circular.(9), (10), (11)

1.13. ANTENNA PATTERN:

A. Radar; Transmitting: Beacons do not require any special radar antenna pattern characteristics; however, side lobes should be as small as possible. See 2.13B.

B. Beacon;Receiving: The beacon antenna problem usually is an extremely difficult one because of the wide variation in viewing aspect that is required. This variation produces changes in the received signal strength through changes in the absolute gain and thru cross-polarization. In view of the fact that a null or loss of only 6 db cuts the maximum beacon range in half, the beacon antenna system often is the critical element in a radar/beacon system.

1.14. RF PULSE DURATION: The radar's RF pulse (envelope) duration, between -3 db points (50% peak power points), shall be (selectable by push-button): 0.25 µs ± 20% or 1.00 µs ± 10%. An additional value of 0.50 µs ± 10% is highly desirable. Herein, "peak" power is "smooth peak" as defined by paragraph 4.16.3.3 of MIL-E-1c.

1.15. RF PULSE RISE AND FALL: The radar's RF pulse (envelope) rise time, from -10 db to -0.5 db (10% to 90% Peak Power) shall not exceed 0.05 µs. The fall time from -0.5 db to -10 db shall not exceed 0.15 µs, and preferably should be 0.10 µs or less.

1.16. RF PULSE JITTER: The radar's RF pulse (envelope) must not have leading edge jitter exceeding ± 0.01 µs with respect to the pretrigger.

1.17. RF PULSE TOP: A radar's RF pulse (envelope) between the outer -1.0 db points (80% peak power points), shall at no point deviate more than 0.5 db from the "smooth curve" defined by paragraph 4.16.3.3 of MIL-E-1c.

1.18. RF PULSE GROUPING: For interrogation coding and command-control purposes, the radar shall be capable of transmitting pulse groups as follows (herein, pulse spacing is between leading -3 db points):

A. 0.25 µs pulses: Up to 5 pulses, spaced 1.00 µs, or more.(12)

B. 1.00 µs pulses: One pulse.
It is highly desirable that the radars also be capable of the following (at reduced duty ratios if necessary):

C. 0.50 µs pulses: Up to 3 pulses, spaced 1.5 µs, or more.(13)

D. 1.00 µs pulses: Up to 2 pulses, spaced 3.0 µs, or more.[14]

1.19. PEAK POWER DIFFERENCE: The peak power difference between any two pulses of a pulse group shall not exceed 1 db.

1.20. PULSE GROUP REPETITION FREQUENCY (GRF):

A. A radar's GRF shall fall within the range 100 groups/sec. to 1,800 groups/sec.

B. In a chain radar operation it is sometimes desired to use up to five radars interrogating the beacon in time sequence. Therefore, the effective GRF at the beacon can be up to five times that of one of the radars.

1.21. RECOVERY TIME: For high performance beacons with interrogation coding, the beacon's receiver shall recover to within 1 db of normal sensitivity within:

A. 1 µs after any single pulse and

B. 10 µs after the last pulse of the beacon's reply.

C. See 1.20 above and also PART II, 2.21, 2.22 and 2.23.

1.22. BLANKING GATE: For maximum beacon availability and for minimum under-powered or off-frequency replies, the beacon's receiver should incorporate a blanking (disabling) gate that extends from just ahead of the first pulse of the beacon's reply to the end of the beacon's recovery period following the last pulse of the reply. This is to prevent triggering before the beacon's modulator has recovered fully.

1.23. DUTY RATIO: The radar's transmitter should have as high a duty ratio as practical and shall have a duty ratio capability no less than 0.0010.

1.24. PULSE CODES; General:

A. Radar and Beacon: Within these system standards, all pulse spacings or pulse time specifications are for the leading -3 db points of radio frequency pulses, unless otherwise specified.[25]

B. Radar: For pulse coding, a radar shall transmit two, or more, equal duration RF pulses in a group. One of these pulses will trigger the beacon. This "Triggering Pulse" will (except as it may be advanced in time to compensate for the Beacon's Reply Delay) be the equivalent of the normal single pulse of the radar in the skin-tracking mode. One or more of the other pulses will, with the Triggering Pulse, form an "Interrogation Code". One or more of still other pulses of the group, time modulated with respect to the Triggering Pulse, (or modulated on and off), will serve for transmitting control commands via the beacon. These modulated pulses, with the Triggering Pulse, are called the "Control Code". In some instances the pulses that form the Interrogation Code may also be time modulated with respect to the Triggering Pulse to serve the command-control function in addition to forming the Interrogation Code. This type of code is called a "Combination Code". The total pulse group is called "Radar's Code". The Triggering Pulse is also called "Beacon Ranging Pulse".[15]

C. Beacon: The beacon will receive the Interrogation Code pulses and (if the pulse spacings are correct) the Triggering Pulse will trigger the beacon's transmitter through a fixed delay line. The beacon should also deliver, for command control purposes, video pulses corresponding to the Triggering Pulse and the modulated pulses of the Control Code.

1.25. INTERROGATION CODES:

A. Radar: The Interrogation Code shall consist of either 2 or 3 fixed RF. pulses, the last of which is the Triggering Pulse; two-pulse codes shall be used only for minimum-performance beacons. These pulses shall meet the following:

a. A pulse shall not be more than 9.50 μs (and should not be more than 6.00 μs) before the Triggering Pulse.[18]

b. Any two pulses shall not be closer together than the minimum values given in 1.18.

c. The RF. pulse timing, with respect to the Triggering Pulse, shall have an absolute inaccuracy (including jitter) of not more than ± 0.05 μs at all times.

d. When three pulses are used, the two spacings preferably should be unequal and it is preferable that one spacing not be an integral multiple of the other.

e. Each nominal spacing shall be the sum of quanta of exactly 1/10 μs, starting at zero. For example, a spacing of 1.30 μs is admissible but 1.25 μs is not.

f. The different codes in use on the same frequency at one time should be sufficiently different for the beacon to reject all except the one for which it is adjusted.[23]

g. A pulse of the Interrogation Code shall be no closer to another pulse (including Control Code pulses) than the minimum values stated in 1.18. This applies to a command-control pulse when it is in the position of its peak time deviation under modulation.

B. Beacon: The beacon's interrogation decoder:

a. Should be of the delay-line type (rather than a multivibrator type) to reduce susceptibility to blocking by interference. To reduce susceptibility to blocking or to false interrogations, the decoder should be of the non-reflecting, or matched load delay-line type.

b. Should be adjustable to accept single pulse interrogations and (in the case of a 3-pulse decoder) should be adjustable to receive 2-pulse interrogations.

c. Should be adjustable to cover a family of several different interrogation codes. It is suggested that there be at least 4 different codes and preferably several times that many.

d. Shall have acceptance slots and rejection zones such that the beacon accepts the codes (for which it is adjusted) at least 99% of the time and rejects all other codes of that family of codes at least 99% of the time. This is for the beacon's rated range of input signal strengths and for the permitted tolerances of the radar's pulses.

e. Shall reject single pulses of any length (except when intentionally disabled) and shall reject CW signals, including AM, FM, and swept frequency signals.

f. Shall have its delay-lines adjusted so that the beacon always triggers on the leading edge of the Triggering Pulse (which is the last pulse of the Interrogation Code) rather than on the leading edge of one of the other pulses as delayed by a decoder delay-line. In other words, for a 3-pulse code, the first pulse should be delayed to coincide exactly with the second pulse but the resulting 1-2 coincidence pulse should be delayed so that its center coincides with the leading edge (rather than the center) of the third pulse.

g. Should have one or more families of 3-pulse interrogation codes that are formed by keeping two pulses fixed and moving the other pulse. This will make it easier for the radar to instantly shift from one code to another of that family (merely by moving one pulse).

h. Preferably should reject pulses more than twice as long, or less than half as long, as the rated interrogation pulse width.

1.26. CONTROL CODES:

A. Radar: In addition to the pulses of the Interrogation Code, one (or two) additional pulses may be used for command-control only. These pulses may be placed before or after the Interrogation Code pulse group. These modulated Control Code RF pulses shall meet the following:

a. Under peak time-modulation conditions, no two pulses, including the pulses of the Interrogation Code, shall be spaced closer than minimum values stated in 1.18.

b. Under peak time-modulation a pulse shall not be more than 12.0 μs (should not be more than 6.00 μs) earlier than the Triggering Pulse.[18]

c. Under peak time-modulation, no pulse shall follow the Triggering Pulse by more than the amount indicated by 2.28-A-(b), -(c), and -(d).

d. Under zero time-modulation, the control pulses shall be spaced according to 1.25-A-(c) and -(e).

e. Time-modulation shall be one of the following four types and shall have the non-linearity (the error in time deviation proportional to modulating voltage) be no greater than 2% of the total stated maximum deviation:

± 0.50 μs maximum, 0 to 900 cps Sine Wave or Square Wave*.

± 2.00 μs maximum, " " " " " " " " ".

Zero to + 4.0 μs maximum, " " " " " " ".

Zero to -4.0 μs maximum, " " " " " " ".

*(Components up to 9,000 cps shall not be down more than 3 db).

f. The modulation sensitivity of each pulse shall be adjustable. The adjustment shall have sufficient resolution and stability to make two pulses maintain the same spacing at all times when both are time modulated by the same voltage. The spacing shall, within the specified linearity tolerance, meet the pulse time inaccuracy of 1.25 -A-(c) above.

g. Control pulses (when unmodulated) should be spaced so that no two pulse pairs of the Radar's Code have identical spacings and so that no two spacings add up to equal a third spacing.

1.27. COMBINATION CODES:

A. Radar: Pulses of the Interrogation Code may be used for command control by time modulating one, or two, interrogation code pulses with respect to the Triggering Pulse. These modulated pulses shall meet the requirements of 1.26 except that they cannot, by definition, follow the Triggering Pulse. This method gives the least number of pulses for both interrogation and command but it does not provide the maximum interrogation selectivity.

B. Beacon: Note that, with this method, the interrogation code is not as secure as one in which interrogation pulses are not modulated because the decoder acceptance slots have to be wide enough to pass the time modulation and the increased spacing error.

1.28. REPLY DELAY: (See 2.28, for this subject).

1.29. AGC AND LIMITING:

A. Because of the great range of signal strengths that a beacon's receiver (and decoder) must handle and because of the desire for small Reply Delay Variation (See 2.28), the receiver should have Automatic Gain Control or equivalent. When only one radar is interrogating a beacon, a conventional gated slow AGC is very satisfactory. However, when several radars of a chain are time-sharing a beacon, such an AGC is not satisfactory because the stronger signals discriminate against weaker ones (received signals will vary in strength even when radar Power Programming is used. See 1.31.). Possible solutions are either Instantaneous Automatic Gain Control (IAGC) or the use of a logarithmic receiver (possibly with a very limited amount of gated and delayed slow AGC).

B. If AGC is used:

a. There should be means to disable the AGC;

b. The AGC shall be gated and the level should be set by either the 3rd pulse or the 4th pulse, selectable by a bench adjustment. By using the 4th pulse, 3-pulse radars tracking the beacon would not affect the AGC level, thereby providing maximum accuracy for the 4-pulse radar;

c. There shall be means to adjust the time constant and range.

d. The nominal time-constant should be about 0.1 second.

e. The range should be such that there is 12 db of delay (no AGC in the 12 db above the triggering threshold) and such that the beacon does not reject valid interrogations that are as much as 18 db below the strongest signal (that is setting the AGC level).

f. The beacon shall accommodate interrogations from up to 5 radars of a chain.

g. The AGC shall operate over the full interrogation rate range of the beacon, including the sporatic interrogation of acquisition.

1.30. STC: Sometimes a beacon is over-interrogated by local interference such that it would be desirable to have its sensitivity reduced at first and then programmed up with time after launch (or to have its sensitivity adjustable by remote control).

1.31. POWER PROGRAMMER:

A. Radar power should be programmed automatically as a function of the range setting. The principal purpose of this is to minimize beacon reply delay variation. See 2.28. (Reply Delay). Therefore, the programming should be according to the inverse square law and should be over as great a power range as possible. However, it should be possible to select the radar range at which the program starts and the radar range at which the program ends. A power programmer serves other purposes such as reducing beacon crystal burnout problems and reducing the skin-tracking side-lobe problem. See 2.30. (STC). Although a power programmer is extremely valuable for beacon operations, it does not solve all problems of varying signal strength at the beacon.[24] See 1.29. (AGC).

1.32. TRACKING GATES: Not applicable to the interrogation link.

1.33. REPLY CODE: Not applicable to the interrogation link.

1.34. FALSE REPLIES: Not applicable to the interrogation link.

1.35. CRYSTAL PROTECTION:

A. Beacons, as well as radars, should incorporate TR tubes and crystal shutters (or other crystal protectors).

1.36. SYNCHRONIZATION:

A. All radars of a chain (or of adjacent chains) should be synchronized (but not necessarily isochronized). Normally all adjacent radars should be pulsed simultaneously (isochronized) to prevent mutual interference. However, the requirement to "leap-frog" to avoid interfering pulses or to avoid "beacon stealing" sometimes prevents this (See 2.34). Therefore, adjacent radars should be synchronized and operated on different radio frequencies and with different interrogation codes. Since all radars of one chain must be on the same frequency and have the same code, this means that two radars of one chain should not be adjacent (unless one has its transmitter off and is tracking beacon reply pulses elicited by the other radar).

B. Although "leapfrogging" with synchronized radars (for the prevention of "beacon stealing") is reasonably satisfactory with two or even three radars in a chain, a chain with more radars in use at one time may not be satisfactory. Therefore, a radar chain should have automatic computers and data links for causing the interrogations from different radars to be interlaced in time at the beacon by continuously adjusting the time of triggering of each radar (except one).

1.37 DISPLAYS AND MONITORS:

A. Radar: Radars should have on the console monitoring displays of:

a. Frequency.
b. Pulse Width.
c. Code (Pulse Number and Spacing).
d. Peak Power.
e. Transmitter Voltage and Current, etc.

B. Beacon:

a. A beacon's superheterodyne receiver having a broad flat-topped pass-band is difficult to tune accurately with simple field equipment. Therefore, such a beacon should have an auxiliary detector and high Q circuit, tuned to the center of the IF pass-band, for use with an external tuning indicator.

b. Beacons should have externally available signals for adjusting or checking the beacon's receiver or for monitoring in-flight performance by means of telemetry:

(1) L.O. Signal.
(2) L.O. Frequency Indication. (Usually not incorporated in beacon).
(3) Mixer Current.
(4) Receiver tuning indicator.
(5) AGC Voltage (or signal strength monitor).
(6) Video Output.
(7) Audio Indication (possibly use blanking gate - See 1.22).
(8) Power Voltages.

PART II

RESPONSE LINK
Beacon to Radars

2.1. FREQUENCY RANGE: (1)

A. Beacon's Transmitter: Shall be tunable to any frequency within 5,400 to 5,900 mc/sec. (MC/S means million cycles per second; sometimes written "mcps", or even "mcs" for short.)

B. Radar's Beacon Receiver: Shall be tunable to any frequency within 5,400 to 5,900 mc/sec.

2.2. FREQUENCY INACCURACY (ABSOLUTE): (2)(1)

A. Beacon's Transmitter: Shall hold ± 4 mc/sec or less at all times and the drift rate shall not exceed 1 mc/sec/min., (any and all pulses).

B. Radar's Beacon Receiver: Shall have AFC to follow the beacon's frequency to within ± 0.2 mc/sec or better over a range of at least ± 6 mc/sec for $S/N \geq$ 6db.

2.3. FREQUENCY JITTER:

A. The pulses of a single beacon reply shall not differ in frequency by more than 0.2 mc/sec.

2.4 FREQUENCY OFFSET:

A. It is not required that the beacon's transmitter operate on a frequency less than 25 mc/sec away from the beacons receiving frequency. (3)

2.5. FREQUENCY SPECTRUM:

A. Beacon's Transmitter: The RF pulse spectrum shall not be wider between -6 db points than 3.0/pulse width under maximum vibration and ordinarily no wider than 2.0/pulse width . For example, for 0.5 µs pulses, the spectrum width shall not exceed 4 mc/s except under maximum vibration. (4)

B. Radar's Receivers: See 2.10 (RF Bandwidth).

2.6. LOCAL OSCILLATOR FREQUENCY:

A. The radar's L.O. for beacon reception shall be capable of operating on either side of the beacon's frequency. Normally this L.O. should be below the beacon's frequency. (20)

B. Normally the same radar's skin-tracking L. O. should be above the radar's frequency. (20)

2.7. INTERFERENCE RADIATION:

A. Both the transmitter and the receiver shall meet Military Specifications MIL-I-006181 and MIL-E-16400 (SHIPS), as applicable, except as specified herein.

B. Radiated power at frequencies outside of 5,400 to 5,900 mc/s should be at least 60 db less than the C-Band fundamental, except for the theoretically expected harmonics of the C-Band RF pulse.

C. Local Oscillator C-W energy delivered to the antenna should be less than -40 dbm.

2.8. IMAGE FREQUENCY REJECTION:

A. The radar's receiver should have at least 60 db rejection of the image frequency, and preferably more. (5)

2.9. INTERFERENCE SUSCEPTIBILITY:

A. The radar's receiver should have at least 60 db rejection of CW or pulse signals outside of 5,400 - 5,900 mc/s, except for the theoretical pass-band of the receiver. (5)

2.10. BANDWIDTH: (17)

A. Beacon's Transmitter: See 2.5 (Frequency Spectrum).

B. Radar's Receiver: The RF pass-band should be optimum for the pulse width to be received and should have steep skirts for selectivity, but not so steep as to slow the pulse rise and fall unduly or to cause overshoots. Since the radars track the center of gravity of a video pulse (rather than the leading edge), a short rise time (a broad pass-band) is less important than in the case of a beacon, which triggers on the leading edge. The use of receiver AFC makes it unnecessary to widen the pass-band to accommodate the frequency errors of the beacon's transmitter and of the radar's receiver. However, the pass-band shall be wide enough so that the AFC tuning error will not distort the pulse shape, for this could shift the center of gravity of the received pulse, thereby introducing a range error. Doppler frequency shift (usually negligible) is also accommodated by the AFC. Generally speaking, the radar's RF bandwidth should be about 2 mc/s for a 1 μs pulse, about 4 mc/s for 0.5 μs pulse and about 8 mc/s for 0.25 μs pulse. (6)(7). Video bandwidth should be about 5 mc/s or more for short rise and fall times.

2.11. RF. CHANNELS:

A. Beacon's Transmitter: It is recommended that the beacon transmitter frequency assignment ordinarily be about 40 mc/s below the frequency assigned to the radar's transmitter.

B. Radar's Beacon Receiver: This receiver must be tuned to the frequency assigned for the beacon's transmitter; it is recommended that the L.O. normally be set below the beacon's frequency. The radar's IF is 30 mc/s.

C. Radar's Skin Receiver: For simultaneous skin and beacon reception, the skin L.O. normally should be set above the radar's transmitter frequency. The radar's IF is 30 mc/s.

D. Two-Way Channels: The frequency assignments and L.O. settings as mentioned above in 2.11 and 1.11 were based on the desire to separate skin and beacon signals and upon mutual interference considerations. It was assumed that the radars have had added some kind of image rejection device such as preselectors, and that the beacons have an IF of 60 mc/s, or have adequate image rejection. It should be possible to provide six independent two-way (offset) radar/beacon channels within 5,400 to 5,900 mc/s. With present tunable radar magnetrons, the channels would be limited to five. If the lowest frequency channel is reserved for high power fixed tune radars for skin-tracking only, the number of channels reduces to four. Without image rejection devices on the radars, there may be some unavoidable mutual interference with these frequency assignments and L.O. settings. (See 1.36).

Spot frequency assignments are considered by some of the test ranges to be classified. Therefore, specific frequency recommendations have not been included.

2.12. POLARIZATION:

See Part I, 1.12.

2.13. ANTENNA PATTERN:

A. Beacon Transmitting: Beacon transmitting antenna pattern requirements are identical with those for the beacon's receiving antenna. See Part I, 1.13.

B. Radar Receiving: In beacon-tracking, there is more danger of accidentally locking on with a radar side lobe than there is in skin-tracking an isolated target. For this reason, the pattern side lobes should be as small as possible (and the radar's Sensitivity-Time-Control should be used). Under clutter conditions, there is far less danger when using a beacon having a frequency offset.

2.14. RF PULSE DURATION: The beacons's RF pulse (envelope) duration ordinarily shall be 0.50 μs, ± 10%, between -3 db points (50% peak power points). It is desirable that a beacon be adjustable to provide either 0.50, 0.75, or 1.00 μs, ± 10%. It is highly desirable that the beacon's reply pulses be longer than the interrogating pulses in order to facilitate visual discrimination between the beacon reply and skin returns. Herein "peak" power is "smooth peak" as defined by paragraph 4.16.3.3 of MIL-E-1c.

2.15. RF PULSE RISE AND FALL: The beacon's RF pulse (envelope) rise time, from -10 db to -0.5 db (10% to 90% peak power) shall not exceed 0.05 μs. The fall time from -0.5 db to -10 db shall not exceed 0.10 μs and preferably should be shorter.

2.16. RF PULSE JITTER: The beacon's RF pulses (envelopes) (with a video trigger substituted for the receiver output) shall not have leading edge jitter exceeding ± 0.01 μs, pulse width jitter exceeding ± 0.02 μs, nor peak power jitter exceeding ± 0.2 db. When an RF pulse group into the receiver is used to trigger the transmitter, the leading edge jitter shall not exceed ± 0.05 μs.

2.17. RF PULSE TOP: The beacon's RF pulse (envelope) between the outer -1.0 db points (80% peak power points), shall at no point deviate more than 0.5 db from the "smooth curve" as defined by paragraph 4.16.3.3 of MIL-E-1c.

2.18. RF PULSE GROUP: For telemetry (or identification) purposes, the beacon should be capable of transmitting a second reply pulse the same as the first but delayed over the range 25 to 125 μs according to the data to be telemetered. It is recommended that the modulator for the second pulse be in a separate removable unit to minimize the beacon needed for applications not requiring the second pulse. When the second pulse is available, there must be means to disable it.

2.19. PEAK POWER DIFFERENCE: The two pulses of a beacon reply shall not differ by more than 1 db.

2.20. PULSE GROUP REPETITION FREQUENCY: (GRF)

A. The beacon shall respond at least 95.0% of the time to valid interrogations over at least the range from 100 to 2,000 interrogations/sec. Over this range the sensitivity of the receiver and the peak power of the transmitter should not vary more than 2 db.

B. The beacon shall not be damaged by interrogations up to 10,000/sec and shall recover from an over interrogation within 2,000 μs.

C. It is highly desirable that the beacon respond to up to at least 5,000 interrogations per second (for chain radar operations).

D. During acquisition, the interrogations may be very weak or sporatic. Therefore, the beacon shall respond to any single valid interrogation at least 95% of the time, regardless of the time between interrogations (so long as the time is greater than 1/2,000 second).

E. The beacon shall not incorporate repetition rate tuning unless it can be disabled easily.

F. See also Part I, 1.21 and see 2.21, 2.22, 2.23 and 2.24 below:

2.21. RECOVERY TIME: The beacon's transmitter should recover, to within 2 db of normal peak power, within 20 µs after the last pulse of the beacon's reply. For beacons not requiring chain-radar tracking, a longer recovery time, up to 400 µs, is acceptable. However, it is strongly recommended that beacons that cannot be tracked by a radar chain not be used.

2.22. BLANKING GATE: See Part I, 1.22.

2.23. DUTY RATIO: The beacon's transmitter duty ratio should be as large as feasible within the above stated parameters. In no case shall the duty ratio be less than 0.0010. A maximum duty ratio of 0.0020 or more is highly desirable, even though this may result in a slightly reduced peak power at the high interrogation rate during chain radar operations.

2.24. PULSE CODES; GENERAL:

A. Beacon and Radar: Within these system standards, all pulse spacings or pulse time specifications are between leading -3 db points of radio frequency pulses, unless otherwise specified.

B. Beacon: The beacon's reply, if coded, shall consist of the usual beacon reply pulse used for tracking, plus a second pulse for telemetry or for identification purposes. The second pulse should be of the same duration as the first. This pulse code is called the "Beacon's Code" or "Reply Code".(16)

C. Radar: The radar operator may use the second pulse for identification by observing it on one of the oscilloscope displays. To use the pulse for telemetry, it must be time modulated and the radar must be modified and auxiliary telemetry equipment added.

2.25, 2.26, and 2.27: Not applicable to the Reply Link.

2.28. REPLY DELAY:

A. Beacon: The beacon shall have, at its antenna, an intentional fixed delay between the Triggering Pulse and the beacon's first reply pulse. This delay is to permit separation of simultaneous skin and beacon returns at the radar, or to permit the use of control pulses following the Triggering Pulse, or to permit separation of returns from two simultaneously triggered beacons on the same frequency by having the reply delays different. The beacon's Reply Delay (RD) shall meet the following:

a. When no radar pulses follow the Triggering Pulse, the delay shall not be less than (interrogation pulse width +1.25 μs). For example, (0.25 μs +1.25 μs) = 1.50 μs. This delay is to provide the tracking gate clearance required to permit simultaneous monitoring at the radar of skin returns while tracking the beacon return, and vice versa.

b. When one or more Control Code pulses follow the Triggering Pulse, the minimum delay shall be (interrogating pulse width +1.25 μs) plus (the maximum possible time after the Trigger Pulse of the latest modulated pulse when under maximum modulation). This keeps the same gate clearance as in the previous case.

c. The beacon's Reply Delay shall be a fixed value of 9.50 us or less and should be 5.50 μs or less. (19)

d. A nominal fixed Reply Delay value shall be the sum of quanta of exactly 1/10 μs starting with zero. The fixed delay shall be measured by triggering the beacon with an RF interrogation of -30 dbm peak power into the beacon's receiver.(19)

e. The fixed Reply Delay, as measured above, should hold to an absolute inaccuracy of no more than ± 0.05 μs at all times and under the expected environment.

f. The Reply Delay jitter, with signal strength varied from 10 db above the smallest signal that triggers the beacon 95% of the time, to the largest signal the beacon is rated for, should not exceed 0.02 μs peak to peak.

g. Reply Delay Variation with strength of the interrogating signal usually is the greatest position measuring error caused by a beacon. Therefore, this variation (neglecting jitter) should be reduced to the greatest practical degree. See 1.10 (Bandwidth) and 1.29 (AGC). The Reply Delay Variation, with signal strength varying from 10 db above the smallest signal that triggers the beacon 95% of the time, to the largest signal the beacon is rated for, shall not exceed 0.05 μs (about 10 yds) except as follows:

(1) Where poorer range measuring accuracy is tolerable.

(2) Where several radars of a chain are sharing the beacon. In this case the strongest signal shall be replied to with the specified accuracy and the other signals replied to with the best possible lesser accuracy. See 1.29 (AGC), and See 2.31 (Power Programmer).

(3) During the transient conditions of acquisition.

B. Radar: The beacon's Reply Delay (RD) introduces a large fixed error in the measured range unless it is compensated. Because of the frequent need for realtime data, the radars shall incorporate Reply Delay Compensation (RDC). The RDC shall cover reply delays up to 9.50 µs. The RDC:

a. Shall have an adjustment range of zero to at least 9.90 µs.

b. Shall have adjustment increments (or calibration increments) of exactly 1/10 µs. Additional smaller increments are permissible.

c. Shall have an absolute inaccuracy no greater than ± 0.030 µs, (should be no greater than ± 0.020 µs). The inaccuracy is that of any interrogation, not of the mean of several interrogations.(21)

d. Should be directly calibrated (in microseconds of RDC, starting with zero) so that reference to calibration curves or tables is not necessary.

e. Shall have a fine adjustment means (trimmer) having a resolution or increment no larger than 0.010 µs. The trimmer should have an approximate calibration and shall have a range of at least plus or minus 0.050 µs about the set (calibrated) value.

f. Should be in duplicate to permit a push-button selection, by the radar operator, between two different pre-set values of RDC. This is to permit the use of two beacons on the same frequency in one vehicle. See 2.28 A.

g. Shall have range zero-set means to adjust for RD being measured from leading edges and for the beacon's pulse duration being different from the radar's pulse duration. The zero-set shall be independent of the skin-tracking range zero-set and shall hold for both of the duplicate RDC adjustments. (21) (22)

2.29. AGC AND LIMITING:

A. Radars shall have signal-actuated, gated, automatic gain control for the receivers. Logarithmic receivers may be advantageous. See 1.29. and see 2.30., following:

2.30. STC:

A. Since signal-actuated AGC may not keep a radar from locking on a side-lobe of the radar's antenna pattern, Sensitivity-Time Control is required in the radar. For best results, the STC should have a dual slope capability, one slope for beacon-tracking (square law) and one for skin-tracking (fourth power law). Since side-lobe tracking is more likely with beacon-tracking, (except under clutter conditions) the STC should have a square law slope if only one slope is available. A Radar Power Programmer (See 1.31) helps solve this problem in the case of skin-tracking but does not do so for beacon-tracking. A boresight TV system (See 1.36) sometimes is extremely valuable for determining whether tracking is being done with a side-lobe.

2.31. POWER PROGRAMMER: (Not applicable to Response Link).

2.32. TRACKING GATES:

A. Radars shall have selectable beacon-tracking gates for beacon pulses of 0.50, 0.75 and 1.00 µs duration. See 2.14 (RF Pulse Duration).

B. Radars should have selectable skin-tracking gates for radar pulses of 0.25, 0.50 and 1.0 µs duration so that skin-tracking can be done while interrogating a beacon with radar pulses of any of these durations. See 1.4 (RF Pulse Duration).

2.33. REPLY CODE:

A. Beacon: Beacons having a second reply pulse for telemetry purposes shall space the second pulse 25.0 µs after the first pulse when no time-modulating voltage is applied to the beacon. The pulse spacing shall vary linearly out to 125 µs when the voltage increases to plus 5.00 volts. For synchronizing data decommutators and for transmitting reference voltage data, the beacon shall be capable of increasing the spacing to the range 130 to 165 µs when the modulating voltage is increased. These specifications are those of the AN/DKT-9 beacon telemetry system.

B. Radar: Some radars should be fitted with AN/DKT-9 telemetry equipment.

2.34. FALSE REPLIES:

A. Beacon: A false reply is a beacon reply that is valid in all respects except that it is elicited by noise or by other radars rather than by the radar of interest. The beacon, when connected to a dummy antenna, shall not transmit more than five false replies per second, averaged over 100 replies, or over one minute.

B. Radar: The radar shall have means to avoid false replies (and other potentially interfering pulses). The radar should have means to shift the phase of the radar's train of interrogations to avoid a pulse train that is drifting into the tracking gate. This is sometimes called "Leapfrogging" in that the undesirable pulse appears to jump over the tracking gate.

2.35. CRYSTAL PROTECTION:

A. Beacons, as well as radars, should incorporate crystal shutters and TR tubes, or other crystal protectors.

2.36. SYNCHRONIZATION: Not applicable to response link.

2.37. DISPLAYS AND MONITORS:

A. Beacons: Beacons should have externally available signals for adjusting or checking the beacon's transmitter or for monitoring of in-flight performance by means of telemetry:

(1) Transmitter Signal
(2) Transmitter Frequency Indication. (Usually not incorporated in Beacon Proper).
(3) Transmitter Power Indication.
(4) Modulator Pulses.
(5) Power Voltages.

B. Radars: The radars should have at the console:

(1) Indication of the frequencies to which the receivers are tuned.
(2) Telemetry displays for real time monitoring of beacon performance in-flight.
(3) Receiver Noise Figure Test.
(4) The usual range indicating oscilloscopes.
(5) Boresight television.
(6) An auxiliary PPI oscilloscope.

PART III

NOTES
for
(PART I AND PART II)

(1) By "frequency" is meant the frequency of the major component of the spectrum of the RF pulse. Any and all pulses shall meet these specifications. In the case of a receiver, "frequency" means the frequency of a signal that is in the center of the pass-band of the receiver. See (17).

(2) The frequency inaccuracy (error) tolerance includes the error of the wavemeter; therefore, the radar's instability plus the radar's setting-error must be better than the stated absolute inaccuracy. Usually the wavemeter error is about 0.5 mc/s. Note that error or inaccuracy is sometimes called accuracy - "The accuracy of the meter is 0.2 percent".

(3) It is desirable to be able to operate with a frequency off-set less than 25 mc/s; or at least to have the receiver protected against damage from tuning the transmitter through the receiver pass-band. Normally use a 40 mc/s offset.

(4) The wider spectrum is permissible under condition of maximum vibration only when unavoidable. Beacon frequency modulation causes radar errors - See Reference D-3(b).

(5) The rejection-ratio is to be measured with CW signals, or with a pulse that is long enough to have insignificant harmonics at the other frequency. Note that FPS-16 and MPS-26 radars do not incorporate image rejection at this time. For information on image rejection without preselection filters, see Page 4A of Proceedings of the IRE for January 1960.

(6) See <u>MIT Radiation Laboratory Series</u>, McGraw-Hill; Vol I, page 34; Vol 3, page 152, page 367; Vol 23, pages 215 and 181; Vol 24, pages 208, 209 and 212.

(7) See <u>MIT Radiation Laboratory Series</u>, McGraw-Hill; Vol 23, page 156.

(8) See <u>MIT Radiation Laboratory Series</u>, McGraw-Hill; Vol 23, page 214.

(9) Note that linear "vertical" polarization gradually changes to linear horizontal polarization as the elevation angle of the radar increases to 90°. The reference here is the vertical axis

of the radar antenna mount.

(10) The Institute of Radio Engineers defines a Right-Handed Polarized Wave as one receding from the observer and radiated by an electric vector rotating clockwise in a fixed plane that is in front of the observer and at right angles to the direction of propagation of the wave in question. The definition of classical physics is exactly opposite to the IRE definition, therefore, be wary when concerned with polarization sense descriptions. Note that circular polarization and linear polarization are merely limiting cases of elliptical polarization. Properly speaking, ellipticity is a measure of deviation from a circle, but some writers use the term elliptical polarization to mean polarization other than linear.

(11) When using a circularly polarized radar to accommodate a beacon in a rolling and/or tumbling vehicle, the beacon antenna pattern should be extremely free of circularly polarized components, or should be so that the sense of the circularly polarized component does not reverse in any viewing aspect. This is because the sense of a circularly or elliptically polarized wave reverses as the viewing aspect is reversed; when the polarization senses of the beacon and the radar are opposite, the attenuation is very large. It is for this reason that a circularly polarized beacon antenna often is not satisfactory with a circularly polarized radar (but usually would be satisfactory with a linearly polarized radar).

(12) AN/FPS-16 radars, as first made, cannot space the fifth pulse as close as 1 μs. It is expected that the radars will be modified to satisfy this requirement. See APPENDIX B, paragraph B-3.

(13) AN/MPS-26 (XN-1) radars, as first made, do not provide 0.50 μs pulses in addition to 0.25 μs and 1.0 μs pulses. AN/FPS-16 radars are known to be capable of two 0.50 μs pulses spaced 1.25 μs. It is understood that three 0.50 μs pulses can be spaced as close as 1.3 μs apart (leading edges).

(14) Nothing is known yet about the ability of MPS-26 radars to transmit groups of 1 μs pulses. It is understood that FPS-16 radars can space two 1 μs pulses as close as 2.8 μs apart (leading edges).

(15) On-off modulating of Control Code pulses is permissible only in special cases because the resulting changes in radar duty-ratio complicate the radar frequency stability problem.

(16) These Standards cover simple beacon telemetry systems such as AN/DKT-9. Future development of beacon telemetry systems may require a more complex reply code consisting of more than two pulses.

(17) A. "Bandwidth" means the width of a pulse spectrum or of a frequency pass-band. The receiver of a radar or beacon cannot be characterized easily by a single bandwidth figure, for there are several links in the chain: antenna, preselector, duplexer, RF amplifier, mixer, IF amplifier, video detector and video amplifier. An antenna ordinarily does not affect bandwidth; if an antenna does affect bandwidth, it shall (for purposes of these System Standards) be considered a part of the receiver. It is possible to describe the receiver bandwidth characteristics by lumping all RF links (including the antenna and IF links) under the topic "RF Bandwidth" and by lumping the Video Detector and Video Amplifier under the topic "Video Bandwidth":

(a) By "RF Bandwidth" is meant the width of the Carrier Pass-Band: "The Frequency Difference between the two outer -3 db points of the curve of Radio Frequency Output Power (delivered to the video detector) vs Frequency of an Unmodulated Sinusoidal (C-W) Input Signal.

(b) By "Video Bandwidth" is meant the width of the Modulation Pass-Band: "The frequency difference between the two outer -3 db points of the curve of Video Output Power vs the Frequency of Sinusoidal Modulation of an Amplitude-Modulated input Carrier of the proper Frequency (RF or IF) applied to the Video Detector". Note that some writers use the term Video Bandwidth to mean the C-W bandwidth of the Video Amplifier alone, ignoring the video detector.

B. "Pulse Bandwidth": Another way to characterize receiver bandwidth is to state the RF carrier frequency range over which RF pulses of stated envelope shape and power characteristics are delivered as video pulses of stated shape and amplitude characteristics. Although this method is much more difficult to specify, it has the advantage of including phase distortion effects, (which the previous definitions do not include) and of including the effect of all parts of the receiver through the video amplifier. Although this "Pulse Bandwidth" method more closely describes the actual operation of a receiver, it is not used in these System Standards.

(18) It is highly desirable that all pulses (including modulated pulses and including the beacon's first reply pulse) be entirely within -6.0 μs to + 5.5 μs of the Triggering Pulse in order to see all pulses when the Triggering Pulse

is in the gate in the Center of the 2,000 yd (12.2 μs) range oscilloscope. A secondary desire is that no pulse be more than 9.90 μs from the Triggering Pulse in order to make possible the use of a digital type multiple-trigger generator or encoder (with only two decade switches) (this is also the reason for requiring 1/10 μs quanta). All C-Band beacons existing or under development, except AN/DPN-54, satisfy the above desires. AN/DPN-54 requires the first pulse to be at minus 9.0 microsecond, modulated to -12.0 microseconds. These System Standards do accommodate AN/DPN-54 beacons but the longer codes will exceed the limits of the 2,000 yd oscilloscope.

(19) Beacon reply delay should not exceed 5.50 μs in order to keep the first reply pulse within the 2,000 yd range oscilloscope while the radar is skin-tracking the Triggering Pulse and displaying it in the center of the 2,000 yd oscilloscope. To do this with a longer reply delay would require the radar to be modified to move the skin gate to the left of center, thereby possibly crowding some of the interrogation code pulses off the 2,000 yd oscilloscope. Note that the RF cable from the antenna to the beacon introduces a delay. Therefore, high accuracy beacons should have means to trim the reply delay to compensate for cable delay.

(20) These L.O. frequency settings were selected to minimize L.O. beat interference, and Image interference between radars. With these settings, skin and beacon signals can be received individually or simultaneously. Never place an L.O. within the pass-band of another receiver and avoid separating two local oscillators by multiples or sub-multiples of the IF. For example: current radars have an IF of 30 mc/s, therefore, the skin and beacon local oscillators should not differ by 60, 30, 15, or 7.5 mc/s, etc.

(21) Note that Reply Delay is measured from the leading edge of the Triggering Pulse to the leading edge of the first Reply Pulse but the radar tracks the center of gravity of the Reply Pulse (or of a Skin-Tracking Pulse). Therefore, the RDC device must incorporate a zero-set adjustment to compensate for the range measurement difference that occurs when the Skin-Tracking Pulse width differs from the Beacon's Reply Pulse width.

(22) It is recommended that the radar's Multiple-Trigger Generator (Encoder) be timed from the radar's Pre-Trigger so that the Beacon Reply Pulse is received at exactly the same time that a Skin-Tracking Pulse of the same duration would have been received, and that one of the skin-tracking gates

be used for beacon-tracking. This method requires that any beacon delay compensation device that is integral with the radar be set to zero or disconnected. The only disadvantage of this method is that the skin gate is in the center of the 2,000 yd oscilloscope and, therefore, the radar's code may extend off the left end of the oscilloscope while beacon-tracking. To avoid this, it would be necessary to modify the radars to shift the gate to the right end of the oscilloscope when beacon-tracking. A minor modification of FPS-16 radars may be necessary to obtain a radar's pre-trigger (for the Encoder) when operating from external synchronization.

(23) The radar's Encoder should have duplicate channels for one of the pulses so that remote control pushbutton selection between two pre-set interrogation codes is possible. These pulses should be settable to be either the first or the second pulse of a 3-pulse interrogation code.

(24) A closed-loop power programming system, in which the signal strength at the beacon is telemetered to the radar, would be useful if the data could be commutated between the radars of a chain.

(25) AN/DPN-50 beacon will be built with the unusual characteristic of triggering on the trailing, rather than leading, edge of the triggering pulse. This is because the DPN-50 receiver characteristics are such that the delay variation with signal strength is less on the trailing edge of a symmetrical pulse. With such a beacon, beacon delay considerations must take into account the radar's pulse width (and variations thereof) and any difference in the leading edge and trailing edge slopes. (See 1.18). Later versions of AN/DPN-50 may be changed.

APPENDIX A

NOMINAL CHARACTERISTICS OF AN/FPS-16 and AN/MPS-26(XN-1)

C-BAND INSTRUMENTATION RADARS

At this writing, AN/FPS-16 radars are being installed at all but one of the IRIG ranges and AN/MPS-26 (as well as FPS-16) radars are being installed at Pacific Missile Range. In addition, FPS-16 radars are being installed by NASA at Wallops Island, Va., and Bermuda; by the Army at Ft. Huachuca Proving Grounds; and by the United Kingdom at Woomera, Australia. The following data were obtained piecemeal from many different sources such as contract specifications, instruction manuals, and conversation and correspondence with representatives of the manufacturers. An early draft was reviewed officially by the manufacturers and their comments have been incorporated herein. Note that, except for a few items where a maximum or a minimum is stated, the data are nominal values. That is, tolerances on the stated values are not given. This is because the tolerances are not known or are negligibly small.

The data given are for the radars as first produced. However, a number of needed or potential future modifications are mentioned in the footnotes. In the future, current information on the radar characteristics should be obtained directly from the test range at which the radars in question are located. It is intended that future modifications of radars at the IRIG ranges conform to these standards (or later revised issues of these standards). If changes that would vitiate these standards should become desirable, it is expected that entirely new standards will be agreed upon by the IRIG ranges and published.

The data are arranged into the following categories:

ITEM NO.	TOPIC
A-1	MECHANISM
A-2	OUTPUT DATA
A-3	INPUT DATA
A-4	ANTENNA
A-5	TRANSMITTER
A-6	RECEIVER
A-7	MISCELLANEOUS
A-8	PERFORMANCE

Items having some relationship to beacon compatibility are marked with an asterisk in the front of the item name. Values that are doubtful or unavailable at this writing are marked with a question mark thus (?).

Herein:

A. By "Range", slant range from the intersection of the mount axes is meant.

B. A Mil is, by definition, exactly 360°/6,400. Therefore, 1 mil = 0.056250°, and 1° = 17.77778 mils.

C. K means 1,000.

D. μ means 1/1,000,000.

E. 1 yd is exactly 0.9144 Meter,
(The International Yard).*
(The old U.S. Yard was 0.91440183 Meter).

F. 1 Nautical Mile is exactly 1,852 Meters,
(The International Nautical Mile).*
(This is 6,076.115486 International Feet).
(This is 6,076.10333 American Survey Feet).
(This is 6,076.10333 Old U.S. Feet).
(The old U.S. Nautical Mile was 6,080.20 old U.S. Feet).

G. Note that the 2,000 yd unit used by some radars is not a mile.

---

* "Units of Weight & Measure", NBS Pub. No. 214, July 1955.
"Technical News Bulletin", Jan 1959, NBS.

A-1. MECHANISM	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
Type of Mount:	Two-Axis	Two-Axis	
Azimuth Tracking Range:	Continuous	Continuous	
Elevation Tracking Range:	-10° to +85°	-1° to +88°	a-1
Elevation Motion Range:	-10° to +190°	-1° to +88°	a-1

A-1. MECHANISM (Cont'd)	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
Range-Tracking Range:	500 yds to 400K yds	500 yds to 400K yds	a-2
Azimuth Tracking Rate:	750 mil/sec (42°/sec) max.	1,060 mil/sec (60°/sec) max.	
Elevation Tracking Rate:	400 mil/sec (22.5°/sec) max.	530 mil/sec (30°/sec) max.	a-17
Range-Tracking Rate:	8K yds/sec max.	8K yds/sec max.	a-2
Azimuth Acceleration:	550 mil/sec^2 max.	400 mil/sec^2 max.	
Elevation Acceleration:	550 mil/sec^2 max.	400 mil/sec^2 max.	
Range Acceleration:	4,000 yds/sec^2 max.	10g max. Normal. (20g on Switch)	a-37
Slewing Rates:	Range: 30K yds/sec max. Az: 45°/sec max. El: 24°/sec max.	15K yds/sec max. Az: 60°/sec max. El: 30°/sec max.	a-30
Manual Tracking:	Possible	Possible	
*Range Search; Automatic:	± 1,000 yds (Adjustable to ± 5,000 yds)	None, but has available a ± 1,000 yd acquisition gate	
*Angle Search; Automatic:	A. Circle Scan: 0.9°, 2.3°, or 3.1° at 1, 1/2 or 1/4 cy/sec.	6°cone at 1 cy/sec	a-25

A-1. MECHANISM (Cont'd)	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
	B. Raster Scan: 10° x 6°, or 6° x 10°, at 1/2 cps on 6° & 1 cpm on 10°		
	C. Sector Scan: Az or El: 10°, 20°, or 30° at 1,2, or 4 cy/min.		
Servo Bandwidths (B-W):	Each servo manually variable at console: Az: 0.10 to 5 cps; El: ditto; R: 1 to 10 cps	Az & El: 6 Values 0.013 to 2.5 cps; R: 5 or 10 cps approx.	a-29
Angle Velocity Lag (until out of beam):	A. At max. servo B-W: 0.004 mils/mil/sec (Kv= 250/sec)	A. At max. servo B-W: 0.0065 mil/mil/sec	a-3
	B. At min. servo B-W: 0.0067 mils/mil/sec (Kv= 150/sec)	B. At min. servo B-W: ? mil/mil/sec.	
Range Velocity Lag (until out of Range Gate):	A. At max. B-W: 1 yd for 5K yd/sec (Kv Constant at 5,000/sec.)	Negligible	a-3
	B. At min. B-W: 1 yd for 5K yd/sec (Kv Constant at 5,000/sec.)	B. Negligible	
Angle Acceleration Lag (until out of beam):	A. At max. B-W: 0.02 mil/mil/sec/sec. (Ka= 50/sec^2)	A. At max. B-W: 0.065 mil/mil/sec/sec	
	B. At min. B-W: 33 mil/mil/sec/sec. (Ka=0.03/sec^2)	B. At min. B-W: ? mil mil/sec/sec	

A-1. MECHANISM (Cont'd)	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
Range-Tracking Range:	500 yds to 400K yds	500 yds to 400K yds	a-2
Azimuth Tracking Rate:	750 mil/sec (42°/sec) max.	1,060 mil/sec (60°/sec) max.	
Elevation Tracking Rate:	400 mil/sec (22.5°/sec) max.	530 mil/sec (30°/sec) max.	a-17
Range-Tracking Rate:	8K yds/sec max.	8K yds/sec max.	a-2
Azimuth Acceleration:	550 mil/sec² max.	400 mil/sec² max.	
Elevation Acceleration:	550 mil/sec² max.	400 mil/sec² max.	
Range Acceleration:	4,000 yds/sec² max.	10g max. Normal. (20g on Switch)	a-37
Slewing Rates:	Range: 30K yds/sec max. Az: 45°/sec max. El: 24°/sec max.	15K yds/sec max. Az: 60°/sec max. El: 30°/sec max.	a-30
Manual Tracking:	Possible	Possible	
*Range Search; Automatic:	± 1,000 yds (Adjustable to ± 5,000 yds)	None, but has available a ± 1,000 yd acquisition gate	
*Angle Search; Automatic:	A. Circle Scan: 0.9°, 2.3°, or 3.1° at 1, 1/2 or 1/4 cy/sec.	6°cone at 1 cy/sec	a-25

A-1. MECHANISM (Cont'd)	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
Range Acceleration Lag (until out of gate):	A. At max. B-W: 1.25 yd for 1,000 yd/sec/sec. (Ka=800/sec^2)	A. At max. B-W: 10 yd for 1,000 yd/sec/sec.	a-3
	B. At min. B-W: 1 yd for 40 yd/sec/sec. (Ka=40/sec^2)	B. At min. B-W: ? yds for ? yd/sec/sec.	
Mount, Normal Leveling:	Elevation Axis Leveled (± 0.025 mils)	Elevation axis leveled	
Normal Orientation:	Azimuth "zero" to True North	Same as FPS-16	

A-2. OUTPUT DATA	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
Azimuth Scales:	Increase clockwise (Observer above the radar)	Same as FPS-16	
Elevation Scales:	Increase with elevation	Same as FPS-16	
Range Scales:	Increase with range	Same as FPS-16	
Data Output, Synchro:	60 cps; Range: 3-speed; Angle: 2-speed	60 cps; 3-speed and 2-speed	a-24
Data Output, d-c Potentiometer:	Sin-Cos & Slant Range (Max. input voltage ± 125V)	Same as FPS-16	
Data Output, Digital Resolution:	Angle: 17 bits, (0.0027466°/bit or 0.048828 mil/bit), straight binary	Angle: 16 bits, (0.0976 mil/bit), straight binary	a-16 a-34
	Range: 20 bits, (calibrated 0.500 yd/bit), straight binary	Range: 19 bits, (1 yd/bit), straight binary	
Data Output, Digital Sampling Rate:	Up to 100 samples/sec (depending on Aux. Equipment)	Up to 100 samples/sec	a-16

A-2. OUTPUT DATA (Cont'd)	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
Data Output, Auxiliary:	3 Tracking-error signals, 3 Tracking-rate signals, AGC voltage, & other miscellaneous signals available	Miscellaneous signals available	
Data Output of associated d-c computer: (Not part of radar)	X,Y,H (or Z) ± 125 V (H=Height above sea level)	Same as FPS-16	
*Max. short-time Precision (S/N = 30db):	Random Errors Ra and Rr have S=0.1 mil & 5 yds, or less. (S is "Standard Error of Estimate")	Not yet determined	a-10 a-14
*Max. Angle Accuracy: (Excl. Glint, Scintillation, Servo Lag, Refraction, Multipath, Weak-Signal Errors)	Absolute Error $A_a \cong R_a \pm 0.1$ mil or less (Predicted Value)	Not yet determined (About ± 0.5 mil)	a-1 a-3 a-10 a-14
*Max. Range Accuracy: (Excl. Glint, Scintillation, Servo Lag, Multipath, Weak-Signal Errors; any Beacon Delay Error & any Velocity of Propagation Error)	Absolute Error $A_r \cong R_r \pm 5$ yds, or less. (Predicted Value)	Not yet determined (About ± 10 yds)	a-10 a-14
Range for Balance between Range & Angle Errors:	About 25 n. miles	About 10 n. miles	
PPI Indicator:	No. (Can add standard Navy Unit as Auxiliary)	Yes	a-38
*Range Displays:	A. Dual A-Scope: (a) Full Range with 10K yd Expanded	A. Four A-Scopes: (a) 400K yds (b) 32K yds	a-21 a-38

A-2. OUTPUT DATA (Cont'd)	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
	(b) 2K yd with Range Notch.	(c) 2K yd beacon (d) 2K yd skin	
	B. 2-speed Synchro Dials (in yds)	B. Same as FPS-16	
	C. Digital (Octal, "Nixie" tubes) (Sample rate 1/sec.)	C. No digital display	
Az and El Displays:	A. 2-speed Synchro Dials (Degrees)	A. Same as FPS-16	a-21 a-38
	B. Digital (Octal, "Nixie" tubes) (Sample rate 1/sec.)	B. None	
Auxiliary Signal:	Signal from Two Console push-buttons:	"Lost Target" Light	
	A. "Data Acceptable" (Manual Only)		
	B. "Data Not Acceptable" (Manual; and Automatically when lose track)		
Auxiliary Recorder:	4 channel Sanborn Model 154-100BC Hot Stylus Recorder. Normally record the 3 servo error signals & time. Signal Strength (AGC) & Tracking Rates available for recording.	30 channel Larson ON-OFF function Recorder	a-26

A-2. OUTPUT DATA (Cont'd)	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
Digital Data Recorder:	Not part of the radar proper	Not part of the radar proper	a-16
Plotting Board & Its Computer:	Not part of the radar proper	Not part of the radar proper	
Boresight Telescope:	Provided	Provided	
Boresight Camera:	Provisions for	Provisions for	a-35
Boresight Television:	Provisions for	Provisions for	

A-3. INPUT DATA	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
Target Designation: (For acquisition)	Will slave to 60 cps Synchro data on Az, El & R; or Az & R; or Az & El. Req'd Accuracy ± $3/4^{\circ}$ & 1K yd. Can select from 2 sources. (Radar automatically nulls & then sweeps 2K yd in Range)	Similar except Az and El only and can select from 3 sources. (Lower accuracy data OK)	a-28
*Synchronization:	Master or Slave (82K c/s & 341 c/s Sine wave signals)	Master or Slave (82K c/s, 5.12K c/s & Pretrigger Pulses)	a-27

A-4. ANTENNA	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
Antenna Type	Parabolic Reflector	Parabolic Reflector	
Antenna Diameter:	12 Feet	10 Feet	a-8
*Antenna Polarization:	"Vertical"	"Vert", Horizontal or Circular (Pushbutton selection, while tracking)	a-9
*Antenna Feed:	Monopulse (4-Horn)	Nutating (30/sec) (Non-rotating)	a-39
Antenna Sweep	(See A-1 MECHANISM)	(See A-1 MECHANISM)	
*Beam Crossover:	Zero db	-1 db, or -3 db (adjustable)	
Antenna System Power Capability:	3MW peak	(?)	
Antenna Efficiency (Gain) Factor:	0.55	0.55	
*Antenna Beam Width at -3 db Points:	1.2°	1.5°	
Antenna Power Gain over Isotopic Radiator (includes Efficiency Factor):	25,100 (44 db) min (at lowest frequency)	15,800 (42 db) min (at lowest frequency)	
*Antenna Side Lobes:	-25 db	-25 db	a-41
Beam Collimation Error vs Frequency:	Negligible for most applications. (About ± 0.15 mil)	Negligible	

A-4. ANTENNA (Cont'd)	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
Radome:	None	None	a-40
Mount:	Two-axis	Two-axis	

A-5. TRANSMITTER	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
R.F. Line Loss, Transmitting:	2 db	1.5 db	
*Tuning Range (Exclusive of Magnetron):	5,400-5,900 mc/sec.	Ditto	a-4
*Peak Power, Tunable (5,450-5,825 mc/sec.) (at Magnetron):	200Kw. Min. (83 dbm)	200Kw. Min. (83 dbm)	a-4
*Frequency Stability of Tunable Magnetron:	Unknown	Unknown	a-5
Integral Wavemeter:	± 1 mc/sec. (± 0.5 mc/s with chart)	3 mc/s Accuracy	
Peak Power, Fixed (5,480 ± 30 mc/sec.) (at Magnetron):	800 Kw., Min. (89 dbm)	None	a-6
*Power Programmer (Beacon Function of Range):	40 db; 4 Selectable ranges	None	a-7
*Pulse Widths, microseconds:	Radar's: 1.0, 0.50, or 0.25 (Beacon's; Optimum: 0.75) Tolerance ± 0.05 µs)	Radar's: 1.0, or 0.25 (Beacon's; Optimum: 0.50) (Tolerances unknown)	a-19

A-5. TRANSMITTER (Cont'd)	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
*Duty Ratio, Max:	0.0010	0.0010	a-15
*Pulse-Group Repetition Freq: (GRF)	Twelve: 341 to 1,707/sec.	Ten: 320 to 1,707/sec.	a-2
Multipulse Capability:	To five 0.25 μs pulses (or two 0.50 μs pulses)	To five 0.25 μs pulses, or fewer totaling 1.25 μs)	a-11
Closest Spacing of Pulses:	Four 0.25 μs pulses: 1.00 μs. Two 0.50 μs pulses: 1.25 μs.	Five 0.25 μs pulses: 1.00 μs	a-11

A-6. RECEIVER	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
*Tuning Range:	5,400-5,900 mc/sec		
*Integral Wavemeter for Local Oscillators:	Separate Wavemeter, ±4 mc/s Accuracy (±0.5 mc/s with chart)	Same wavemeter as for transmitter. (±3 mc/s Accuracy)	
RF Line Loss:	0.75 db	1.5 db (?)	
Noise Figure of Receivers:	11 db Max.	10 db Max.	a-10
Bandwidth of Skin Receiver:	2 or 8 mc/sec.	Opt. for 0.25 to 1.0 μs Pulses	a-20
*Bandwidth of Beacon Receiver:	8 or 2 mc/sec.	Opt. for 0.5 μs Pulses	a-20
Sweep and AFC Pull-in of Skin Receiver:	Each ± 10 mc/sec.	Each ±7 1/2 mc/sec.	a-18

A-6. RECEIVER (Cont'd)	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
AFC of Beacon Receiver:	± 12 mc/sec (with S/N = 25 to 60 db)	± 10 mc/sec, Electronic, plus Mechanical 5,400 to 5,900 mc/sec.	a-18
*Sensitivity of 2 mc/sec. Receiver (0 db S/N); (Marginal-Tracking)	-100 dbm, or better	Same as FPS-16	a-10
*Sensitivity of 8 mc/sec. Receiver (0 db S/N): (Marginal-Tracking)	-94 dbm or better	Does not apply	a-10
*I.F. (Skin & Beacon):	30 mc/sec.	30 mc/sec.	
*A.G.C. Circuits:	A. One only. (Skin or Beacon)	A. Skin (Fast & slow) B. Beacon (Fast & slow)	a-22
*S.T.C.:	A. One only. (Adjustable in cabinet)	A. Skin B. Beacon	
*Parts Common to Skin & Beacon Receivers:	All except A.F.C.	Mixer and IF Preamp.	a-12
*Image Rejection:	Zero db	Zero db	a-13
*C-W Rejection:	None (will angle-track C-W)	None (C-W Tracking unknown)	a-31
*Dynamic Range of Receiver Gain Control:	93 db	93 db	

A-6. RECEIVER (Cont'd)	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
Crystal Shutters:	Yes	Yes	
*Range-Gate Widths:	0.25 μs Wider than Pulse to be Received (Normal Beacon's PW=0.75 μs) (When acquiring, gates 0.75 μs wider than pulse to be rec'd)	Two times Pulse Length: (Skin: 2 μs) (Beacon: 1 μs)	a-19

A-7. MISCELLANEOUS	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
Specification:	Navy BuAer Contract Spec. XEL-303, and about 25 Conference Minutes	Navy BuAer Contract Spec. "Canoga Model 7240, 20 Dec 1957"	
Security Classification:	Unclassified	Unclassified	
Manufacturer:	Radio Corp. of America, Moorestown, N.J.	Underwood Corp. Canoga Division, Van Nuys, Calif.	
Instruction Manuals:	NAVAER 16-30FPS16 -50. (5 Volumes, totaling 12" thick) (Addendum 1 covers kit for extending range limit to 1,000,000 yds)(Vol 6)	(?)	
*Size & Form:	2-story concrete bldg. 27' x 65'	Trailer Van 20' long. (SCR-584 van)	a-34

A-7. MISCELLANEOUS (Cont'd)	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
Power Input:	170 KVA 120/208Y V, 3 phase, 60 cps	18 KVA, 120 V Delta, 3 phase, 60 cps	a-33
*Ranging Crystal Oscillator:	81.959kc/s ± 1/10^6; adjustable ± 4.0 cps	81.946kc/s(± 2 cps, 10° to 50° C); Adjustable ± 4.0 cps	a-36
*Pre-Trigger:	-16,000 yd (-98 µs)	-390 µs	
*Phase Shifting of Pulses (For "Leap-frogging" of Interference):	Pushbutton shifting 180° of 341 cps incoming, plus fine control knob for 82 kc/s incoming	82kc/s Ranging Crystal Frequency Adjuster for Operator	a-27
Servo Coasting:	Yes	Yes	
*Beacon Delay Compensation (Integral):	Adjustable +0.25 to +3.3 µs	Adjustable -3 to +6 µs	a-23
Other Versions of Basic Radar:	See Note a-42	See Note a-43	a-42 a-43

A-8. PERFORMANCE (RANGE)	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
Skin-Tracking; Actual Examples (Data from Manufacturer):	A. Skin-Tracking; 1 MW, 1 µs; on 6" Dia. Metal Sphere (0.018 square meter Scattering Cross Section): To more than 130K yd under ideal conditions.	(?)	a-32

A-8. PERFORMANCE (RANGE) (Cont'd)	AN/FPS-16	AN/MPS-26 (XN-1)	NOTE
Skin-Tracking; Predicted Range Performance (Data from Manufacturer):	A. Skin-Tracking; 1 MW, 1 µs; on 50 cal. bullet: 30 db S/N: 4 NM 20 db S/N: 7 NM 10 db S/N: 12 NM 0 db S/N: 22 NM B. Skin-Tracking; 1 MW, 1 µs; on 1 sq. meter Scattering Cross Section: "Should acquire & track at 150 to 200 miles" C. Ditto; Corner Reflector 3 ft across: "Good S/N at 400 miles"	(?)	a-32
Beacon Tracking:	See APPENDIX C.	See APPENDIX C.	

NOTES FOR APPENDIX A

a-1. Note that there is a "cone of silence" (above the radar) in which normal tracking is not possible. AN/FPS-16 radars will track to higher elevation angles if the rates are slow, and will track to +190° elevation if the target passes exactly through the zenith. Although the radars can track down to zero degrees elevation, or lower, the energy reflected from the earth at low elevation angles introduces angle errors, particularly in elevation angle data, and also reduces range by multipath (destructive interference). For AN/FPS-16 radars, these errors and multipath effects begin to become negligible as the elevation increases above about 3°. The actual errors remain to be calibrated for each radar type, radar site, sea-state, etc. See Reference D-5(e).

a-2. A 1,000,000 yd Range Extension Kit for AN/FPS-16 radars has been developed by RCA. This unit operates at a GRF of 142/sec (which GRF replaces the former 1,707/sec) and has a range rate of 10K yd/sec maximum. With the 1,000,000 yd Kit, one bit represents 1 yd instead of the usual ½ yd and the kit uses 3-speed range synchros instead of 2-speed. Therefore, range acquisition data will have to be in 3-speed form instead of the usual 2-speed form. For details on this Kit, see ADDENDUM 1 of the FPS-16 Handbook. Under BuAer Contract No. 58-865c, RCA is developing a Kit to extend the range to 8,000 NM by using the "Nth time around" ranging. The 8,000 NM Kit will be an all-electronic range machine, therefore, target acquisition range data will not be usable directly in synchro form. The GRF will be around 160/s for 8,000 NM and around 640 for 2,000 NM. At 20 db S/N, the rate will be 20,000 yds/sec (max) and the precision will be 3 yds rms. See B-19. Canoga has proposed to BuAer development of a 2,500 mile range mechanism for MPS-26.

a-3. FPS-16 servo lags can amount to 8 mils or more. A modification kit is being developed by RCA for real-time correction of FPS-16 digital data errors caused by servo lags. MPS-26 has similar servo lag errors.

a-4. Present tunable magnetrons, rated 250 Kw nominal, do not tune the entire frequency range of the radars. A 3 megawatt Klystron Kit, to increase the FPS-16 tunable power to 3 MW nominal over the full range, has been developed by RCA. No such kit is planned for the AN/MPS-26. An Amplitron Kit for a 1 MW tunable output is being studied by RCA for FPS-16 radars and by Canoga for MPS-26 radars.

a-5. The present 250 Kw tunable radars do not have magnetron AFC. The frequency stability is unknown but it is expected that AFC kits will have to be added for satisfactory beacon operation. RCA is developing an AFC kit for FPS-16 radars and Canoga is developing one for MPS-26 radars.

a-6. The present FPS-16 fixed-tune magnetrons have a nominal peak power of 1 MW and a scatter band of ± 30 mc/s. Frequency stability of the 1 MW transmitter is about 2 mc/s after a 7 mc/s warm-up drift. Normally this magnetron cannot be used for beacon operations because its frequency cannot be adjusted, as is essential for chain-radar operations with beacons. To change from 250 KW tunable to 1 MW fixed requires the shifting of a piece of waveguide.

a-7. The AN/FPS-16 power programmer is to reduce beacon range errors (beacon reply delay variation) caused by varying signal strength at the beacon. Power is programmed (per Inverse Square Law) with range setting, over one of four selectable ranges: 0.5-50 Kyd; 1-100 Kyd; 2-200 Kyd; 4-400 Kyd. MPS-26 does not incorporate a power programmer but it should be possible to add one.

a-8. RCA is developing a 16 foot dish with a hydraulic servo. The larger dish will not reduce the depression angle of 10 degrees. The beam width will be 0.8° and the gain will be 46.5 db minimum.

a-9. Note that "vertical" polarization gradually changes to horizontal as the elevation increases to 90°. The MPS-26 has pushbutton selection of polarization except that the circular sense must be set in advance by a change in the antenna feed. A circular polarization kit for FPS-16 radars has been developed by RCA. This requires a new reflector. The polarization sense is R-H (by IRE definition). (See PART III, Note 10). This kit will consist of a "hat" to place over the feed horns and will include a new reflector. For maximum accuracy, it is necessary to boresight after changing polarization.

a-10. Precision is a measure of repeatability only. Accuracy is affected by errors that do not affect precision. For example, calibration errors do not affect precision. Some writers express overall error as the rms of all errors (random, erratic, systematic, and constant). Zero db is considered a marginal-tracking S/N for all radars. Stronger signals give higher precision (smaller random errors). AN/FPS-16 radars usually will track down to a S/N of a -3 db and sometimes to -6 db. FPS-16 angle and range errors decrease until the S/N increases to about 30 db. "Smooth Tracking" requires a S/N of about 10 db or better; "High Accuracy" about 20 db, and "Maximum Accuracy" about 30 db. It is anticipated that addition of a hydraulic servo to FPS-16 will increase maximum precision such that a S/N up to 70 db or more would be useful when deriving real-time velocity data from the radar. Note that FPS-16, being a monopulse radar, is less affected by scintillation (amplitude jitter) than is MPS-26, a nutating radar.

a-11. The radars require multiple trigger generators in order to provide multiple pulses. Under Specification XAV-62, BuAer has requested proposals for a contract for the design and production of such devices. FPS-16 cannot, without modulator modifications, provide any spacing less than 1.0 μs and cannot space the fifth 0.25 μs pulse any closer than about 8 μs. Modulator modifications may permit all five 0.25 μs pulses to be spaced as closely as 0.5 μs. (See B-3). Such modulator modification would improve pulse shape and pulse-to-pulse frequency stability. MPS-26 will space all five 0.25 μs pulses to 1.0 μs and possibly to 0.6 μs. MPS-26 requires triggers between 0.30 and 0.80 μs duration and of greater than 20 volts (either polarity) into 100 ohms. The trailing edge must be at least 0.70 μs from the next leading edge (1.0 μs recovery). MPS-26 will also accept width modulated pulses from 0.2 to 1.2 μs with the closest trailing edge to leading edge being 0.70 μs. The pulses must be at least 40 volts into 100 ohms and of positive polarity.

a-12. This means that either skin or beacon signals, or both simultaneously, can be received but that simultaneous signals cannot be split into separate channels. Therefore, in order to monitor both signals while tracking one, the beacon reply delay must be large enough to keep skin echoes out of the tracking gate when tracking a beacon, and vice-versa. MPS-26 has a wider skin-tracking gate than is optimum for this purpose. FPS-16 local oscillators have a warm-up drift, therefore, signals should not be turned off by turning off the L.O. The development of some other means is needed. See B-28.

a-13. No pre-selector is used. When C-Band becomes crowded, it may become necessary to install a pre-selector to reduce interference from signals on the image frequency.

a-14. S/N means the ratio of peak signal power to rms noise power, averaged over a short time. An ideal target and S/N $\geq$ 30 db is assumed in this accuracy statement. Actual accuracy values are being determined. See "Accuracy of a Monopulse Radar" by David K. Barton, in 1959 Conference Proceedings of the IRE Professional Group on Military Electronics

(8 Pages) & see "Evaluation of AN/FPS-16 (System Nr 1) at WSMR," K.E. Pearson; US Army SMSA Tech Memo. No. 606, Feb 59; WSMR. For detailed background, see "Instrumentation Radar AN/FPS-16(XN-1)", Final Report, Contract DA-36-034-ORD-151, by RCA, Moorestown, N.J., and see the similar report for AN/FPS-16(XN-2), Contract No. NOas55-869c. Random errors have approximately a Gaussian (normal) distribution. "S", the "Standard Error of Estimate", is the rms of the deviations from a curve of regression (a curve having a least squares fit to the data points). Since there are numerous possible regression curves (one of which touches every point so that "S" is zero) the meaning here is a realistic regression curve. By realistic regression curve is meant the best estimate (of the true curve) that can be made in light of the measured data and prior knowledge of the phenomenon observed. For a discussion of "S" as related to the more commonly used "σ" (Sigma, for Standard Deviation), see pages 87 and 179 of Mathematics of Statistics, Vol I, by John F. Kenney, Van Nostrand, 1947. Also see page 283 of The Elements of Statistics, by E.B. Mode, Prentice-Hall, 1941. For a discussion of criteria for choosing one from the infinity of possible regression curves, see "The Critical Examination of Empirical Equations", U.S. Naval Ordnance Test Station Technical Memorandum No. 291 by Paul Peach, November 1951, and see An Introduction to Scientific Research, by E.B. Wilson, Jr., McGraw-Hill, 1952. For variate difference method of estimating "S", see Morse & Grubbs, Annals of Math. Statistics, 18, No. 2, pages 194-214 (June 1947). (This is the Journal of the Institute of Mathematical Statistics, Baltimore, Maryland.)

a-15. AN-FPS-16 radars were originally supplied with a QK447 tunable magnetron and had a duty - ratio of 0.00165 max. These magnetrons are being replaced by QK-662 for longer life. The QK-662 will limit the duty - ratio to 0.0010 max. unless (as may be possible) tube rating is increased to match the 250Kw modulator rating of 0.00165 max. The 1MW magnetron is a QK-539.

a-16. At some test ranges digital data readout and recording equipment added to the AN/FPS-16 radars will limit the sampling rate to values less than 100/sec. AN/FPS-16 digital data is true binary, low order first (in serial readout). At some future date FPS-16's may be changed to the simpler high order first readout. AN/FPS-16 Code Wheels are in Gray Code (sometimes called Reflected Binary Code): Angle; 5-bit Mechanical geared to 13-Bit Optical. Range; same except 8-bit Mechanical. Simultaneous serial readout of Az, El and R registers begins 500 µs after interrogation. Readout bit rate is 100 Kc/s and the longest word is 20 bits; therefore, the serial readout requires another 200 µs making a total of 700 µs. The MPS-26 radar proper does not include digital code wheels and readout equipment. PMR is having these added by Cook Electric Company. Data out will be true binary, high order first in serial readout. Minimum delay in start of readout is 500 μs. The maximum bit rate is 5Kc/s.

a-17. Most FPS-16 radars will track in elevation at a higher rate. Some will track up to 30 or 40 degrees per second.

a-18. AN/FPS-16 AFC will pull in ± 6mc/s on S/N = 6 db and will hold down to 3 db (the beacon AFC has own IF strip and develops own AGC).

a-19. AN/FPS-16 Skin-Tracking gates are automatically switched as pulse width is switched. When the beacon-tracking mode is selected, the gate is switched to a width optimum for a 0.75 μs beacon pulse. It probably is feasible to re-wire the radar so that any pre-selected one of the four gates would be selected in the beacon mode. The normal gate cannot accommodate pulses shorter than 0.45 micro-seconds or longer than 1.0 micro-seconds. AN/MPS-26 has one skin-tracking gate optimum for 1.0 μs pulses and one beacon-tracking gate for 0.50 μs pulses. It will be necessary to add a gate for 0.25 μs pulses if it is desired to permit switching from beacon-tracking (with 0.25 μs radar pulses) to skin-tracking on the skin echoes from the 0.25 μs pulses that are interrogating the beacon. The beacon gate cannot accommodate pulses shorter than 0.40 μs or longer than 0.75 μs. Therefore, the radar should be modified to permit a selection of the beacon gate from four gates optimum for 0.25, 0.50, 0.75 and 1.0 μs pulses. The FPS-16 radars should be similarly modified. AN/MPS-26 pulse width is adjustable in 0.04 μs steps from 0.20 to 1.2 μs.

a-20. FPS-16 skin-tracking mode automatically selects 2 mc/s band-width for 1.0 μs pulses and 8 mc/s for 0.50 or 0.25 μs pulses. In beacon-tracking mode, 8 mc/s band-width is automatically selected. However, the operator has an overriding band-width selector on the console.

a-21. FPS-16 synchro dials in mils instead of degrees are available in Kit. The three FPS-16 digital displays are in true binary numbers indicated in OCTAL form by "NIXIE" tubes, each indicating an arabic symbol 0 thru 7. Each "NIXIE" numeral represents three places in the true binary number; 0=000, 1=001, 2=010, 4=100, 5=101, etc. The least significant NIXIE is at the right.

a-22. FPS-16 has a non-tracking IF strip, with independent manual gain control, for monitoring skin return pulses while tracking a beacon. MPS-26 has independent receivers, each with own AGC (and gate) for this purpose.

a-23. It is planned that Beacon Delay Compensation of greater range will be incorporated in the auxiliary Multiple Trigger Generator (Encoder) that will be added to each radar by the test ranges.

a-24. The 1,000,000 yd Range Extension Kit has a 4-speed synchro output.

a-25. For the FPS-16 only the two Raster Scans and the Sector Scan size are selectable at the console. The other optional values are cabinet adjustments.

a-26. The FPS-16 recorder has several paper speeds from 0.25 to 100 mm/sec. The recorder cannot record some high frequency timing signals. The addition of a special 5th channel for this purpose may be possible. FPS-16 angle error voltages are proportional to error within 0.1 mil up to 1 mil and within 0.013 mil up to 0.1 mil.

a-27. FPS-16 has automatic phase shifting of received 82Kc/s sine wave to match the received 341cps sine wave, (cable delay slope compensation).

a-28. Range synchro data must be 2-speed and angle data 1-speed. The 500 mile range kit requires 3-speed. Auxiliary monitors for displaying Target Acquisition data should be installed since such monitors are not integral with the radar.

a-29. FPS-16 Az, El and R servos each have at the console a manual band-width adjustment. There is a provision for adding a computer to provide automatic band-width control in which band-width varies with servo velocity and with signal characteristics. Implementation of this requires the development of a computer. To accommodate sudden changes in tracking rates, such as at separation, there is a need to add to the radars a push-button for instantly opening all servo band-widths to maximum (and possibly for inserting a boost signal).

a-30. Most FPS-16 radars will slew in angle at higher rates.

a-31. Since the FPS-16 radar will angle-track a CW signal, a CW "beacon" can be used for "theodolite" type-tracking with 2 or more radars. However, the radar receiver band-width is much wider than would be optimum for CW. Therefore, to reduce the "beacon" power required, narrow banding of the receivers would be desirable. A free running pulsed "beacon" could be used for angle-tracking (without receiver modification) so long as the apparent range rate is not too high for the Range Tracking Servo and so long as the range limit stops are not hit. RCA said it probably is feasible to add an automatic device to keep the range gate approximately centered to avoid the limit stops.

a-32. If the PRF is not stated, it is not known at this writing but it probably is the maximum possible for the range.

a-33. Loads are connected loads, average power will be somewhat less. FPS-16 power requires two transformer banks. When a 3MW kit is added to FPS-16, a third bank will be required to supply a connected load of 45Kva at 277/480Y volts 3 phase 60 cps. The stated MPS-26 load does not include power for any external air conditioning machinery.

a-34. RCA is developing a multi-trailer version of FPS-16. Nomenclature probably will be AN/MPS-25. In the initial plan this version would not include Gray to Straight Binary code conversion equipment. RCA is studying and has proposed a shipboard FPS-16 with data stabilization. An airborne version of MPS-26, with stabilized data, probably will be needed to extend the beacon horizon but no work is being done on such a radar.

a-35. Usually a 40 inch focal length Mitchell "High Speed" or similar camera.

a-36. The correct ranging-oscillator frequency depends on the Net velocity of propagation over the ray path and on the calibration of the range mechanism. For the FPS-16 and the MPS-26, the range calibration is exactly 2,000 International Yards per cycle of the "82" kc/s Ranging-Oscillator. If one assumes the velocity of propagation in a non-bounded vacuum to be: c = 299,792.5 ±0.4 Km/sec* (327,857,064 ±437 International Yards/sec), then, for a vacuum, the correct frequency would be 81,964.2660 c/s.

For a non-dispersive medium (one in which velocity is independent of frequency; for example, the atmosphere when not ionized) the correct frequency is the vacuum frequency divided by the Net Index of Refraction over the ray path. Several examples follow:

Net Index of Refraction	Frequency in c/s	Notes
1.000 000 (Vacuum)	81,964.27	
(1.000 064)	(81,959)	Original FPS-16 Frequency
1.000 100	81,956.07	
1.000 200	81,947.88	

Net Index of Refraction	Frequency in c/s	Notes
(1.000 223)	(81,946)	Original MPS-26 Frequency
1.000 300	$81,939.6\overline{8}$	
1.000 400	$81,931.4\overline{9}$	
1.000 500	$81,923.3\overline{0}$	

It is not known how the original FPS-16 and MPS-26 frequencies were selected. It is suspected that the FPS-16 frequency was picked up by the Signal Corps very early in the FPS-16 development as being optimum for the high and dry conditions at WSMR and that the MPS-26 frequency is that picked by AMR for their Mod III Radars (from which the MPS-26 derived) as being optimum for the low and humid conditions at AMR.

For maximum accuracy of real-time range measurements, it would be desirable to automatically program the ranging oscillator frequency as a function of range, elevation angle, and an Index of Refraction profile (or to continuously insert a computed correction into the digital range data output). At the very least, it would be desirable to adjust the oscillator to a new fixed frequency each time test conditions are changed. FPS-16 Instruction Manual says the ranging crystal can be tuned ± 50 c/s but tests on two PMR radars indicate that the correct value probably is ± 5 c/s maximum. See also APPENDIX B, paragraphs B-14 and B-13. PMR is procuring for its FPS-16's, ranging crystals of the MPS-26 frequency (81,946 cps).

> *NOTE: This value of "C" is recommended by the International Scientific Radio Union (URSI). (See IRE for July 1958, page 1357). In their joint meeting of 2 September 1959, the IRIG working groups on Electronic Trajectory Measurements and on Electromagnetic Propagation recommended that the ranges use this value.

a-37. Tested at 4,000 yds/sec^2 - The peak might be as much as 16,000 yds/sec^2.

a-38. To improve target acquisition with FPS-16, RCA has worked out (for NASA, for the MERCURY Project) preliminary plans for adding an intermediate-range sweep to the range indicator and for adding an oscilloscope to display Azimuth vs Range and Elevation vs Range.

a-39. FPS-16 is a monopulse radar of the amplitude comparison, phase-sensing, type. For information on monopulse techniques, see "Introduction to Monopulse" by D. R. Rhodes, McGraw-Hill, 1959.

a-40. For unusually severe environments, RCA is investigating a radome for FPS-16.

a-41. A major source of error is side-lobe lock-on and tracking (usually unsuspected). Development of means to test for side-lobe tracking and for switching track to the main beam (without losing the target) is needed.

a-42. There have been several versions made of the basic AN/FPS-16 (and more versions will be made):

"AN/FPS-16(XN-1)": The first experimental model was made with an X-Band RF System and a lens type antenna. It later was changed to C-Band with a reflector antenna. This radar was further modified for use on VANGUARD and is now in use at the Atlantic Missile Range, Patrick AFB, Florida.

"AN/FPS-16(XN-2)": Two of this model were made. One was installed on Grand Bahama Island, BWI, for the VANGUARD program and one remains at RCA, Moorestown, N.J. These radars are almost identical to later production models.

"AN/FPS-16, Production": These basic AN/FPS-16 radars are described in the Standards and by the AN/FPS-16 Instruction Manual referenced in APPENDIX D. The (XN-2) models, described by the "Final Report on Instrumentation Radar AN/FPS-16(XN-2)", referenced in APPENDIX D, are essentially identical to the production model.

"AN/FPS-16(XN-3)": This is an experimental version of AN/FPS-16(XN-2) that includes a 3-MW modification kit, a Circular Polarization Kit, a Data Correction Kit, and a Boresight Television Kit. This radar is at RCA, Moorestown, N.J.

"AN/FPS-16AX": This is a Production AN/FPS-16 modified according to (XN-3) above. Three radars have been so modified. They are at White Sands Missile Range.

"AN/MPS-25": This is expected to be the nomenclature of a trailer-mounted production model AN/FPS-16. The first model will be delivered to PMR early in 1960.

"AN/FPQ-4": An adaptation of AN/FPS-16 that was made for use as a target-tracker in the land-based TALOS system. Two models were installed at WSMR. Two more models, with modifications, were installed on a ship for use in the Atlantic Missile Range on the DAMP program. A third such radar is at RCA, Moorestown, N.J., as a part of the DAMP research facility.

"AN/FPS-16-??": As additional modification kits are added to the basic production model AN/FPS-16, doubtless new nomenclature will be assigned.

a-43. Instrumentation Radar AN/MPS-26 has not yet been produced except for several sets of the (XN-1) model.

APPENDIX B

RECOMMENDED MODIFICATIONS OF AN/FPS-16 AND AN/MPS-26(XN-1) RADARS

These briefly described modifications are of three classes. In the first group are modifications needed to provide compatibility with beacons that meet these System Standards. In the second group are improvements that would improve beacon tracking performance but that do not affect compatibility; most of these improvements apply also to skin tracking performance. In the third group are potential improvements having no special relation to beacon tracking; these are listed merely for completeness. Note that many of these modifications are interrelated, and that some may be incompatible with others.

GROUP I; MODIFICATIONS FOR BEACON COMPATIBILITY

B-1. Multiple-Trigger-Generator (Encoder):

(a) Each FPS-16 and MPS-26 radar requires such a device, which must be developed. PMR has prepared specifications for a development, and BuAer will award a contract under BuAer Specification XAV-62, of 15 May 1959. Throughout specification XAV-62, the term **RACON** (for Radar-Beacon) is used in lieu of the term BEACON. It is understood that Canoga has been selected as the contractor.

B-2. Automatic Frequency Control of Transmitter:

(a) FPS-16 and MPS-26 radars require such devices. The operator at the console should be able to adjust the frequency to an absolute accuracy of ± 0.5mc/s or better and monitor it continuously. The AFC should hold ± 1.5mc/s or better. Pushbutton selection of 4 pre-set frequencies is **highly** desirable. The AFC features should be retained in any modification kit for increasing transmitter power.

(b) RCA is developing an AFC kit for the FPS-16 and Canoga is developing one for the MPS-26.

B-3. Multiple Pulsing:

(a) FPS-16 radars require improvement of the 250Kw modulator to make available all five 0.25 microsecond pulses spaced as close as 1.00 microseconds (and preferably as close as 0.5 microsecond), to improve the pulse shape, and to improve the pulse-to-pulse frequency stability and peak power uniformity. This improvement probably can be made by removing the 1/1 pulse transformer from the modulator and substituting a direct-drive circuit. A better transformer has been developed for the mobile FPS-16. This permits five 0.25 microsecond pulses to be spaced as close as 1 microsecond apart. This transformer could be used to replace the transformer of a fixed FPS-16.

(b) MPS-26 is believed to be satisfactory in this regard but this remains to be determined.

(c) Any future power-increasing kit must retain the pulse improvements.

B-4. Tuning Range:

(a) The radar transmitters should tune the entire 5,400 to 5,900mc/s band.

At present the tunable magnetrons limit the tuning range to 5,450 to 5,825mc/s.

B-5. Beacon-Tracking Gates:

(a) FPS-16 and MPS-26 radars should be modified to provide pre-selection of the beacon-tracking gate so that it is optimum for a beacon pulse width of 0.50, 0.75, or 1.00 microseconds. If possible, an additional value, 0.25 microseconds, should be included. With a proper Multiple Trigger Generator, the skin-tracking gates can be used for beacon tracking. The XAV-62 unit (See B-1) has this capacity.

B-6. Skin-Tracking Gates:

(a) MPS-26 skin-tracking gate is optimum for 1 microsecond pulses. It is, therefore, too wide for skin-tracking narrow pulses, as is desirable while tuning for an interrogation-coded beacon and skin-tracking at the same time. Therefore, skin-tracking gates optimum for pulse widths of 0.25 and 0.50 microseconds should be added.

B-7. Pulse Widths:

(a) MPS-26 should have added to the present 0.25 and 1.00 microsecond radar pulse widths a third pulse width of 0.50 ±0.05 microsecond.

B-8. Power Programmer:

(a) For improved beacon range measurement accuracy, MPS-26 should have added a power programming device like that in FPS-16.

B-9. Polarization:

(a) FPS-16 and MPS-26 radars should have pushbutton selection of "Vertical", Horizontal, and Circular polarizations. Ideally there should be also a pushbutton choice of the sense of the circular polarization. The IRE definition of sense should be used.

(b) MPS-26 has the three pushbutton polarization selections but the circular polarization sense change requires an antenna adjustment.

(c) FPS-16 polarization is linear and "vertical". A circular polarization modification has been developed by RCA (Navy Contract NOas 55-869c). This modification kit includes new dish skirts having a different perforation pattern and includes a "hat" to be placed over the feed horns.

B-10. Image Rejection:

(a) FPS-16 and MPS-26 should both have added a pre-selector or other means of rejecting interfering signals on the image frequency.

B-11. Beacon Telemetry:

(a) Some of the radars should be equipped to receive and record 2-pulse reply telemetry signals from the beacon. Such a beacon telemetry system (AN/DKT-9) is being developed by the Army. At some future date, the IRIG may publish a System Standard covering such telemetry systems for use at the IRIG ranges.

B-12. Beacon Command Control:

(a) Some radars should be equipped with tone generators for time-modulation of the radar pulses (through the trigger encoder) for command control purposes. At some future date IRIG may publish System Standards in this area.

GROUP II; PERFORMANCE IMPROVEMENTS

B-13. Data Correction, Post Flight:

(a) FPS-16 and MPS-26 radars have significant compensable errors in the form of servo lags. These errors can be calibrated in terms of the servo error voltages. The radars should have added means to digitize and record the error voltages, along with range time signals, for later automatic insertion into data reduction computers. For correcting for velocity of propagation errors, the exact frequency of the ranging crystal should be made a matter of record for each event. See Appendix A, a-36.

B-14. Data Correction; Real-Time:

(a) In addition to corrections for servo lags, measurements can be corrected for velocity of propagation errors and for atmospheric refraction errors. For real-time applications such as impact prediction, these corrections must be made in real-time. See Appendix A, a-36.

(b) RCA is developing a real-time data correction kit for FPS-16 radars. (Navy Contract NOas 55-869c) (AMR funds).

(c) FPS-16 radars should be equipped with such data correction kits, at which time the error signal recorder mentioned above would no longer be needed.

B-15. Data Resolution and Velocity Data:

(a) For real-time determination of velocity, FPS-16 resolution could profitably be increased by one-speed (directly coupled) digital code wheels having higher resolution and/or by directly-coupled high precision angular accelerometers. To take advantage of higher resolution, the servos probably should be changed from electric to hydraulic. RCA has proposed studying velocity measurement methods under an Army contract based on RCA CONFIDENTIAL proposal DS-105-596-5641A. Ford Instrument Co. proposed to PMR the development of a CW doppler system to work in conjunction with an FPS-16 in order to provide better range rate and angle rate data. This proposal is numbered SP58-146A.

B-16. Receiver Noise Figure:

(a) The S/N required by the FPS-16 radars for maximum accuracy tracking is so much greater than that required for marginal tracking (about 0db) that improvements such as parametric amplifiers should be incorporated as soon as technically feasible. The present FPS-16 precision improves up to a S/N of about 30db. FPS-16's modified for velocity measurement may have high enough resolution to make much higher S/N ratios profitable in the form of improved precision and in more accurate velocity determinations. RCA has proposed (DS-105-596-5673) to BuAer the development of a 3-channel parametric preamplifier for FPS-16. This would yield a 6db improvement in noise figure, which is equivalent to doubling the possible beacon-to-radar range. The device would be manually tunable over 5,400-5,900 mcs and would have a band width of 10mcs. Canoga has proposed to BuAer a parametric preamplifier for MPS-26.

B-17. Transmitter Power:

(a) FPS-16 tunable power should be increased to 1MW or 3MW and, if possible, MPS-26 increased to 1MW. In anticipation of future improved detection techniques, the modifications should provide an extremely stable (coherent) carrier.

(b) RCA and Canoga have studied a 1MW Amplitron kit for their radars. AMR has funded the development of a 1MW tunable amplitron kit for FPS-16. This will replace both magnetrons of the FPS-16 (the driver will be a degaussed magnetron included in the kit).

(c) RCA has developed a 3MW Klystron-chain kit for FPS-16 radars. (Navy Contract NOas55-869c).

B-18. Antenna:

(a) Some FPS-16 radars should, when feasible, have the reflector changed from 12' diameter to 16' diameter, and the servomechanism changed from electrical to hydraulic, for higher performance. RCA is developing such an antenna and servo.

B-19. Range Mechanism:

(a) Some FPS-16 radars should have the 400,000 yard mechanism changed to 1,000,000 yards or, if feasible, to 8,000 N.M. Velocity measurement requirements should be kept in mind when considering range increases, as should these System Standards.

(b) RCA has developed a 1,000,000 yard range extension kit and, with AMR funds, is developing an all-electronic range machine of 8,000 N.M. range. The prototype is expected to be operational by October 1960. The kit incorporates automatic beacon-sharing facilities. See also paragraph a-2.

(c) To permit angle-only tracking of a free-running pulsed "beacon", the radars should be modified to keep the range mechanism from running into the limit stops.

(d) An intermediate range sweep per Note a-38 should be added to FPS-16's to facilitate target acquisition.

(e) Some MPS-26 radars should have the range limit extended to 2,500 or 5,000 N.M.

B-20. Boresight Television:

(a) This should be added to all radars as an acquisition aid for testing for side-lobe lock-on and for other purposes. Both FPS-16 and MPS-26 have provisions for adding such a system.

(b) RCA has developed a boresight TV kit for FPS-16 (Navy Contract NOas 55-869C).

B-20A. Side-Lobe Tracking:

(a) The development of means to test for side-lobe tracking and for switching track to the main lobe (without losing track) is needed.

B-20B. Entirely New Techniques:

(a) Available new radar techniques, along with compatible beacons, should be developed, and revised System Standards issued. RCA is preparing for AMR a proposal on a coherent-carrier kit for FPS-16 and a compatible coherent beacon. Convair has proposed to PMR the conversion of an FPS-16 to an AZUSA transponder tracker for increased range and improved range rate data.

GROUP III; MISCELLANEOUS IMPROVEMENTS

B-21. Digital Data Form and Readout Order:

(a) MPS-26 digital serial readout is true binary, high order first. FPS-16 readout is true binary, low order first. For data system compatibility all radar data should be the same. Since high-order first is preferred by some data processing engineers, it may be advisable to modify the FPS-16 radars.

(b) The mobile version of FPS-16 as first planned did not include the Gray to straight binary code conversion equipment of the FPS-16 radars. For data system compatibility, the radar should deliver straight binary data.

(c) Sin-Cos Az & El code wheels may simplify computations somewhat.

(d) Push-pull code wheels may improve reliability or resolution, or both.

B-22. Wide-Band Microwave Telemetry:

(a) Some FPS-16 antennas should be equipped with a receiving antenna feed for receiving microwave telemetry signals from the vehicle that the radar is tracking. This is because a high gain receiving antenna is necessary for long range telemetry at microwave frequencies.

(b) For this purpose RCA has developed a 2,300 mc/s circularly polarized telemetry antenna feed for the present FPS-16 antenna. Under Navy (Patuxent) Contract Nonr-2990(00)-(x), an MPS-26 was equipped to receive signals in the range 1,435 to 1,535 mc/s.

B-23. Mobile FPS-16 Type Radars:

(a) RCA is developing a multi-trailer version of FPS-16. This version must incorporate all beacon compatibility modifications mentioned above in Group I and as many as possible of those in Group II. These radars should deliver data in the same form as FPS-16 radars. This radar probably will be called AN/MPS-25.

(b) RCA has proposed a shipboard version of FPS-16 (this confidential proposal, RCA Proposal No. 337521A, is dated August 1957 and is numbered DS 105-596-5619). These radars must incorporate the modifications of Group I above and as many possible of those in Group II above.

(c) There is a need for an airborne C-Band instrumentation radar suitable for installation in a large high altitude radar aircraft such as the WV-2 Super-Constellation. No work has been done on such a radar and the associated data reference system.

B-24. Miss Distance Measurement:

(a) RCA proposed the addition to FPS-16 radars of a second tracking system for tracking a second target while it passes through the radar beam that is tracking the first target. Any such modification kit that is developed must permit the use of beacons according to these System Standards. The RCA proposal document is dated February 21, 1958 and is not numbered.

B-25. Acquisition Data Monitor:

(a) An Auxiliary display for monitoring target acquisition data for quality should be added to the radars at the console.

(b) An intermediate range sweep as described in Note a-38 should be added to FPS-16s.

B-26. Servos:

(a) It sometimes is difficult to acquire a target that starts from rest with a high acceleration. Such a target is a rocket launched from the surface or from an aircraft. Since the time of launch can be signaled and since the probable motion is known in advance, it may be possible to add to the radars a programmer that will program the servos according to the expected target motion and thereby facilitate acquisition. NASA has plans to have RCA develop a kit for inserting a pre-set range rate into FPS-16. This is to facilitate acquisition of the Mercury satellite beacon.

(b) A simpler modification that may be useful would be a pushbutton switch and a relay for opening all servo bandwidths to maximum for acquisition.

(c) A computer for automatic FPS-16 servo bandwidth control should be developed.

B-27. C-W Rejection:

(a) The radars should, if possible, be made capable of rejecting C-W signals.

B-28. Signal Switching:

(a) When both skin & beacon local oscillators of FPS-16 are running, there is a 3db sensitivity loss in each receiver. If a LO is turned off, it cannot be switched on instantly because it must warm up. A means of instantly switching between the three modes is needed.

B-29. Monitors:

(a) MPS-26 should have a monitoring oscilloscope like FPS-16.

B-30. I-R Tracker:

(a) Some radars should be equipped with an infra-red tracking head for angle tracking rocket flames at very low elevation angles or under severe clutter where radar tracking is not satisfactory in angle.

B-31. Extended Range Tracking:

(a) For tracking beyond the FPS-16 range mechanism limit stop by "Nth Time Around Tracking", the range mechanism should be modified (according to a simple method developed by PMR) so that the angle servos are in "coast" while the range servo is being slewed back to zero. When an 8,000 mile range kit is added, this modification may no longer be needed.

B-32. Radomes:

(a) For unusually severe environments, a radar should be equipped with a radome.

APPENDIX C

MISCELLANEOUS RECOMMENDATIONS

This appendix includes miscellaneous recommendations and suggestions that are, in general, peculiar to beacon systems.

C-1. Beacon Range Calculations:

(a). A convenient way to calculate the interrogation range, or the response range, is to equate the net system gain to the free-space (unbounded vacuum) attenuation between isotropic antennas.

(b). The following is such an example worked in decibels, using 1 milliwatt as the power reference and using an isotropic radiator as the antenna gain reference. The example is for a conventional AN/FPS-16 radar and a conventional high-performance beacon of 500 watts peak power and minus 65 dbm sensitivity (both near 5.5 kmc/s). The example is for an unusually difficult situation such as an aircraft system where the beacon's antenna cable is long and where tracking at very low elevation angles (about 3° and less) over the sea introduces destructive interference (multipath attenuation).

Example:

Radar to Beacon		Beacon to Radar	
A. Gains:		A.' Gains:	
Radar's Transmitter (200 kw)	83	Beacon's Transmitter (500 w)	57
Radar's Antenna Gain	44	Beacon's Antenna Gain	0
Beacon's Antenna Gain	0	Radar's Antenna Gain	44
Beacon's Receiver	65	Radar's Receiver[1]	94
Total Gain =	192	Total Gain =	195
B. Losses:		B.' Losses:	
Radar's Transmission Line	2	Beacon's Transmission Line	6*
Radar's Beam Crossover	0	Beacon's Antenna Nulls[4]	6*
Atmosphere. (200 n. Miles)[3]	3	Atmosphere. (200 n. Miles)[3]	3
Multipath. (At low Angles)	12*	Multipath. (At low Angles)	12*

Example: (Cont'd)

Beacon's Antenna Nulls(4) - - - - - - - - 6*	Radar's Beam Cross-over - - - - - - - - - - 0
Beacon's Transmission Line - - - - - - - - - 6*	Radar's Transmission Line - - - - - - - - - - 1
Total loss = 29	Total loss = 28
C. Margins:	C.' Margins:
To Reduce Reply Delay Errors.(2) - - - - - - 6*	To Reduce Tracking Noise(1) - - - - - - - - 10*
D. Net Gain: (A-B-C) = 157 db	D.' Net Gain: (A'-B'-C') = 157 db
E. Equivalent Range (5)(6)(7) = 165 n.mi. (or 190 st.mi.)	E.' Equivalent Range (5)(6)(7) =165 n.mi. (or 190 st.mi.)

Notes:

* Value arbitrarily assumed for purposes of illustration.

(1) Assumes the wide-band receiver used and assumes sensitivity measured at 0db S/N, which provides only marginal tracking. Good tracking requires a margin of at least 6 db S/N and high precision tracking requires a margin of at least 18 db S/N. Tracking precision (and consequently accuracy) increases with S/N up to about 30 db S/N. It should be noted that a S/N adequate for marginal tracking usually is not adequate for the initial target acquisition. See B-28.

(2) A margin of excess S/N at the beacon's receiver output is desirable for reducing reply-delay variation and jitter, thereby increasing range measurement accuracy.

(3) First approximation (for standard atmosphere). Other sources of attenuation that should be considered are Rocket Flame, Re-entry Ion Sheath, and Rain (which varies from about 0.025 to 0.35 db/N.Mi.- see Radio Wave Propagation, Consolidated Summary Technical Report of the Committee on Propagation, NDRC). It should be noted that, in addition to attenuation, a cloud of raindrops causes random scattering of a wave such that some of the randomly scattered wave appears as noise in a receiver. This noise can degrade the net S/N of either the beacon's receiver or the radar's receiver, or both.

(4) Include cross-polarization effects (including reversed-sense circular polarization components) and Faraday rotation of polarization by the ionosphere (usually the latter is completely negligible).

(5) For beacon range calculation, see MIT Radiation Laboratory Series, Vol. 3, "Radar Beacons", McGraw-Hill, 1947. For data on the free space attenuation between isotropic antennas, see "Reference Data for Radio Engineers", 3rd Edition; Federal Telephone & Radio Corp., 1949.

(6) For rapid calculations, see BEACON RANGE NOMOGRAPH NO. AV-3U9 by AVION, 11 Park Place, Paramus, N.J. (Published in ELECTRONICS, Sept. 4, 1959, Page 60). Also see GLENNITE Communications System Calculator, by Gulton; Metuchen, N.J.

(7) It should be remembered that 6 db is equivalent to a factor of 2 in range (under unbounded vacuum conditions, and approximately so under most conditions).

C-2. Diversity Operation of Beacons:

(a) When a beacon/radar system is unbalanced because the beacon's receiver is not sufficiently sensitive, an improvement sometimes can be had by using two receivers and two receiving antennas of complementary pattern coverage. Note that if the system is balanced, diversity reception offers no advantage.

(b) Ordinarily it is not satisfactory to connect two antennas together directly in an attempt to improve pattern coverage because this usually results in a two-element antenna array that has many narrow nulls that are very deep. Any beacon power splitter for multi-element antennas should be removable to permit single antenna operation.

(c) One way to provide improved antenna coverage is to have a full diversity system by having two completely independent beacon installations with complementary antenna patterns. In such a system the beacons are identical in all respects except that the reply delays differ. The radar operator selects the beacon reply that is the best one at any given time.

(d) Another way to provide improved antenna coverage is to install two complementary antennas and a SPDT signal-seeking switch that hunts continuously until a satisfactory signal is received. The switch must have high speed, a long life under repeated cycling, and a low mismatch. It may be necessary to inhibit the beacon's transmitter during each switching operation to avoid a damaging mismatch. For possible use with such a switch, beacons should be provided with a signal to indicate reception of a satisfactory signal and should be made so that a momentary shorting or opening of the line by the switch would not damage the beacon. If the latter cannot be done by means of a load isolator, or other means, it may be necessary to provide for the use of an inhibiting signal from the switch.

(e) Sometimes the beacon's duplexer loss may be excessive such that an improvement can be had by removing the duplexer and using separate antennas for the receiver and the transmitter.

C-3. Long-Line Effect:

(a) Beacon magnetrons generally are very sensitive to load mismatches. When the load is at the end of a transmission line many wavelengths long, the sensitivity is greatly increased. Because of the difficulty of maintaining a sufficiently small and constant mismatch at the beacon, the beacon should incorporate a load isolator, such as a ferrite unidirectional coupler, at the magnetron output. When this is not done, great care should be taken to keep the transmission line short and the VSWR very low. Some installations not having a load isolator have used a "line-stretcher" to adjust the phase of the mismatch to a favorable value. This often is unsatisfactory because the electrical length of the line changes with temperature. A load isolator is best incorporated into the duplexer. It is desirable that beacons be able to tolerate a VSWR of at least 1.5/1, and preferably 2/1, of any phase, and with any transmission line length up to several hundred wavelengths. For details on the Long-Line Effect, see MIT Radiation Laboratory Series, Vol. 3, titled "Radar Beacons", pp 265-267, McGraw-Hill, 1947.

C-4. Beacon Antenna Studies:

(a) In 1956, the U. S. Army Signal Corps, awarded a 5 part study contract (DA-36-039-SC-71205) to Stanford Research Institute, of Menlo Park, California. The 5 tasks are:

Task I - "Criteria for Selecting Beacon Antenna Systems for Missile Tracking at White Sands Missile Range"

Task II - "Research Investigation of Beacon-Tracking Antennas For Redstone Missiles at White Sands Missile Range"

Task III - "Research Investigation of Beacon-Tracking Antennas for Drone Aircraft at White Sands Missile Range"

Task IV - "Research Investigation of Beacon-Tracking Antennas for Aerobee-Hi at White Sands Missile Range"

Task V - "Study of General Problems of High Altitude Beacon Tracking of Missiles"

As of June 1959, final reports on the first four tasks had been submitted. Copies of the reports may be obtained from the Armed Services Technical Information Agency (ASTIA), Arlington Hall Station, Arlington 12, Virginia.

C-5. Reply-Delay Changing:

(a) As was discussed under 2.28, one purpose of the reply delay is to permit separation of beacon and skin returns. In some instances it is desirable to quickly change the delay value. For example, consider a beacon in a missile on a pad near a large gantry crane. If the skin return from the gantry is so large that the frequency offset does not prevent it breaking through, and if the range is such that skin return interferes with the beacon's reply signal, then the quickest solution usually is to switch the beacon's reply delay to another value.

C-6. Radar Beacon System Studies:

(a) The U.S. Army Signal Corps, awarded a broad study contract (DA-36-039-SC-73038) to Armour Research Foundation of Illinois Institute of Technology, Chicago 16, Illinois. As of January 1959, eight quarterly progress reports had been submitted. These should be available through ASTIA.

APPENDIX D

REFERENCES & BIBLIOGRAPHY

D-1 RADARS & BEACONS IN GENERAL:

(a) "Principles of Radar", MIT Radar School Staff, McGraw-Hill, 1946

(b) MIT Radiation Laboratory Series (Particularly Vol 1 and Vol 3), McGraw-Hill, 1947

(c) "Introduction to Monopulse", Donald R. Rhodes, McGraw-Hill, 1959

D-2 INSTRUMENTATION RADARS AND BEACONS:

(a) IRIG Electronic Trajectory Systems Catalog (IRIG Secretary, White Sands Missile Range, New Mexico)

Vol I: Trajectory Systems
Vol IA: Trajectory Systems (Confidential)
Vol II: Radar Beacons (Specifications)
Vol IIA: Radar Beacons (Comparison Charts)
Vol IIB: Radar Beacons (Confidential)

(b) "Signal Corps Transponders and Associated Equipment" by U.S. Army Signal R&D Lab., Ft. Monmouth, N.J., 1 May 1959

(c) Beacon Study Contracts - (See APPENDIX C, paragraphs C-4 and C-6)

D-3 AN/FPS-16 RADAR CHARACTERISTICS AND TEST DATA:*

(a) Barton, David K., "Accuracy of a Monopulse Radar", 1959 Conference Proceedings, IRE Professional Group on Military Electronics, pages 179 - 186.

(b) "Final Report, Instrumentation Radar AN/FPS-16(XN-2)", Contract NOas 55-869c; RCA, Moorestown, N.J. (To be published early in 1960).

(c) "Final Report, Instrumentation Radar AN/FPS-16(XN-1)", Contract DA-36-034-ORD-151, RCA, Moorestown, N.J., March 1958.

(d) "AN/FPS-16 Instruction Manual", NAVAER 16-30 FPS16-50, U.S. Navy Bureau of Aeronautics, (5 Volumes totaling 12" thick), (ADDENDUM 1, in a 6th Volume, covers Kit for converting the range mechanism to 1,000,000 Yards.)

(e) "Evaluation of the AN/FPS-16 (System Nr 1) at WSMR", U.S. Army Signal Missile Support Agency, Technical Memorandum 606, Feb 1959, WSMR, N.M.

(f) "The Accuracy of Atlantic Missile Range Instrumentation", AFMTC TN-58-16, 15 Dec 1958.

(g) Barton, David K., "Sputnik II as Observed by C-Band Radar", Presented at National IRE Convention, N.Y., March 24, 1959 (7 pages).

D-4 TERMINOLOGY:

(a) IRIG Glossary of Terms (In preparation), IRIG Secretary, White Sands Missile Range, New Mexico.

D-5 PROPAGATION ERRORS:

(a) "The Refraction Correction Developed for the AN/FPS-16 Radar at White Sands Missile Range", U.S. Army Signal Missile Support Agency, Technical Memorandum No. 577, Nov 1958.

(b) "Technical Presentation at Joint Session of Data Reduction and Computing, and Electromagnetic Propagation Working Groups of IRIG", 16 Oct 1957 (65 pages), IRIG Secretary, White Sands Missile Range, New Mexico.

(c) "Electromagnetic Theory", Stratton, McGraw-Hill, 1941.

(d) "Optics", Sommerfield, Academic Press, 1954.

(e) "Propagation of Short Radio Waves", Kerr, (MIT Radiation Lab Series, Vol 13), McGraw-Hill, 1951.

D-6 "PRECISION" AND "ACCURACY" IN INSTRUMENTATION:

(a) See D-4(a) above.

(b) "Design & Use of Instruments and Accurate Mechanism", T. N. Whitehead, Dover Publications, 1954.

(c) "An Introduction to Scientific Research", E.B. Wilson, Jr., McGraw-Hill, 1952.

(d) "Instrument Engineering", Draper, McKay & Lees (3 Volumes), McGraw-Hill.

(e) "Introduction to the Theory of Error", Yardley Beers, Addison Wesley Publishing Co., 2d Edition, 1958.

(f) "The Theory of Measurements", A. Palmer, McGraw-Hill, 1912.

D-7 Statistical Analysis of Data:

(a) "Mathematics of Statistics" (Vol. I and Vol. II), John F. Kenney, Van Nostrand, 1947.

(b) "Elements of Statistics", E.B. Mode, Prentice-Hall, Inc. 1941.

(c) "Statistical Methods for Research Workers", R.A. Fisher, Hafner Publishing Co., 1950.

(d) "The Critical Examination of Empirical Equations", U.S. Naval Ordnance Test Station Technical Memorandum No. 291, Nov. 1951.

(e) Morse & Grubbs, "Variate Difference Method", Annals of Mathematical Statistics, 18, No. 2, pp 194-214 (June 1947), (The Journal of the Institute of Mathematical Statistics, Baltimore, Md.).

(f) (See D-6 above).

D-8 Polarization:

(a) "Antennas" by Kraus, McGraw-Hill, 1950.

(b) IRE Standard 50 IRE 24.S1, Proceedings of the IRE, Nov. 1950, page 1266.

D-9 Integrated Radar Range Instrumentation Systems:

(a) Five Reports on MINSTREL Study by RCA, for Signal Corps (Contract DA36-039-SC-74853) (Task Report No. 2 was published late in 1959).

*The reader is cautioned to distinguish between the three experimental versions of AN/FPS-16 and the production model. See the second footnote of the Introduction of this document, and see a-42.

D-10 Inter-Range Instrumentation Group

(a) "IRIG, Inter-Range Instrumentation Group; History, Functions and Status 1959" by B. W. Pike; presented at the IRE "1959 National Symposium on Space Electronics and Telemetry", San Francisco, California, 28-30 September, 1959. This paper is scheduled to be published in the IRE Transactions on Space Electronics and Telemetry. It probably will be in the March 1960 issue.

NOTE: After the above paper was prepared, the Commanders' Conference (in March 1960) added as a Member Range, the Air Force Flight Test Center (Edwards AFB, California) and deleted the WSMR resident organizations AFMDC and NOMTF. As a result, full membership in the Commanders' Conference, the IRIG Steering Committee and the IRIG Working Groups is now limited to the six Member Ranges: AFFTC, AMR, APGC, NOTS, PMR and WSMR.

Typical Modern C-Band Beacons (All UNCLASSIFIED except as indicated)

The following are the principal modern C-Band beacons that are nearly developed or are in production at this time.* Some of them do not appear in the IRIG Beacon Catalogs. For the latest and official information, communicate with the sponsoring service or the manufacturer. Where the information is CONFIDENTIAL, it is indicated by the letter (K).

Military Type No.	Mfgr. Type No.	Rec. Type	Sens. dbm	Interr. Pulses	Peak Power	Manufacturer	Mil. Sponsor	Remarks
LOWER PERFORMANCE BEACONS:								
AN/DPN-31-(c)	-	Xtal	-40	1,2,or 3	50W.	Hazeltine; Little-Neck, N.Y.	Signal Corps; Ft. Monmouth, N.J.	Hard Tube Modulator
AN/DPN-42	323	Xtal	-41	1 or 2	50W.	AVION; Paramus, N.J.	" "	Thyratron Modulator
MK-425	353	Sup.	-65	-	-	" " "	" "	Converter for AN/DPN-42
AN/DPN-57	-	Xtal	-40	1,2,or 3	100W.	Hazeltine	" "	Transistorized
AN/DPN-63	-	Xtal	-45	1	200W.	Motorola; Scottsdale, Arizona	APGC; Eglin AFB, Fla.	
-	-	Xtal	-41	1	400W.	Vought Electronics, Dallas 22, Texas		Transistorized
HIGH PERFORMANCE BEACONS WITH A/N NOMENCLATURE:								
AN/DPN-50	S-C700	Sup.	-65	1,2,or 3	500W.	Stromberg-Carlson; Rochester, N.Y.	Signal Corps	Hard Tube
AN/DPN-54	-	Sup.	-70	1,2,or 3	500W.	Motorola; Scottsdale, Arizona	AMR; Patrick AFB, Fla.	Hard Tube
AN/DPN-55	469	Sup.	-65	1 or 2	400W.	AVION	Signal Corps	Thyratron
HIGH PERFORMANCE BEACONS WITHOUT A/N NOMENCLATURE:								
Spec XAV-28A	-	(K)	(K)	(K)	(K)	Canoga; Van Nuys, Calif.	Navy, BuAer	Aircraft Beacon.**
Spec TE-E-117C	-	Sup.	-60	3	400W.	AVION. (For TEMCO; Dallas, Texas)	Navy, BuAer (PMR)	Missile Test Beacon. (TEMCO Spec.)***
-	480	Sup.	-68	1 or 3	400W.	AVION	-	High-Temp. Transistors.
-	149-C	Sup.	-70	1 or 2	400W.	AVION	-	High-Temp. Transistors.
-	Spec NCS-1652-A-2	Sup.	-65	1 or 2	400W.	General Elec. Co. Utica, N.Y.	Air Force (?)	Nose-cone Test Beacon; High-Temp. Transistors.
-	D10-50736	Sup.	-68	1 or 3	500W.	Motorola; Scottsdale, Arizona	Air Force (Boeing)	
-	AGA C/T Mod. II	Sup.	-65	1 or 2	300W.	Aero Geo Astro; Alexandria, Va.	-	Transistorized.
AN/DPN-66 (?)	SST-102	Sup.	-70	1, 2 or 3	500W.	Motorola, Scottsdale, Arizona	AMR, Patrick AFB, Florida	High-Temp. Transistors.

*For data on pioneer C-Band beacons that were developed and produced by Canoga and by Melpar (Falls Church, Va.), See IRIG Beacon Catalogs.

**Spec. XAV-28 is classified CONFIDENTIAL at this time.

***Only one page of Spec. TE-E-117C is classified CONFIDENTIAL. This page discloses the altitude and temperature functions of a specific missile.