18 October 1967

U. S. ARMY TEST AND EVALUATION COMMAND
COMMON ENGINEERING TEST PROCEDURE

RANGING SYSTEM TEST

1. OBJECTIVE

The objective of this MTP is to prescribe methods for testing two major ranging systems which utilize phenomena associated with electromagnetic propagation.

2. BACKGROUND

The technique of determining distance from some reference point to the target is called ranging. Normally, ranging systems related to missiles employ either a geometric ranging method or a method which measures the propagation time of RF energy. (See Appendix A and B, Pages A-1, and B-1. The importance of accurate ranging is related to a particular Radar System's ability to correctly fix a target's location in space for any given time. Target velocity, coordinates, and range are all interrelated and inaccurate determinations of any one of these variables may result in inaccurate or false values for the other two. In order to evaluate a particular Radar System's ability to perform its designated mission, it is necessary to evaluate the related ranging system in terms of its measurement accuracy and response. Tests contained herein facilitate an evaluation of two basic ranging systems and may be incorporated into general Radar System Evaluations.

3. REQUIRED EQUIPMENT AND FACILITIES

a. Appropriate Testing Range
b. Optical Tracking Facilities
c. FPS-16 Instrumentation Radar
d. Calibrated Test Instruments
e. Surveying Equipment
f. Automatic Data Recording Equipment
g. Appropriate Radar "Targets"
h. Equipment Test Log

4. REFERENCES

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5. SCOPE

5.1 SUMMARY

This MTP describes a method for evaluating the performance of two typical ranging systems under both static and dynamic conditions.

5.1.1 Geometric Ranging Subtests

The geometric ranging system subtests are designed to describe methods of determining range accuracy, maximum and minimum ranges, and the effects of range tracking noise on a system employing geometrical ranging. Specific subtests are described as follows:

a. Target position - beam axis determination (static) - The objective of this subtest is to determine the magnitude of the off axis error signals, generated under static conditions, resulting from the beam axis of the system under test failing to bisect the target.

b. Target Position - beam axis determination (dynamic) - The objective of this subtest is to determine the magnitude of the off axis error signals, generated during tracking.

c. Positioning accuracy (static) - The objective of this subtest is to determine the degree of accuracy present in the measuring of position by the test system under static conditions.

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d. Positioning accuracy - (dynamic) - the objective of this subtest is to determine the degree of accuracy present in the measuring of position by the test system under dynamic conditions.

e. Coordinate transformation error - The objective of this subtest is to determine the amount of error present when using the system under test to range on targets of varying range.

d. Propagation error determination - The objective of this subtest is to determine the magnitude of error introduced into the test system as a result of propagation of energy through the atmosphere.

g. Maximum and minimum range determination (Electrical) - The objective of this subtest is to determine the maximum and minimum ranges as determined by stated electrical parameters.

h. Maximum and minimum range determination (Geometric) - The objective of this subtest is to determine the minimum and maximum ranges as determined by stated geometric parameters.

i. Range tracking noise - The objective of this subtest is to determine the effects of range tracking noise on a ranging system employing the principle of triangulation to measure range.

5.1.2 Propagation Time Measurement Subtests

The propagation time measurement subtests are designed to test the range accuracy, maximum and minimum ranges, maximum tracking range, effects of range tracking noise, selectivity, and the target resolution capability of a propagation time ranging system.

a. Range accuracy determination subtest (Static) - The objective of this subtest is to determine the level or degree of accuracy of a ranging system which measures the range of a particular target by measuring the time of energy propagation, under static conditions.

b. Range accuracy determination subtest (Dynamic) - The objective of this subtest is to determine the level or degree of accuracy of a particular target by measuring the time of energy propagation, under dynamic conditions.

c. Maximum and minimum range subtest - The objective of this subtest is to determine the maximum and minimum ranges for detection of a target by a ranging system.

d. Maximum tracking range - The objective of this subtest is to determine the maximum range at which the system under test can track a given target.

e. Range tracking noise subtest - The objective of this subtest is to determine the range tracking error associated with range tracking noise.

f. Range resolution capability subtest - The objective of this subtest is to determine the minimum separation distance in range between two targets that can be discerned by the radar system under test.

5.2 LIMITATIONS

Test contained in this MTP are intentionally general and are applicable to a variety of ranging systems with the exception of systems using "comparison ranging" methods based on comparing a known length or size to that of a similar object of undetermined length or size at an unknown range.

6. PROCEDURES

6.1 PREPARATION FOR TEST

6.1.1 Prescheduling Conditions

Ranging system tests should be scheduled and conducted during periods of low humidity and good visibility to preclude high frequency radar signal attenuation by rain and moisture and to prevent signal blockage by low lying clouds when using optical methods of range determination.

6.1.2 Pre-testing Conditions

a. Personnel responsible for conducting the test should ensure that applicable instructions and design specifications are available.

b. Reports of previous ranging system tests should be available when appropriate.

c. Operating instructions for test instruments to be used in the conduct of the test should be obtained and available to test personnel.

d. A test log book or folder should be prepared and utilized to record data during tests.

e. Availability of the test racking range facilities should be checked and firm scheduling verified.

f. Ensure that all test instruments have been calibrated to within desired tolerances.

g. Test personnel should be briefed prior to testing on the purpose of the test and the degree of accuracy expected.

6.2 TEST CONDUCT

This MTP contains tests applicable to the evaluation of two ranging systems. The overall tests are designed to measure and evaluate the performance of specific aspects of the particular ranging system under test. The overall tests are further divided into subtests corresponding to the characteristics evaluated.

6.2.1 Geometric Ranging System Test (See Appendix A, Page A-1.)

6.2.1.1 Target Position - Beam Axis Determination (Static)

a. Prior to beginning test, arrange equipment as shown in Figure 1, Page 7 . The selected target should have coordinates which have been precisely determined by a first order survey and should be highly reflective to the energy of the system under test. (A corner reflector shall be used as the target).

b. Zero the antenna beam of the system under test on the target by focusing the beam on the target such that no error signals are generated by the sensor. (Error signals will not be generated if the target is bisected by the beam).

c. Measure and record elevation and azimuth readings for the zero position as determined above.

NOTE: The ranging radar under test should be mounted, and directed toward the target, in such a manner so as to eliminate or significantly reduce the unwanted effects of ground reflection.

d. Fix the antenna under test in the zero position in both azimuth and elevation.

e. Vary the angular position of the target along the horizontal and vertical axis of the plane containing the target.

f. Ascertain and record the coordinates of each new target position.

NOTE: A minimum of 10 different target positions along each axis should be recorded.

g. Turn equipment on and after allowing sufficient warm up time, measure and record the phase angle and voltage magnitude of the signal generated by the system under test as a result of the beam axis not bisecting the target. (This generated signal is called the "off axis" error signal and is proportional to each variation in target position when the target does not fall on the beam axis.

NOTE: The "off axis" error signals are voltages whose polarity and magnitude are proportional to direction and distance, respectively, of the target removed from the "zero" position. In a perfectly functioning system, these voltages, when applied to the antenna drive of the test system, would cause the antenna to be driven in such a manner so as to cause the beam axis to again bisect the target. In this test, although the error signals are converted to drive signals, the antenna drive is caged and consequently does not move. The drive signals thus generated are monitored and displayed.

6.2.1.2 Target Position-Beam Axis Determination (Dynamic)

a. Prior to beginning tests, arrange equipment according to diagram shown in Figure 2, Page 9. The target used during this test should fly a known trajectory.

b. Turn on equipment, allowing sufficient warm-up time prior to beginning tests.

c. Release target along the pre-planned trajectory.

d. Zero the antenna beam of the system under test, on the target such that no error signals are generated.

e. As the target moves along the trajectory, allow the radar system under test to track.

f. Monitor and record the off axis errors generated by the sensor, on a calibrated recorder.

6.2.1.3 Positioning Accuracy (Static)

a. Zero the ranging system under test, in terms of position, by slewing the antenna until position indicators read zero° in elevation and azimuth. (Azimuth Reference = Mag. North; Elevation Reference = Horizontal

b. Verify the zero elevation and azimuth readings by optically determining position.

NOTE: If not actually in the zero position, adjust the system until "zeroing" is achieved and so indicated by the system's position indicators, and by verifying equipment.

c. From the zero position, slew the antenna in azimuth through a minimum of 20 different angular positions. Verify, by optical means each angular position observed on the system's position indicator. Record the indicated value of azimuth position as well as the verified value of position.

NOTE: The azimuth angle is usually taken to be the angle between the vertical plane containing magnetic north and the vertical plane containing the beam axis. The elevation angle is defined as the angle that the beam axis makes with the horizontal.

d. Repeat procedures in c, above for elevation.

6.2.1.4 Positioning Accuracy (Static)

a. Refer to Figure 2, Page 9 for equipment set-up

b. Prior to beginning dynamic tests, ensure that the ranging system under test has been zeroed in azimuth and elevation.

c. Apply a sinusoidal driving signal from a calibrated source, to the asimuth input of the antenna drive servo of the system under test.

d. Record the antenna response as a function of signal strength and phase.

e. Repeat steps 2 and 3 while varying the signal magnitude and phase of the input signal.

f. Replace the sinusoidal signal with a step signal and repeat procedures outlined in steps 2 and 3 and 4.

g. Repeat steps c through f above for elevation.

6.2.1.5 Coordinate Transformation Error Determination

a. Arrange equipment according to Figure 3, Page 10.

b. Turn equipment on and allow time for warm-up.

c. Place targets at known ranges in the vicinity of the ranging system to be tested. (Targets should be placed in a minimum of 20 different positions).

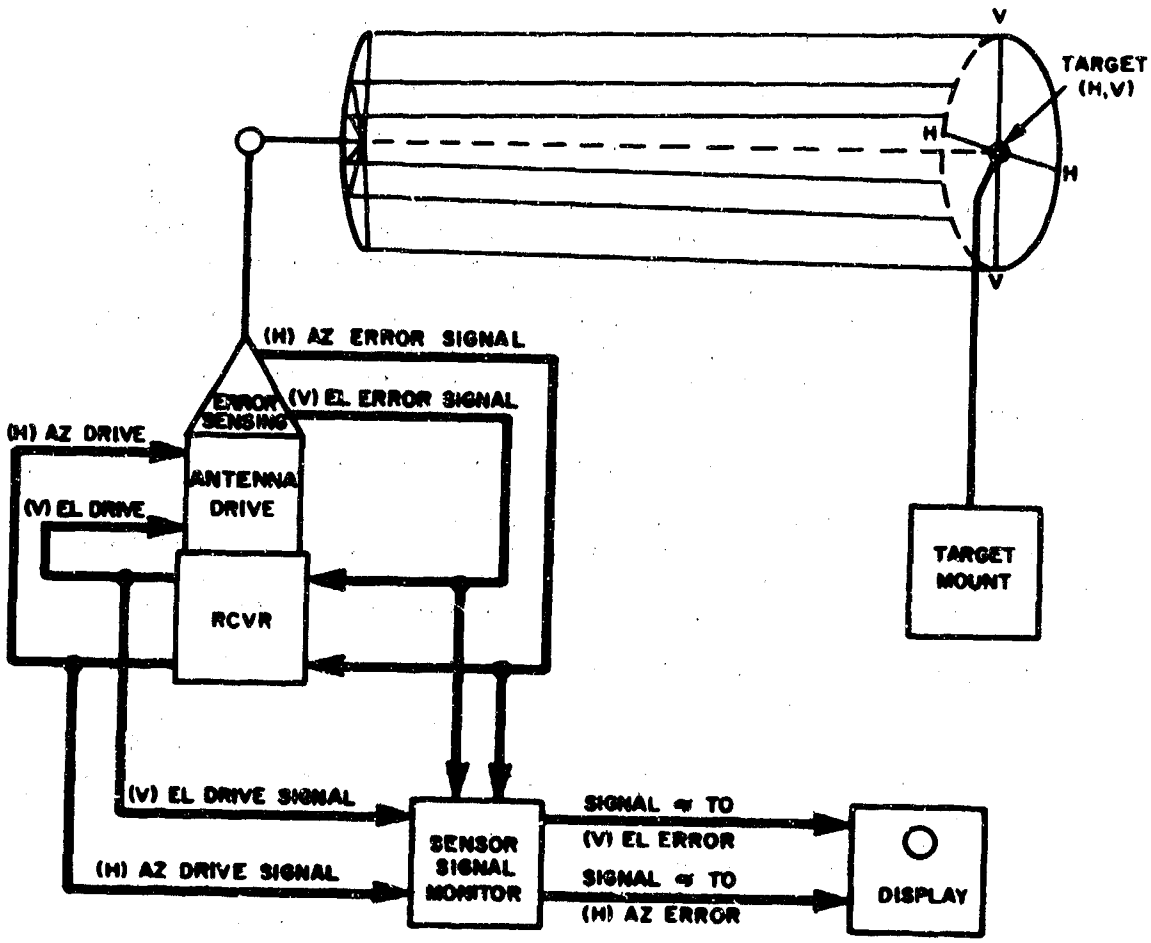

FIGURE I. (TARGET POSITION-BEAM AXIS STATIC TEST)

d. Allow the system to range on the target. (Repeat procedure after varying the target's range).

e. Monitor and record ranges to targets as measured by the system under test.

f. Optically track and range on the target with calibrated measuring equipment.

g. Record actual range to target as measured in f.

6.2.1.6 Propagation Error Determination

a. Direct the antenna beam of the test system on the selected target. (Target should be positioned in such a manner as to be separated from the antenna of the system under test by an amount of atmosphere commensurate with maximum operating conditions).

b. Observe the elevation to the target as shown by the indicator of the system under test. Record this angular reading

c. Measure and record the elevation to the target by using optical surveying equipment.

6.2.1.7 Maximum and Minimum Range Determination (Electrical)

a. Refer to Figure 4, Page 10, for equipment diagram.

b. Locate target (balloon or slow moving aircraft) on a horizontal path which remains equidistant from the two radar antenna under test.

c. Turn equipment on and after warm-up period, triangulate on the target.

d. Monitor the range indicator as the target slowly moves along the pre-designated path.

e. Record the range at which the signal to noise ratio, viewed on the indicator, appears greatest, as a function of the azimuth angle of the two antennas. (This point corresponds to the point of minimum range error due to noise attenuation of the signal).

f. Monitor the range indicator as the target moves away from the antennas along the predesignated path.

g. Record the range at which the signal to noise ratio appears minimum, (maximum range) as a function of antenna azimuth angles.

h. Repeat step f, while target moves toward antennas.

i. Repeat step g, (minimum range).

NOTE: All ranges indicated by the system should be verified by using available surveying techniques

6.2.1.8 Maximum and Minimum Range Determination (Geometrical Parameters).

a. Set up equipment as in 6.2.1.7

b. Same as b, in 6.2.1.7

c. Same as c, in 6.2.1.7

d. Measure and record the range indicated by the system under test as the target moves along the assigned path, toward the antennas as a function of time.

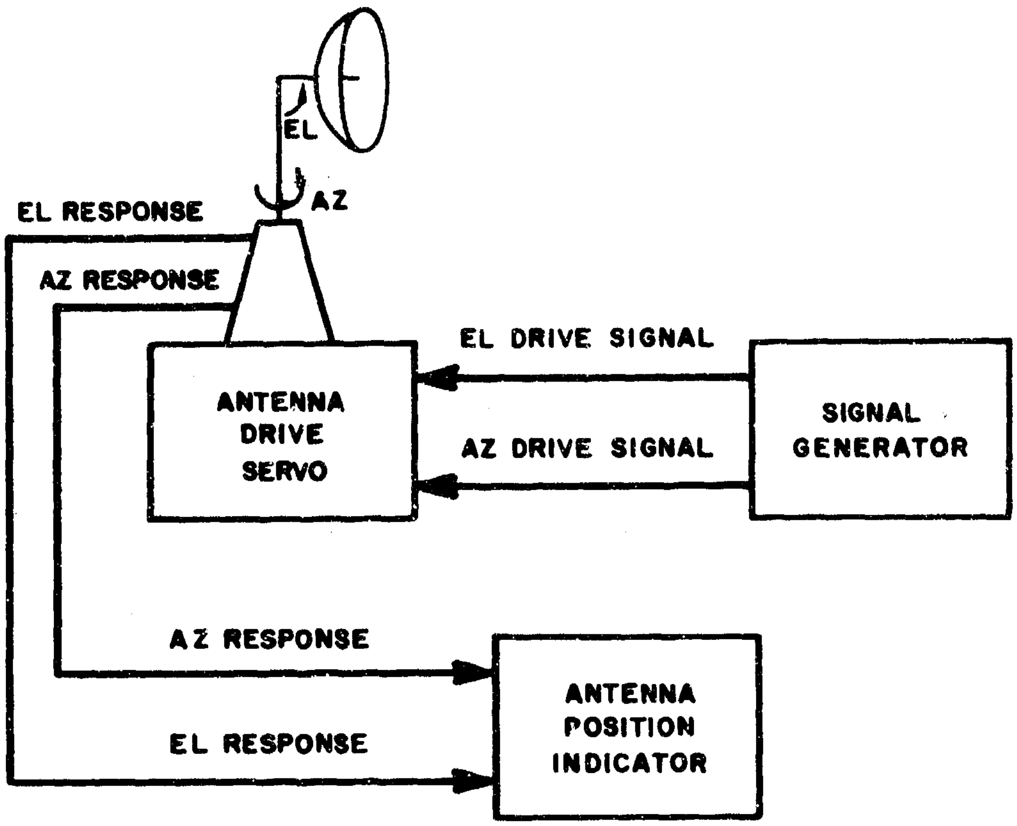

FIGURE 2. (POSITIONING ACCURACY)

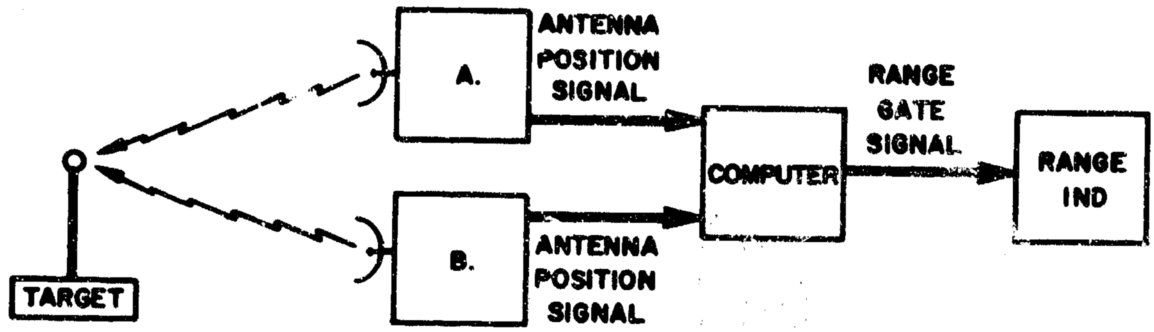

FIGURE 3. (COORDINATE TRANSFORMATION ERROR)

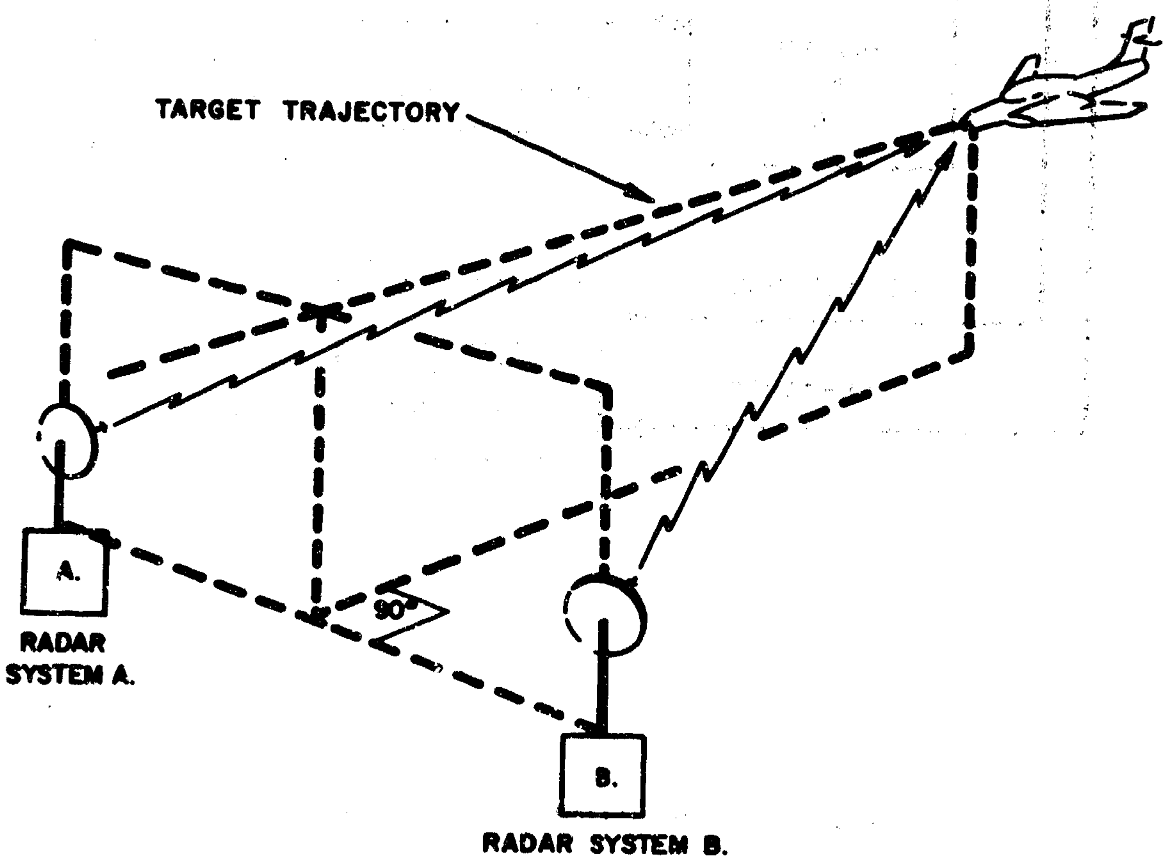

FIGURE 4. (MAX & MIN RANGE DETERMINATION)

e. Repeat procedures outlined in step f, 6.2.1.7 for the target moving away from the antennas.

f. As the target moves according to d, and e, measure and record actual range with optical tracking equipment.

NOTE: Values indicated by the system under test and the optical measurement technique should correspond. The ranges at which the difference between these values exceeds system specifications are the maximum and minimum ranges respectively.

6.2.1.9 Range Tracking Noise (Static)

a. Prior to beginning this test, the system to be tested should be evaluated in terms of the tests described in sections a through j.

b. Locate target as in 6.2.1.7, b, above.

c. Turn equipment on and triangulate on target as it moves along the prescribed path.

d. Record, with an automatic recorder, the range as measured by the test system, as a function of time.

e. Optical tracking equipment, connected to an automatic recorder should be used to measure and record the actual range to the target also as a function of time.

f. Repeat the above procedures a minimum of 3 times.

6.2.2 Propagation Time Measurement Test (See Appendix B, Page B-1).

6.2.2.1 Range Accuracy Determination (Static)

a. Arrange equipment for ranging on a preselected static target.

b. Position and perform a first order survey on targets to be used during ranging tests. Record the surveyed range to the targets. (Position targets so as to allow ranging tests to be conducted over the system's entire expected range).

c. Turn equipment on and direct the energy on the selected target. Determine and record the indicated range to the target measured by the system under test.

d. Repeat the procedure outlined in step c, for all targets within the expected range of the test system.

6.2.2.2 Range Accuracy Determination (Dynamic)

a. A dynamic target should be selected and directed to fly a preplanned trajectory within range of the test system.

b. Turn on tracking equipment of the test system and record the system's indicated range as a function of time on an automatic recorder as the target moves along the assigned trajectory.

c. Observe the moving target on optical tracking equipment and record a second set of position data measured by the optical tracking equipment.

d. Vary the radial velocity of the target through the full range of expected velocities and repeat measurements and recordings.

6.2.2.3 Maximum and Minimum Detection Range Determination

a. Arrange equipment for automatic acquisition and tracking of a preselected target flying a predesignated path.

b. Turn on equipment and allow for sufficient warm-up time before beginning tests.

c. Insert a variable attenuator into the input of the acquisition radar and adjust the attenuation until the maximum received signal strength of the acquisition radar indicates that its maximum detection range is within the maximum range capability of the tracking radar.

d. Record the amount of attenuation placed in c, above.

e. Utilizing a balloon, loft a metallic sphere of known radius and allow the wind to carry the sphere toward the acquisition and tracking radars of the system under test.

NOTE: The sphere should be released beyond the range of the acquisition and tracking radars. (Estimated detection range). A suitable target aircraft of known radar cross section may substitute for the balloon and metal sphere.

f. Acquire and track the target with the acquisition and tracking radars respectively.

g. Note and record the following data:

1) Maximum acquisition radar detection range
2) Target elevation at detection (from tracking radar)
3) BLIP/SCAN ratio

h. Determine the maximum detection range versus elevation angle by allowing the target to approach the radars and obtaining a BLIP/SCAN ratio at increments of 10,000 ft. of altitude.

i. Record target slant range at each 10,000 ft. increment of altitude on a suitable form.

j. Continue to track the target with the acquisition radar until the BLIP/SCAN ratio goes from 1.0 to below 0.5.

k. Record the point at which the situation described in step j, above occurs, as the minimum detection range.

l. Repeat steps 4 through 9, a minimum of 3 times both with and without the MTI operating.

m. If a target aircraft with jamming equipment is used instead of a balloon and metal sphere, repeat steps 4 through 9, a minimum of 3 times for each type and level of jamming.

6.2.2.4 Maximum Tracking Range Determination

a. If the required signal to noise ratio for tracking is not known, set up equipment as in 6.2.2.3.

b. Turn on equipment and allow for warm-up.

c. After receiving appropriate target information from the acquisition radar. Attempt to locate and track the target with the target tracking radar of the system under test.

d. Measure and record automatically, the received radar power and the slant range measured by the tracking radar.

e. Measure and record the minimum detectable signal power of the tracking radar. (This is the least amount of power required to be detectable).

6.2.2.5 Range Tracking Noise Determination

a. Turn on equipment and allow for warm-up.

b. Using the signal generator, simulate variations in pulse shape commensurate with expected actual return pulse characteristics.

NOTE: Variations in pulse shape should include an increase in pulse length as would be expected from a target of considerable depth; a decrease in rise time as would be expected by drifts in AFC or propagation degradation; large signals (saturating signal levels) as would be expected from targets whose cross section varied through a large dynamic range; and low signals which would be expected from small targets at maximum range.

c. Monitor and record the range output for each simulated test above.

6.2.2.6 Range Resolution Capability

a. Place two fixed targets a known distance apart, at a range within the capability of the test system.

b. Turn on the ranging system and range on the two fixed targets.

c. Monitor and record the range output of the system under test while ranging on the two fixed targets simultaneously.

d. Increase the distance between the two targets gradually and repeat steps b and c for each increase.

NOTE: Pulse characteristics such as amplitude, pulse width and shape should be recorded in c above for the two return pulses.

6.3 TEST DATA

6.3.1 <u>Geometric Ranging System Data</u>

6.3.1.1 Target Position Beam Axis Data (Static)

a. Record the elevation and azimuth to the target, as measured by the test system, for the zero position in degrees.

b. Record the coordinates of the target, as surveyed, in degrees and feet. (Elevation and azimuth in degrees and slant range in feet).

c. Record the coordinates of each new target position, in degrees and feet, as the target is moved as stipulated in 6.2.1.1, e.

d. Record the phase angle and voltage in degrees and volts, respectively, of the "off axis" error signals generated by the test system for conditions given in 6.2.1.1., g.

6.3.1.2 Target Position Beam Axis Data (Dynamic)

a. Record the "off axis" error signals generated by the test system as the system ranges or tracks a moving target, in degrees (phase angle), and volts (voltage).

b. Record the time during which tracking takes place in seconds.

6.3.1.3 Positioning Accuracy Data (Static)

a. Record in degrees, the angles observed on both the position indicator of the test system, and the position indicator of the calibrated optical monitoring system, as the test antenna is slewed through a minimum of 20 azimuth positions.

b. Record in degrees, the angles observed on both the position indicator of the test system and the calibrated optical monitoring system, as the test antenna is slewed through a minimum of 20 different elevation positions.

6.3.1.4 Positioning Accuracy Data (Dynamic)

a. Record the phase and signal strength of the sinusoidal driving signals applied to the azimuth and elevation drive signals.

b. Record the antenna response of the test system in degrees for the sinusoidal azimuth and elevation drive signals.

c. Record the phase and signal strength of the step driving signals applied to the azimuth and elevation inputs of the antenna drive servo of the system under test in degrees and volts respectively.

d. Record the antenna response in degrees, to the step signals applied as indicated in c, above.

6.3.1.5 Coordinate Transformation Error Determination Data

a. Record actual ranges to targets, in feet.

b. Record ranges indicated by the system under test in feet.

6.3.1.6 Propagation Error Determination Data

a. Record the elevation to the target in degrees as measured by the test system.

b. Record the actual elevation angle to the target in degrees.

6.3.1.7 Maximum and Minimum Range Determination Data (Electrical)

a. Record in feet the range at which the signal to noise ratio appears minimum as the target slowly moves toward the antennas under test. (Point of minimum range).

b. Record in feet the range at which the signal to noise ratio appears minimum as the target slowly moves toward the antennas under test. (Point of minimum range).

c. Record in feet the range at which the signal to noise ratio appears minimum as the target slowly moves away from the antennas under test. (Point of maximum range).

d. Record in degrees the azimuth of both antennas corresponding to the above three points.

6.3.1.8 Maximum and Minimum Range Determination Data (Geometric)

a. Record the range indicated by the system under test, in feet of the target as it moves along the trajectory. (Should be recorded as a function of time).

b. Record the actual range to the target as it moves along its trajectory, in feet.

6.3.1.9 Range Tracking Noise Data

Record in feet, the test system measured range and the actual range, as a function of time, for a designated target moving along a predesignated trajectory.

6.3.2 <u>Propagation Time Measurement Test</u>

6.3.2.1 Range Accuracy Determination Data (Static)

a. Record surveyed range to targets, in feet.
b. Record range measured by the test system, in feet.

6.3.2.2 Range Accuracy Determination Data (Dynamic)

a. Record the range to the moving target in feet, as a function of time as measured by the test system.

b. Record the actual target position data (range), measured by the calibrated optical equipment, in feet.

6.3.2.3 Maximum and Minimum Detection Range Data

a. Record amount of attenuation in volts.
b. Record the maximum acquisition detection range in feet.
c. Record the target elevation at detection in degrees.
d. Record the blip/scan ratio.
e. Record target slant range at increments of 10,000 feet of altitude, in feet.
f. Record the range at which the blip/scan ratio goes from 1.0 to 0.5.

6.3.2.4 Maximum Tracking Range Data

a. Record automatically, the received radar power and slant range measured by the tracking radar, in DBM's and feet.

b. Record the minimum detectable signal power of the tracking radar.

6.3.2.5 Range Tracking Noise Data

Record the range output in feet, for simulated inputs of section 6.3.2.5.

6.3.2.6 Range Resolution Capability Data

a. Record distance separating targets.
b. Record the range output of the test system in feet, as the distance is increased between targets.
c. Record pulse characteristics such as pulse width, pulse amplitude, and pulse shape.

6.4 DATA REDUCTION AND PRESENTATION

6.4.1 <u>Geometric Ranging System Data Reduction and Presentation</u>

6.4.1.1 Target Position-Beam Axis (Static) Data

a. Reduce data recorded in 6.3.1.1, to tabular form as shown in Figure 5, page 21.
b. Compare the recorded signal values, generated by the system under test, with prescribed signal values for the particular target condition.
c. Calculate the following:

1) Individual raw errors (X_i = Difference between actual and prescribed values)
2) Mean error (μ = average of all raw errors)
3) Difference between raw errors and the mean error ($X_i - \mu$)
4) $(X_i - \mu)^2$
5) $E(X_i - \mu)^2$

d. Using the following formula, calculate the standard deviation (σ):

$$\sigma = \frac{\Sigma(X_i - \mu)^2}{N-1}$$

Where:

X_i = Raw error
μ = Mean error
N = Number of data recorded

e. Compare calculated standard deviation with system tolerance and determine if satisfactory.

6.4.1.2 Target Position-Beam Axis (Dynamic) Data

a. Reduce data recorded in 6.3.1.2, to graphic form as shown in Figure 6.

b. Determine if plotted curve remains within the acceptable band.

6.4.1.3 Positioning Accuracy Data (Static)

Compute standard deviation of error data taken in 6.3.1.3, and compare with system tolerance to determine if static positioning accuracy is satisfactory.

6.4.1.4 Positioning Accuracy Data (Dynamic)

Compute standard deviation of error data taken in 6.3.1.4, and determine if dynamic positioning accuracy is satisfactory.

6.4.1.5 Coordinate Transformation Error Determination Data

Compute standard deviation of errors between measured and actual ranges from data recorded in 6.3.1.5, and compare with system tolerance.

6.4.1.6 Propagation Error Determination Data

Compare system measured elevation to target, as recorded in 6.3.1.6, with true target elevation angle to give an indication of beam refraction.

6.4.1.7 Maximum and Minimum Range Data (Electrical)

a. Compare point of minimum range error as derived from test with prescribed point of minimum range error (should occur when both radars have an azimuth angle of 45°), for an indication of system accuracy.

b. Compare maximum and minimum ranges as determined from test data recorded in 6.3.1.7, with maximum and minimum ranges prescribed for the system under test and determine whether discrepancies fall within acceptable limits.

6.4.1.8 Maximum and Minimum Range Data (Geometrical)

a. Compare target range measured optically with range measured by the system under test and determine the ranges at which the difference between the two exceed system parameters. (These ranges correspond to the maximum range when the target is moving away from the radars and to the minimum range when the target is moving toward the radars).

b. Compare the maximum and minimum ranges of the test system with system specified values to receive an indication of system capability.

6.4.1.9 Range Tracking Noise Data

a. Compare ranges of a designated target measured by the test system, as recorded in 6.3.1.9, with actual ranges and compute the standard deviation of the errors.

b. Compare the calculated standard deviation with system tolerances and determine if within acceptable limits.

6.4.2 <u>Propagation Time Measurement Data Reduction and Presentation</u>

6.4.2.1 Range Accuracy Data (Static)

a. Compute the standard deviation of range data measured by the system and recorded in 6.3.2.1, and data obtained by surveying.

b. Compare the computed standard deviation with system tolerances and determine whether range accuracy is within desired limits.

6.4.2.2 Range Accuracy Determination Data (Dynamic)

a. Same as 6.4.2.1, a.
b. Same as 6.4.2.1, b.

6.4.2.3 Maximum and Minimum Acquisition Detection Range Data

a. Compare recorded values of the system measured maximum detection range, target elevation at detection, blip/scan ratio, and the range at which the blip/scan ratio goes from 1.0 to 0.5, with system prescribed values for each.

b. Determine whether the difference between measured and prescribed values fall within acceptable limits.

6.4.2.4 Maximum Tracking Range Data

Compare the maximum tracking range recorded in 6.3.2.4, with the maximum tracking range prescribed for the test system and determine if the difference exceeds tolerances for the system.

6.4.2.5 Range Tracking Noise Data

a. Compute the standard deviation of errors between the measured range outputs recorded in 6.3.2.5, and the prescribed outputs for the various simulated inputs.

b. Compare the computed standard deviation with prescribed system tolerances and determine if within acceptable limits.

6.4.2.6 Range Resolution Capability Data

a. Compute the standard deviation of errors between values, recorded for the range output in 6.3.2.6, and system prescribed range outputs, as the distance between targets is increased.

b. Compare the computed standard deviation with prescribed system tolerances and determine if within acceptable limits.

GLOSSARY

1. Angular Resolution: The ability of a radar system to distinguish between two targets solely by the measurement of angles. Generally it is expressed in terms of the minimum angle by which targets must be spaced to be separately distinguishable.

2. Attenuation: The reduction in the radar signal effectiveness

3. Chirp: A method of compressing the time duration of a low amplitude return pulse to increase the amplitude of the pulse and range resolution.

4. Empirically: Obtaining results depending upon experiment, experience, or observations alone without using science or theory.

5. Parallax: The apparent displacement or the difference in apparent direction of an object as seen from two different points that are not on a straight line with the object.

6. Propagation: The transmission of variables, such as electromagnetic energy, shock waves, or sound waves, through space or another medium.

7. Range Resolution: The minimum range separation distance between two targets that can be discerned by a radar system.

8. Resolution: Process of separating closely related forms or the degree to which closely related objects can be discriminated.

9. Triangulation: A method (Trigometric) of dividing necessary elements into triangles to find a position or location by means of bearings from two fixed points at a known distance apart.

Prescribed Value	Actual Value	Raw Error (X_i)	Mean Error (μ)	$(X_i - \mu)$	$(X_i - \mu)^2$
					$\Sigma(X_i - \mu)^2$

Figure 5.

$$\frac{\Sigma(X_i - \mu)^2}{N-1}$$

Where: X_i = Individual Raw Errors
μ = Mean Errors
N = Number od Data Recorded

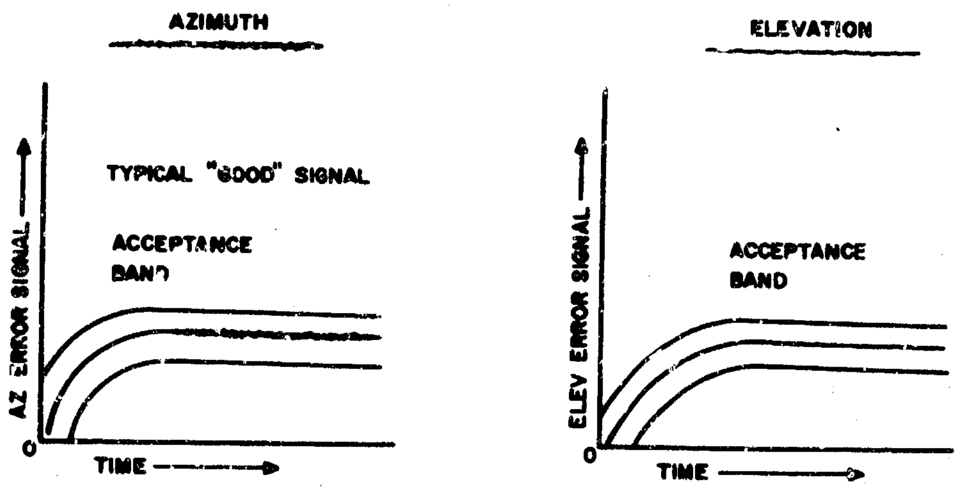

Figure 6. (Target Position-Beam Axis Data-Dynamic)

APPENDIX A

GEOMETRIC RANGING

A. GENERAL

1. Geometric ranging is the measuring of the angular position of a target relative to an established coordinate system. This angular measurement made in one coordinate system must be coordinate-transformed to another angular measurement made from a separate location. The accuracy of angular measurement requires good tracking, resolution, and narrow beam widths. A triangulation ranging system is capable of operating in both an active and passive mode.

2. The technique of geometric or angular measurement for ranging implies the use of at least two different angular measurements made from different known positions. The frequencies used by triangulation systems such as these are usually high (from S-band to ultraviolet). These high frequencies (short wavelength) are required so that a narrow beam width can be provided without an excessive antenna aperture size, consequently infrared (IR). Optical, and ultraviolet (UV) frequencies are particularly adaptable to triangulation systems. The accuracy of angular measurement required by triangulation implies good angular tracking and, in turn, good angular resolution and narrow beam widths. Beam widths from two degrees to approximately 0.5 degrees are obtainable in the S-band to K-band regions, and beam widths from 0.5 degrees to 0.05 degrees are obtainable in the IR, optical, and UV regions.

3. Ranging by triangulation is performed by measuring the angular position of a target relative to an established coordinate system. This angular measurement made in one coordinate system must be coordinate transformed to another angular measurement made from a separate location.

4. The primary advantage of a triangulation ranging system is the capability of operating in both an active or passive mode. Thus, when two angle measuring tracking systems are separated by a base line of known length and are subject to a jamming (high noise level) environment created by equipment within the target of interest, the system accuracy is increased rather than decreased by the additional noise of jamming. The primary disadvantage to triangulation is that the accuracy of ranging is a function of the geometry or relative position of the two angular measuring stations with respect to the target of interest.

B. RANGE ACCURACY

1. The major factors affecting range accuracy and the methods used for their measurement are as follows:

a. The accuracy with which the position of the target within the sensor beams can be measured by the system. This determination is made under static conditions by measuring the amount of off-axis error generated by the sensor for known incremental angular position variations at either the target or the "antenna lens" mount. Under a dynamic situation the standard deviation of a calibrated recording of the off-axis errors can be determined.

b. The accuracy with which the antenna or lens mount can be positioned with respect to the indicated error in the preceding step or to the actual target angular position. Measurements under static conditions are associated with the general pedestal or antenna mount capability and should include all alignment and accuracy checks performed to determine the axis orthogonality, distortions, and repeatability such as are performed on a "transit". Under dynamic conditions, positioning accuracy is a function of the antenna mount positioning servo system and can be described by the transfer functions of this servo system or can be measured by determining its frequency or transient response characteristics.

c. The range accuracy attainable under various target positions with respect to the two-station system.

Figure A-1, illustrates the relative accuracy to be expected as a function of target position from a two-position triangulation ranging system. The most accurate ranging will occur at points A and B. The crosshatched area indicates the area in which the ranging error has increased to an unacceptable value.

Figure A-2, illustrates the relative error of a two-station triangulation system as a function of the cotangent of the angle between the two beam axis of the two-sensors.

2. Coordinate Transformation Error - The ranging accuracy of triangulation systems is largely dependent upon the accuracy with which the coordinates of one sensor are transformed to the other. This transformation is a parallax correction and can be performed by analog means when the system has a short base line. However, when the length of the base line is many miles, the angular information normally is converted to rectillinear coordinates and digitized. It is then transmitted and coordinate-transformed in digital form. The measurements to determine the error in tranformation consist largely of comparison measurements of the position of fixed targets over the expected operating area. Slow moving targets, such as aircraft or balloon suspended targets, are preferred when mapping the ranging accuracy as a function of coordinate transformation error. Final checks on target range accuracy are made by comparing system position data with position data gathered from external range instrumentation.

3. Propagation Error - The ranging accuracy is dependent upon errors introduced into the angular measurement by propagation distortions, such as atmospheric refraction errors and will appear as elevation angle

errors. These errors are a function of frequency, the total elevation angle, and the daily atmospheric density characteristics. Refraction errors are best measured by comparing the ranging system data to external range measuring equipment that incorporates a propagation frequency widely separated from the system under test. Multipath angle errors are a function of the terrain of the site selected for the ranging system, the frequency of the system, the beam width, and the target position. Multipath errors normally increase as the elevation angle to the target decreases.

4. Comparison of range measurements of low level (low elevation angle) targets by external instrumentation will allow mapping of terrain interference areas that must be masked, attenuated, or avoided by the system.

C. MAXIMUM AND MINIMUM RANGES

For triangulation ranging, the maximum and minimum ranges over which the range of a target can be determined are affected by two factors:

1) The sensitivity of the system to view small targets at long ranges.

2) The geometric relationship of the target to the two-station system.

The maximum and minimum ranges can be found by determining where the geometric erros introduced into the system are in excess of the requirements for the system.

D. RANGE TRACKING NOISE

Triangulation range tracking noise is caused by all errors indicated in paragraph 3.5.1. a, and is measured by recording the systems indicated range to the target under both static and dynamic (moving target) conditions. These recordings can be treated statistically to provide values of tracking noise standard deviation or smoothing techniques can be used to provide bias errors. The use of the standard deviation type of analysis for tracking noise is the best common denominator for comparison of two systems.

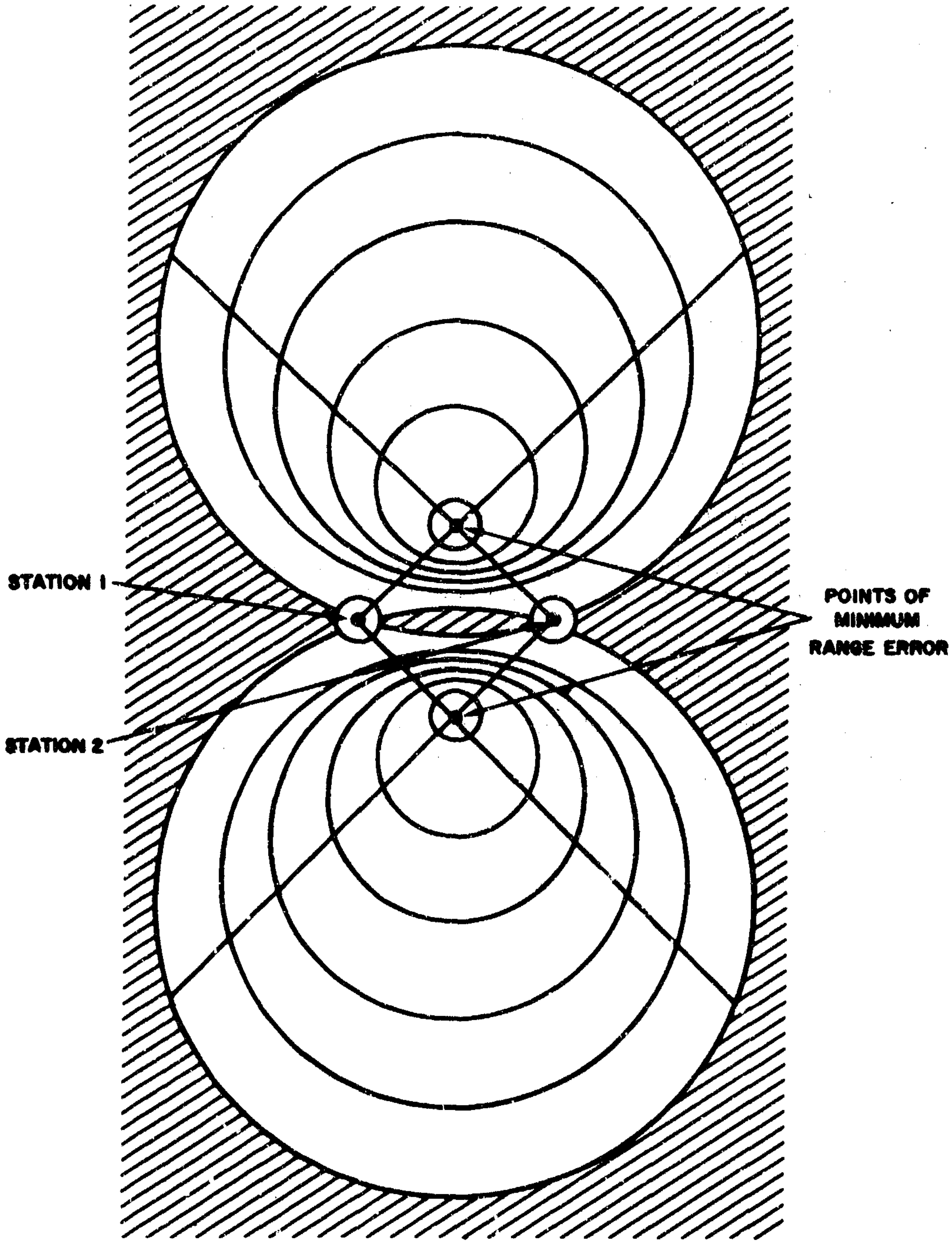

Figure A-1. Relative Accuracy Versus Target Position Using Two-Position Triangular Ranging System

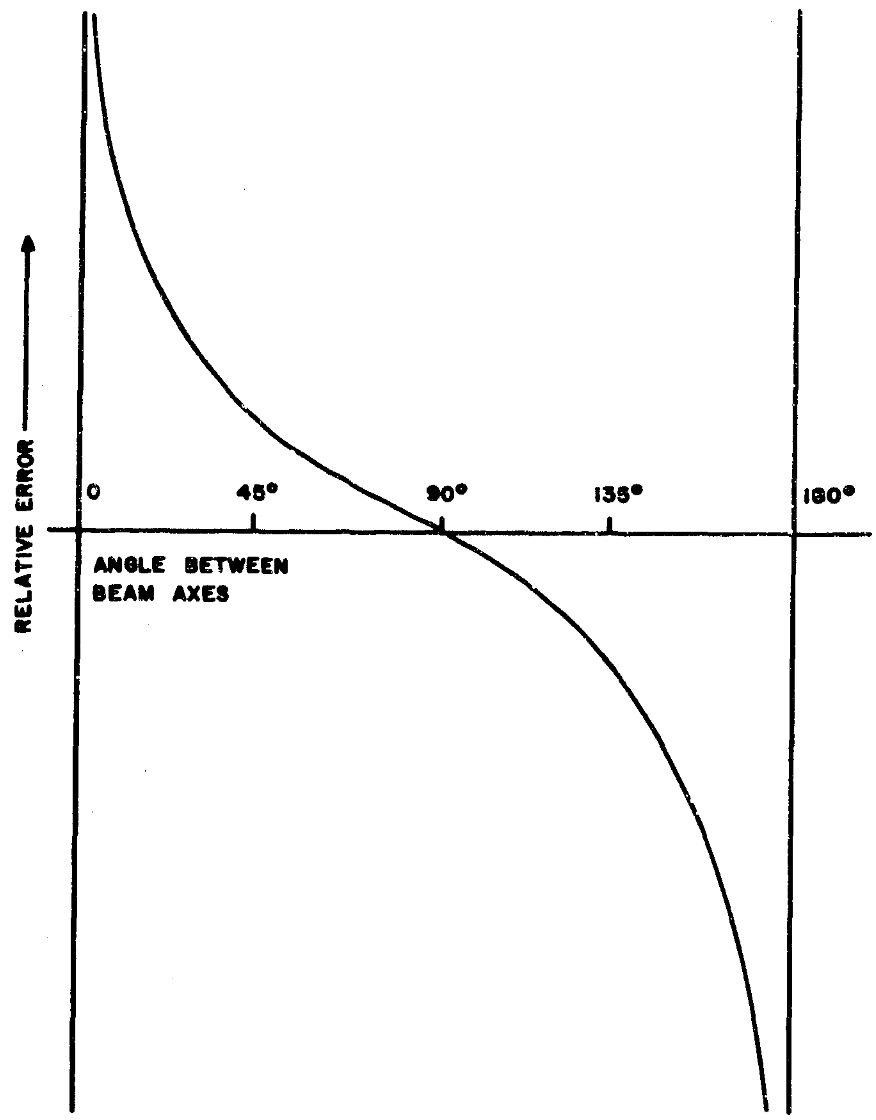

Figure A-2. Relative Error of a Two-Station Triangulation System

APPENDIX B

PROPAGATION TIME RANGING

A. GENERAL

1. Propagational time ranging is accomplished by measuring the total time required for a pulse of electromagnetic energy to make a round trip from source to target and return or by measuring the continuous wave (CW) phase difference between the source and the returning energy from the target. High power amplifier tubes incorporated in modern pulse radar systems permit the advantage of both the pulse and CW radar principles to be shared.

2. The velocity of propagation of light (electromagnetic) energy is a constant in free space. The time measurement of this propagation can be accomplished by two basic methods:

a. The measurement of the total time required for a single pulse or pulse group of electromagnetic energy to make a round trip from source to target and return.

b. The measurement of the CW phase difference between the source and the returning energy from the target. The first method is the principle of normal pulse radar systems and is the most widely used. The second method is the principle used in CW radar systems, pulse loopiler radars, and distinct difference between these two principles; there is a smooth blending from pulse radar to CW systems. Incorporation in modern pulse radar systems of high power final amplifier tubes with the ability to create radio frequency (RF), phase-coherent, transmitted pulses has allowed the advantages of both the pulse and CW radar principles to be shared. Coherent pulse radar systems are becoming the most predominant for military systems because the time available for an offensive or defensive system to track a target usually is limited and pulse radar systems have greater bandwidth than CW systems. To state this another way, the time-bandwidth product of coherent pulse radar systems is now approaching the time-bandwidth product of CW systems and pulse systems have a higher peak power capability.

B. RANGE ACCURACY

The range accuracy of a pulse radar system is a direct function of the radar system bandwidth and the time constants of the video handling circuits and range servo system. There are two general classes of ranging characteristics:

1. The closed loop mechanical servo type
2. The closed loop electronic servo direct reading type. Newly designed radar systems incorporate the electronic ranging system because of the high target velocities expected. In either system, the time of the target return pulse is compared to the time of a range gate. This difference in time becomes the error input into the ranging servo. The range servo transfer function characteristics are determined by introducing a known time modulation

frequency on a test pulse. This test pulse is injected into the input of the sum channel intermediate frequency (IF) amplifier. By recording the input frequency modulation and the output of the range servo, the transfer function is determined. A direct measurement of range accuracy under static conditions is accomplished by direct comparison of the system's indicated range from a fixed target to the range obtained by another external means of measurement. This external measurement normally is in the form of a first order survey. For a complete system checkout, many fixed targets should be used over the system's entire expected range and angular coverage. The dynamic method of measurement consists of recording the system's indicated range while tracking a moving target that is being observed by an external source. By determining the standard deviation of the indicated range, a probability of range accuracy is found and by comparing the indicated range at a specified time to the range indicated by another system at the same time, an estimate of the absolute accuracy is made. Consideration of the range tracking servo system transfer function should be made by performing range tracking through the full range of expected target radial velocities.

C. MAXIMUM AND MINIMUM RANGES

The maximum range of a pulse radar system usually is limited physically by the pulse repetition frequency (PRF) of the radar such that the time required for a pulse to make a round trip from the transmitter to the target and return should not exceed the time between transmitted pulses. This time or equivalent range is considered the unambiguous range. Modern pulse radar systems can extend the unambiguous by using jitter on the PRF of the transmitted pulse.

1. The maximum range performance is also obtained by determining the maximum range that a certain target size will return a signal with sufficient signal-to-noise ratio to accurately range-track. Range tracking with a pulse radar system normally required approximately a 10 db signal-to-noise ratio. Range tracking performance is determined by the standard radar range equation:

$$P_r = \frac{P_t G_t \sigma}{(4\pi R^2)^2}$$

Where:

P_r = Power Received

P_t = Power Transmitted

G_t = Gain of Transmitting Antenna

R = Range to TGT

σ = TGT Cross Section

2. The minimum range is determined physically by the transmitted pulse-width or width of the pulse train. This is considered the radar dead zone. At this time, the receiver is saturated by the transmitted pulse.

D. RANGE TRACKING NOISE

1. The following functions affect pulse range tracking noise:

a) Transmitted pulse variations in amplitude and frequency
b) Target return dynamic range
(receiver-characteristics)
(signal-to-noise ratio)
c) Range tracking servo system noise

2. When measuring range tracking noise, it should be understood that range tracking is affected by the quality of the entire radar system, such as the angle tracking, the receiver characteristics, the automatic frequency control (AFC) and the target characteristics, such as size, length radial velocity, and radial acceleration. The predominant factors are signal return characteristics and target motion.

3. Tests of range tracking noise as a function of return signal characteristics are made by simulating variations in pulse shape and signal-to-noise ratio. Variations in pulse shape should be commensurate with expected actual return pulse characteristics and should include:

a) An increase in pulse lengths would be expected from a target of considerable depth
b) A decrease in rise time as would be expected by drifts in AFC or propagation degradation
c) Large signals (saturating signal levels) as would be expected from targets whose cross-section varied through a large dynamic range
d) Low signals which would be expected when operating on small targets at maximum range. The range output should be recorded during the simulated tests and during the static and dynamic field tests. The standard deviation of the range noise errors should be determined for each condition

E. BANDWIDTH

The amount of selectivity which is incorporated in radar receivers is determined by the type of pulse and by the local oscillator-transmitter stability. The IF bandwidth, generally, must be wide enough to give a reasonably accurate pulse shape reproduction. If the IF bandwidth is too narrow, the pulse will appear rounded on the corners instead of square and all the possible energy of the pulse will not be satisfactorily passed through the chain of IF amplifiers. Accurate pulse reproduction is particularly important in tracking radars. If the IF bandwidth is too wide, excess noise is amplified into the output of the receiver and the signal-to-noise ratio will be correspondingly degraded. In general, the IF bandwidth must be at least 1.
As an example, if the pulse length is 10 microseconds, the IF amplifier pass

band must be at least 100 kilocycles (KC). In many instances, the receiver band-width is made appreciably wider because either special functions must be performed by the receiver of stability considerations dictate the wider IF band-width. The minimum band-width suitable for faithful pulse reproduction will be possible only in the case of extremely stable oscillators, which are either cavity or crystal stabilized. A discussion of optimum receiver band-width for various types of pulse shapes is contained in Reference 11 of this MTP.

F. RANGE RESOLUTION CAPABILITY

1. Range resolution is the minimum separation distance in range between two targets that can be discerned by the radar system. Range resolution capability is an important factor in modern radars that are expected to discern closely spaced targets. Range resolution is a function of the following:

a) The band-width of the receiver system
b) Signal level
c) Signal-to-noise ratio
d) Target length
e) Target size

2. For two return pulses to be resolved in range, the time separation should be equal to the pulse width at the half-power points as illustrated in Figure B-1. Thus, for a one-microsecond pulse width, the range resolution would be 492 feet.

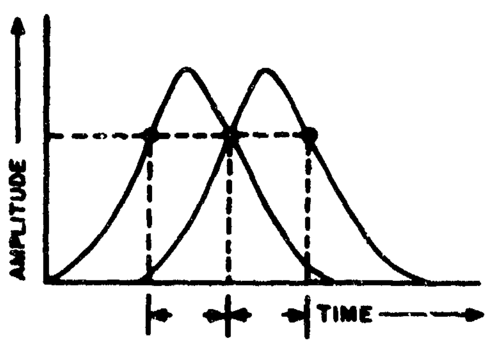

Figure B-1. Pulse Amplitude Versus Time Separation at the Half-Power Points (Ideal Conditions)

3. With modern coherent pulse radar techniques such as "chirp", the transmitted pulse may be as long as 400 microseconds; however, with a collapse ratio of 100 to 1, the pulse would be 4 microseconds long and the range resolution would be approximately 2000 feet rather than 200000 feet as would be indicated by the 400 microsecond pulse.

4. The range resolution of a radar system is determined empirically under a static condition by placing two fixed targets a known distance apart and gradually increasing the distance between them. Note that the pulse return from the two targets should be of equal amplitude for an accurate measure of resolution. If the two pulses are of different amplitudes, the range resolution will be degraded as illustrated in Figure B-2.

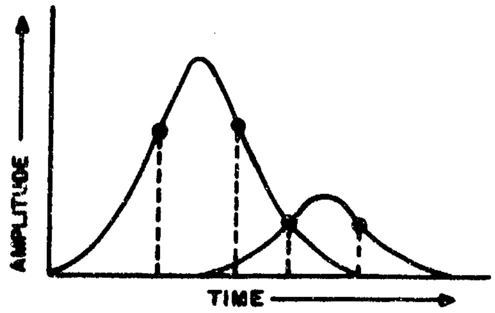

Figure B-2. Degradation of Range Resolution Due to Two Different Pulse Amplitudes.

When the signal levels from two targets are both high, the range resolution is degraded as illustrated in Figure B-3

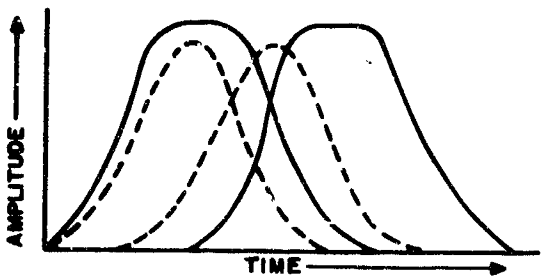

Figure B-3. Degradation of Range Resolution Due to High Signal Levels from Two Targets.

The range resolution is degraded due to normal compression characteristics of a receiver as the signal level approaches saturation. The effect that low signal-to-noise ratios have on range resolution may be a combination of all three conditions illustrated in Figures B-1 through B-3.

5. Target length is particularly important when the target length approaches the pulse-width. This condition is more apparent with narrow pulse-width radars. As an example, if two targets were 123 feet long and the pulse-width of the radar were 0.25 seconds, the normal range resolution would be degraded from 123 feet to 246 feet.