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ELECTRONIC TRAJECTORY MEASUREMENTS GROUP

IRIG TRACKING RADAR COMPATIBILITY AND DESIGN STANDARDS FOR G-BAND (4 to 6 GHz) RADARS (Formerly C-Band 5CM)

WHITE SANDS MISSILE RANGE
KWAJALEIN MISSILE RANGE
YUMA PROVING GROUND
DUGWAY PROVING GROUND
ELECTRONIC PROVING GROUND

ATLANTIC FLEET WEAPONS TRAINING FACILITY
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Prepared by

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Range Commanders Council

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FOREWORD

The mission of the National and Service Ranges has historically been primarily one of performing the tracking function associated with the local workload. Often, two or more ranges are involved in an operation and, on occasion, all or most of the ranges are involved in a single mission. Mercury, Gemini, and to a lesser degree, the Apollo and Titan III programs have required considerable compatibility among radars and radar beacons. The need for global metric data has been largely supplanted by: (1) unified equipment such as NASA's Unified S-Band (USB) and the Air Force's Space Ground Link System (SGLS), (2) a reduction in workload with the completion of some of the manned programs, and (3) improved launch vehicle reliability.

These trends have reduced the demand for inter-range radar standardization from a mandatory condition to one that may be categorized as desirable. This observation excludes the operations that require compatibility among ranges which is primarily of local concern and should be resolved under the existing lead-range-concept. As a consequence, the establishment of restrictive IRIG radar standards, from a radar sophistication or cost approach, is undesirable. Rather, a commonality which has a minimum impact on the member ranges is in order. Each of the National Ranges shall maintain this minimum capability. When a Service Range complements a National Range, the capability requirement extends to that Service Range.

In an attempt to minimize the bulk of this document and establish one common reference for definitions of radar terms, the "Radar Handbook" will be utilized. The "Radar Handbook" is published by McGraw-Hill, edited by Merril I. Skolnik of the Naval Research Laboratory, and identified by Library of Congress catalog number 69-13615.

The utilization of more sophisticated on-site data processing equipment has made the radar data input and output formats more important for inter-range use.

Any additions, deletions, and/or corrections aimed at improving the general and specific goals of this document should be brought to the attention of the Secretariat of the Range Commanders Council, STEWS-SA-R, White Sands Missile Range, NM 88002.

This document, IRIG 252-74, supersedes any previously published IRIG C-Band Standard.

The Range Commanders Council has adopted the use of the International System of Units (SI) to facilitate the transition from several older systems of units normally used in the USA to the internationally accepted SI. For every non-SI value stated in future RCC documentation, the SI equivalent value will be given in parenthesis, i.e., one foot (0.3048 meters).

This policy is adopted as a result of a bulletin issued on 10 February 1964 by the US Department of Commerce (National Bureau of Standards) which stated: "Henceforth it shall be the policy of the National Bureau of Standards to use units of the International System (SI), as adopted by the 11th General Conference of Weights and Measures, except when the use of these units would impair communication or reduce the usefulness of a report. . . ."

INTRODUCTION

The considerations outlined in the "Foreword" section of this document reflect the philosophy of global tracking requirements. This is not intended to nullify the IRIG responsibility to establish guidelines for the design of new instrumentation radars.

This document is presented in two major sections. Section I outlines the minimum noncoherent G-Band (4-6 GHz) radar compatibility standards for inter-range use. Emphasis is placed primarily on the transmitter and receiver characteristics since these are the major radar subsystems which must be standardized to insure compatibility.

Section II provides guidelines for the design of new G-band noncoherent instrumentation radars. The newly designed G-Band radar must be capable of communicating with the many types of transponders currently utilized by the National Ranges. Noncoherent G-Band transponder standards may be found in IRIG Document 254-80.

ACKNOWLEDGEMENT

This document was prepared by an ad hoc committee of the Electronic Trajectory Measurement Group (ETMG), an Inter-Range Instrumentation Group (IRIG) of the Range Commanders Council. The following ETMG members contributed to the finalization of this standard: Mr. K. M. Graves (Chairman), SAMTEC; Mr. J. A. Fredrick, PMR, and Mr. F. W. Mann, AFETR.

SECTION I
INTER—RANGE COMPATIBILITY STANDARDS

1.0 GENERAL

This section outlines the minimum noncoherent G-Band radar parameters for a single track for standard inter-range operational compatibility. The requirements contained herein are intended to minimize the operational parameter by standardizing a single parameter for each function, i.e., pulse repetition frequency (PRF) of 160 pulses per second (pps) in lieu of 620, 320, 160, etc.

1.1 TRANSMITTER REQUIREMENTS

1.1.1 Frequency

a. The transmitter shall be tunable from at least 5600-5800 MHz (5.6 - 5.8 GHz).

b. The transmitter shall be tunable to any selectable frequency within ±2.5 MHz over the 5600-5800 MHz range.

1.1.2 Pulse Repetition Frequency (PRF)

The transmitter shall operate at a pulse repetition frequency of 160 pps as derived from the IRIG Document 103-65, "IRIG Standard for PRF and Reference Oscillator Frequency for C-Band Radars."*

1.1.3 Coding

a. The transmitter shall transmit two pulses spaced a minimum of 5.5 microseconds and a maximum of 9.5 microseconds apart.

b. The pulse spacing shall be measured at the -3 decibel (db) power points on the leading edge of adjacent pulses.

c. The peak power difference between pulses of a code group shall not exceed 1.0 db.

1.1.4 Radio Frequency (RF) Spectrum

The RF pulse spectrum width in MHz measured at the quarter power (-6 db) points shall not exceed 2.0 divided by the pulse width in microseconds, i.e., $2.0 \div 0.50 = 4.0$ MHz.

*Document 103-65 superseded by Document 251-80, _IRIG Standard for Pulse Repetition Frequencies and Reference Oscillator Frequency for C-Band Radars._

1.2 RECEIVER REQUIREMENTS

1.2.1 Frequency

The radar receivers shall be continuously tunable over the frequency range from 5570 to 5830 MHz (5.57 - 5.83 GHz).

1.2.2 Bandwidth

The radar receiver's bandwidth shall be a nominal 4 MHz (.004 GHz) for a received 0.5 microsecond pulse width or a nominal 2 MHz (.002 GHz) for a 1.0 microsecond pulse width.

1.3 ANTENNA

Polarization. Antenna polarization for inter-range use shall be circular.

SECTION II
G–BAND RADAR DESIGN STANDARDS

2.0 GENERAL

It is not the intent of these standards to limit future development of G-Band radars, rather the intent is to provide guidelines around which future G-Band tracking systems may be designed. Since it is unwise to project all of the characteristics of future tracking systems, these guidelines only depict the standards of tracking systems used to meet current program requirements and some of the desirable features that enhance these systems.

2.1 TRACKING RADARS/SYSTEMS

With the requirements for increased accuracy and precision tracking in current and future programs, the need for an improved optical and RF calibration system becomes more evident. On-site, near-real-time calibration of tracking systems through error model coefficient compensation inherently requires more sophisticated data processing equipment and techniques. Therefore, it becomes more difficult to isolate on-site data processing equipment, data formats, peripheral equipments and software routines from the performance characteristics of the radar. Based upon these considerations, the basic G-Band tracking radar is being replaced by a more sophisticated tracking system which includes the entire on-site complex. Because of the techniques utilized in the current optical and RF calibration systems, the inherent errors of the radar pedestal, antenna servo encoders, and ranger become more readily controllable. These techniques obviously affect future design criteria for tracking radars. Current techniques used to resolve a number of these inherent radar errors are provided in the appendices.

APPENDIX A

1.0 ADVANCED RADAR CALIBRATION SYSTEM (ARCS)

1.1 General

The ARCS postulates a model of systematic errors of the radar system and measures the values optically through an Optical Data Corrector (ODC) by tracking stars, then calculates the optical and RF difference through tracking of illuminated satellites. The design goal of the star calibration technique was to enable fitting of the error model coefficients to the data with residuals no greater than 5 arc seconds, RMS. This figure was based upon the resolution of the encoders (2.4 arc seconds, RMS), the precision of the right ascension (1.5 arc seconds, RMS), declination data (1.0 arc second, RMS), refraction uncertainties, and atmospheric turbulence.

NORAD element sets are one standard form for describing the orbital parameters for an earth orbiting satellite. Thus, the capability of designating the radar to a satellite in order to acquire track becomes a major step in controlling the system in the dynamic calibration mode; likewise, this provides a capability that is required in the normal radar support program.

The radar site personnel perform the ARCS procedures as part of the regular site routines. Therefore, the results become immediately available for error model updating in near-real-time.

1.2 Radar Errors

1.2.1 Static Errors

Static errors are a function of the pedestal including mechanical alignment and deformation characteristics. These errors include mislevel, encoder zero set, encoder nonlinearity, nonorthogonality, and droop. The development of static error determination is based upon the premise that if ΔA and ΔE could be measured to a great accuracy for a series of A, E pairs then the pedestal errors are derived by:

$$\alpha A = \alpha 0 + \alpha_1 \sin A \tan E + \alpha_2 \cos A + \tan E + \alpha_3 \sin A + \alpha_4 \cos A + \alpha_5 \tan E$$

$$\alpha E + \beta 0 + \beta_1 \sin A + \beta_2 \cos A + \beta_3 \sin E + \beta_4 \cos E$$

α, β = zero set biases

$\alpha_1, \alpha_2, \beta_1, \beta_2$ = mislevel coefficients

α_1 equals β_2, α_2 equals $-\beta_1$ α_3, α_4, β_3, β_4, = encoder nonlinearity

α_5 = nonorthogonality

This is a typical error model of azimuth and elevation pedestals. Determination of the error model coefficients is accomplished by designating the pedestal to stars and measuring the angular pointing errors for each star with the ODC.

1.3 Dynamic Errors

Antenna error pattern skew, servo characteristics, and antenna pattern droop fall in the category of dynamic errors. The coefficient information, derived from static error resolution, is used to correct pedestal data during tracking operations. Dynamic error can be identified by simultaneously tracking a target with the radar and the ODC.

1.4 Timing/Range Errors

Resolution of timing and range errors is accomplished through the bi-static tracking method. These errors are identified as range biases and data time tagging. Site-to-site data comparisons are made by using radar number one to electronically track a visible object transmitting the data to radar number two for transformation and use as designate data, and observing the errors measured by the ODC on radar two. A network of radars consistent with each other and capable of maintaining that consistency on a routine basis is being developed.

APPENDIX B

2.0 ON–AXIS/DIRECTED TRACKING MODIFICATION (DTM)

2.1 General

a. The On-Axis, or DTM, is probably the most sophisticated tracking system currently being utilized to attain greater tracking accuracies, increased tracking smoothness, and a higher loop gain than the MIPIRs now in use. The On-Axis concept of pointing a tracking instrument with an a priori driving vector and use of the tracking error signal to correct the drive vector and estimate the true trajectory was being considered in the mid-1950's.

b. The fundamental operation of an On-Axis Radar and a conventional auto-track radar is identical. It is the different means by which the two systems achieve angle servo and range machine control which determine their respective performances.

c. The principle of the On-Axis system is based upon utilization of a greater amount of relevant data used in real time in taking measurements. The system uses the target's equations of motion in estimating the current position of a target and projecting its position into the future which allows real-time trajectory estimation. The tradeoff between rejection of noise and dynamic lag is nearly eliminated. This is a great advantage over the conventional auto-track radar because the servo system may be optimized with respect to dynamic response. The on-axis system provides an improved on-site calibration system that is far superior to the normal auto-track radar.

2.2 System Calibration

The limiting factor in the collection of useful data in the day-to-day operation of metric radars and the analysis of data is the calibration of the system. The primary problem areas are the angular channels. Many of the system functions/terms are fairly stable and may be determined by conventional methods. Additionally, some of the functions are very unstable on a daily or hourly basis and the measurement of these terms is so costly or time consuming that it is not feasible to attempt measurement. A prime example is the alignment of the RF axis relative to the physical antenna structure. Boresight towers in the near-field-of-view are not the answer to resolution of RF alignment; nor is the fixed boresight tower extremely accurate in determining antenna droop.

2.3 System Improvement

Current calibration techniques do not allow the accuracies that the system is capable of attaining. This is primarily because of two deficiencies. First, the present operation of the $\alpha\beta$ filter which couples the RF optical observations with the calibration of the RF axis makes it virtually impossible to calibrate to the required levels in a single pass. A recursive $\alpha\beta$ type filter is used to process the monopulse error channel data in real time to estimate the target trajectory, which in turn directs the radar to the expected position of the next measurement. Because the estimated trajectory is used to direct the radar in real time, the recursive equations are used in a closed-loop function as the RF error channel becomes the difference between the actual target position and the estimated position. Investigation into the use of a nine-state Kalman filter for the purpose of RF optical calibration is being conducted. An improved optical measuring device such as the ODC used in ARCS is being considered. The

ODC is used because of the dominant factor of noise on the RF error channel data and on the optical data contributing to pointing uncertainty. The second deficiency is in the use of the hand-fit regression techniques for recovery of the calibration coefficients which limit both the accuracy of the results and the error model. To optimize the optical system calibration, a weighted least-squares technique should be utilized. A test program is being generated to evaluate the optical observations over a period of time to determine the stability level of the various coefficients.

2.4 Environmental Effects

Three significant environmental error sources that adversely effect the On-Axis Radar are refraction, antenna wind loads, and solar heating. Data available from existing radar systems may provide an estimate of the probable level of these environmental effects. Errors produced by these sources usually contain both high frequency and low frequency effects.

2.4.1 Refraction

Refraction has low frequency type errors in range and elevation and high frequency type errors in angular measurements for which no compensation is possible. Because of the On-Axis Radar tracking technique, the handling of atmospheric refraction effects requires not only the usual best correction to adjust the observed range and elevation angle, but also the real-time compensation of refraction to designate the antenna with respect to the target. Additionally, non-real-time refraction correction is essential to the calibration process. Both operational and calibration aspects involve mostly exoatmospheric targets; therefore, only refraction effects looking through the total atmosphere are considered.

2.4.2 Wind

Antenna wind loads can also exhibit both high and low frequency components. Wind induced errors, observed in the servo system, reveal average peak-to-peak pointing discrepancies from 15 to 35 arc seconds (0.07 to 0.18 milliradian) in the presence of wind gusts from 10 to 25 knots. These errors appear in the RF error channel as the radar is essentially blown off-axis by winds of this magnitude. Therefore, there is a potential source of correlated noise on the RF channel data that must be considered in the real-time estimate. The post-flight evaluation effect will depend on where the actual error is located and the processing of the data. Low frequency effects from wind would be minimal and are, therefore, disregarded.

2.4.3 Solar

Solar effects generally appear as low frequency errors resulting as a change in the value of the various RF and optical calibration coefficients. Fluctuations in the coefficients caused by temperature and/or heating rates will eventually determine the frequency with which the various coefficients must be calibrated. Largest errors from heating effects are reflected in mislevel coefficients with magnitudes up to 20 arc seconds over a 24-hour period. Changes in the nonorthogonality coefficient on the order of 10 arc seconds have been experienced. RF and optical misalignment changes are possible although they would be difficult to isolate from receiver drift. Further data must be collected and analyzed to determine exact system calibration effects from heating.

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NOTES: (Apr 85)
Document 115-69 superseded by Document 254-80, same title.
Document 103-65 superseded by Document 251-80, same title.
Document 106-69 superseded by Document 254-80, Noncoherent C-Band Transponder Standards.

The following documents have been cancelled: 102-64, 114-69 and 116-69.