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HEADQUARTERS STRATEGIC AIR COMMAND
UNITED STATES AIR FORCE
OFFUTT AIR FORCE BASE, NEBRASKA

REPLY TO ATTN OF: DI

08 DEC 1961

SUBJECT: (C) Transmittal of Document Defining Technical Procedures for Obtaining Radar Locations

TO: Director
National Security Agency
Ft George G. Meade, Md

1. Attached for your information and retention is a document which outlines the procedures utilized for determination of radar locations. These techniques have been employed in locating V-Beam radars, [redacted] and single beam radars. These location techniques have been developed by this command and are considered to be sufficiently accurate for assisting in defining the operational intelligence required for SAC and SIOP planning. (S)

2. This command intends to continue using these techniques on all future data, and will endeavor to improve whenever possible the procedures as outlined in this document. (U)

FOR THE COMMANDER IN CHIEF

ROBERT N. SMITH
Brigadier General, USAF
Director of Intelligence

1 Atch
GRAB Location Techniques
(1 cy, TS, Limited Dist)

cc: ONI
USAF

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1 November 1961

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GRAB LOCATION TECHNIQUES

Prepared by the Special Projects Branch of the Defense Analysis Center, 544th Reconnaissance Technical Group (SAC), Offutt Air Force Base, Nebraska.

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This document is to be distributed to and read by only those persons who are officially indoctrinated with the GRAB program and who need the information in order to perform their duties.

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23 pages

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GRAB PROCESSING

1. SAC's primary objective when processing GRAB ELINT data is to select, from the total data available, that intelligence which is of immediate value to the current SIOP. Obviously, the most valuable intelligence to be gleaned from such data consists of the type and location of radars considered pertinent to the Sino-Soviet defense structure. ELINT signals, the significance of which cannot be determined due to certain missing parameters or the inability to locate the source, contribute less to the development of the SIOP. Based upon this premise, only those ELINT signals considered truly significant, and which can be located with an acceptable degree of confidence, receive maximum attention and processing. This is not to say that all other signal intercepts are ignored. During the film readout any intercept which appears unusual, regardless of whether or not it can be located, will be noted and subsequently analyzed. All signals contained on the magnetic tape are recorded in video form by time and signal parameters. This video record is always available for immediate and total readout in case a subsequent reference to any signal or signals becomes necessary.

2. The uniqueness of the GRAB collection devices required that certain existing procedures and techniques be modified along with the development of several entirely new processing techniques. Data reduction techniques currently being used are the same as indicated

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in our letter to CNO, Subject: GRAB I Processing, dated 25 August 1961, copies furnished USAF and NSA. The following discussion deals with the modified location techniques developed thus far.

3. Atmospheric Refraction: The altitude of the GRAB collection vehicle presents a heretofore undefined problem of how much a radar beam bends in passing through the earth's atmosphere, and at what point does refraction cease to be a significant consideration.

a. It was assumed that the effects of refraction became negligible at altitudes in excess of 10 NM. A standard refraction of 4/3 earth's radius was assumed within this 10 NM altitude and thereafter considered non-existent (free space). Reference Attachment 3.

b. Results obtained using the above assumption, applied to the V-Beam and [redacted] formulas and isolating the GRAB I annulus over certain areas, validate the technique as being reasonable approximations of the refraction effects.

4. V-Beam and [redacted] Radar Locations: The mathematical solution to the V-Beam and [redacted] range problem is contained in Attachments 1, 2 and 3.

a. In order to achieve the required beam separation and sweep time measurement accuracy, a film viewer/computer (TELEREADEX) is used. This device projects an enlarged portion of the 35mm strip film onto a screen containing movable cursor lines for accurate measurements along the X and Y axis. The computer, a component part, displays the measurements visually or a printout is available if desired. All measurements were made with an accuracy of one (1) second to three (3) decimal places.

b. Position Determination:

(1) Satellite ephemeris data, containing time, sub-orbital point and altitude are entered into the computer (Burroughs 220) via punched cards. From this information a table is formed retaining time, latitude, longitude, and altitude of each sub-orbital point, the increments of each of these values to the next point, and the ground speed and heading of the vehicle. This table, when subsequently accessed by time, allows the interpolated value of each of these parameters to be extracted for any given time.

(2) Intercept data are entered into the computer by punched card giving time, assigned signal number, scan period, beam separation, and an indication to identify V-Beam and [redacted] emitters.

c. Radar Range Computation: For each measurable intercept, a range from the collector to the emitter is calculated. Satellite position at the time of intercept is calculated from the navigation table.

(1) The apparent angle formed by the radar beam and a line tangent to the earth at the emitter is calculated for V-Beam and [redacted] radars using the formulas of Attachments 1, 2 and 3. The basic assumptions used in the development of these formulas are included in the attachments. Two ranges are computed for [redacted] since the vehicle could be in the upper or lower half of the vertical scan cycle.

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(2) Subsequent range computation is accomplished in the same manner for both types of emitters and is outlined in Attachment 3.

d. Location Estimation: In order to provide the analyst an aid in determining the emitter location, the computer makes estimates of the position.

(1) The range computations for each V-Beam and [redacted] signal are divided into three equal (plus or minus one) groups. For each group a bearing is estimated by comparing range and heading change to the computed time and ground speed. This bearing is matched with the average range for the group and an estimated latitude and longitude of the specific emitter is computed.

(2) In the case of V-Beam radars, six locations are computed; one on each side of track for each of the three groups. For [redacted] twelve locations are computed, six groups to consider the short range (upper half of cycle) and six groups to consider the long range (lower half of cycle). These locations are optional outputs of the program.

(3) The locations of the groups, determined above, are then averaged. An average distance from the averaged location, to the two most distant groups is computed. This distance is an indication of the pattern of the range arc cluster.

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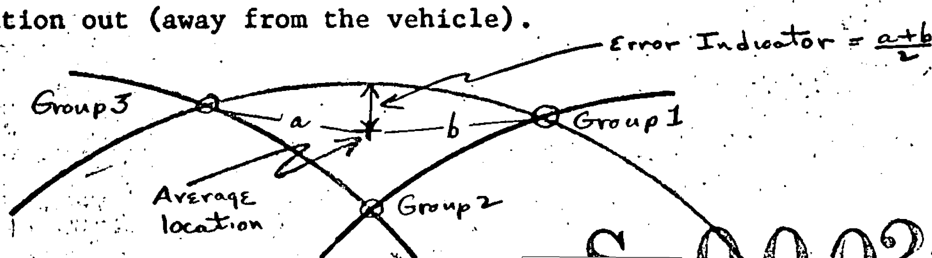
(4) A correction factor (in NM) is then computed to move the averaged location out (away from the vehicle).



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When the error indicator is sufficiently small, the correction factor may be applied and the computer fix used as an estimate of the true location. In actual use, the intermediate locations are used to estimate the possible variation in location and to minimize any errors caused by plotting on a non-spherical surface.

5. Single Beam Emitters: During the processing of GRAB I data several attempts were made, with little or no success, to develop a workable technique which would reliably indicate the location of single beam emitters, using the apparent scan rate variance of a particular intercept (pseudo-doppler).

a. The antenna rotation period of an individual Soviet radar was found to vary by as much as 5%, presumedly due to emitter variables such as wind loading effects, tape recording speed variations, etc. The apparent scan rate variance caused by the speed of the collection vehicle relative to the location of the radar is believed to be something less than 1% under the best intercept conditions (when the relative position of the satellite to the emitter is rapidly changing).

b. In all cases tested, the apparent scan rate variance was found to be too erratic to permit reliable location estimates. No consistent pattern could be determined for intercepts with a total duration of less than 90 seconds.

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c. Signals intercepted for longer durations evidenced a scan rate variance trend (a general increase or decrease) which was sufficient to resolve the left-right ambiquity but would not develop a specific location other than general area (i.e., Kamchatka area, European USSR, etc.).

d. A definite shift in the observed scan rate change did occur when the left or right edge of the annulus traversed over a particular radar for a duration in excess of 4 minutes, however, this occurrence was very rare. Based on an even distribution of radars throughout the Soviet Union, the probability of this event occurring is believed to be less than 2%. Therefore, it was considered unacceptable as a standard location method for single beam emitters.

e. In view of the above, the apparent scan rate variance is used only to resolve left-right ambiguity in those cases when geographical area will not eliminate the possibility of the source being within the left or right portion of the annulus.

6. <u>Location Technique, Single Beam Emitters, GRAB II</u>. Upon receipt of the GRAB II data, numerous checks were made to determine if the addition of new recorders, used during intercept of these data, would reveal the theoretical or true scan rate variance to a point which would permit emitter location. Unfortunately, the rotation periods for the emitters checked were again too erratic to permit anything other than general area location. At this point, it seemed reasonable to assume that the apparent scan rate change is not a reliable factor with which to develop a single beam location technique.

a. Analysis of the relatively low level of intercept activity of GRAB II compared to GRAB I prompted a scheme of signal matching of intercepts between the leading edge and trailing edges of the annulus

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b. Signals intercepted on the leading edge of the annulus can be readily matched to the same signals if intercepted on the trailing edge, by comparison of parametric values, time duration and satellite location. This statement is qualified within the intercept capability and comparatively low level of signal activity detected by the GRAB II vehicle and is based on the assumption that ground collection sites receive and record 80-90% of the data collected by the vehicle during each orbit. Analysis of all active missions through number 600 indicates the above conditions prevail for approximately 40% of the total data. This percentage could be greatly increased by the elimination of the six to eight minute gap in intercept site coverage that currently exists for orbits having a west to east heading over the USSR.

(1) Atmospheric refraction for signals intercepted by the GRAB II vehicle is assumed to be the same as that which was determined to exist in the "S" Band of GRAB I. Reference paragraph 3. Based on this assumption, the line of sight (LOS) distance from the vehicle to the earth is a function of the vehicle altitude. This LOS distance is the outer edge of the annulus for radars intercepted with a consistent elevation angle and can be accurately computed for any specific intercept time, when the exact position and altitude of the collection vehicle is known.

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(2) The Initial Time (It) is defined as the exact time the first illumination is intercepted on the leading edge of the annulus. The distance to the source of an emission is equal to the LOS distance drawn from this time. This assumption is valid if the edge of the annulus moves over the radar site at the exact instant the antenna

of the radar faces the collection vehicle. The possible error caused by not knowing the exact position of the emitter's antenna relative to the collection vehicle is as follows:

Possible error = (Ground Speed/Sec) (Scan time in Sec)
i.e., Possible error = [redacted] Sec) (9.0); 9.0 Sec [redacted]
error = [redacted]

(3) Terminal Time (Tt) is defined as the exact time the last illumination is intercepted within the trailing edge of the annulus. The LOS distance to the emitter is drawn from this Tt. The possible error induced is again a distance equal to one scan time, times the ground speed of the vehicle.

(4) The Mid Time (Mt) is defined as the point at which the emitter is located exactly perpendicular to the heading of the collection vehicle and is determined by:

$$\frac{Tt - It}{2} + It = \text{Mid Time (Mt)}$$

(5) The maximum error (error indicator$_1$) of the combined possible errors in the It and Tt is equal to: $\pm \left(\frac{\text{Scan Time}}{2}\right)$ (Gd Speed)

i.e., (Error Ind$_1$) = $\pm$ (9.0/2) (3.5 NM/Sec)=15.75 NM;
(9.0 FLAT FACE)

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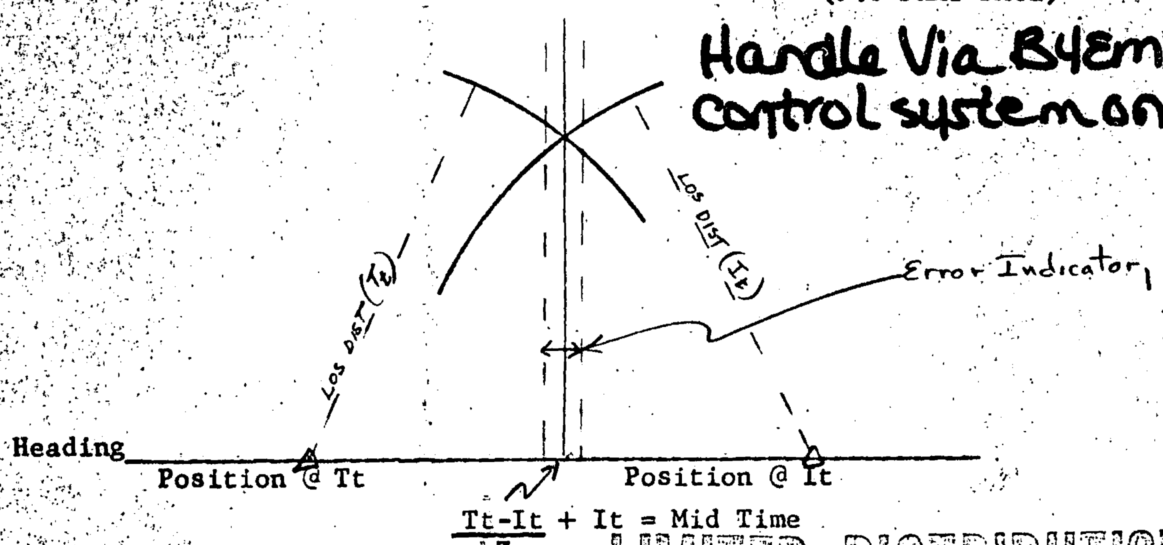
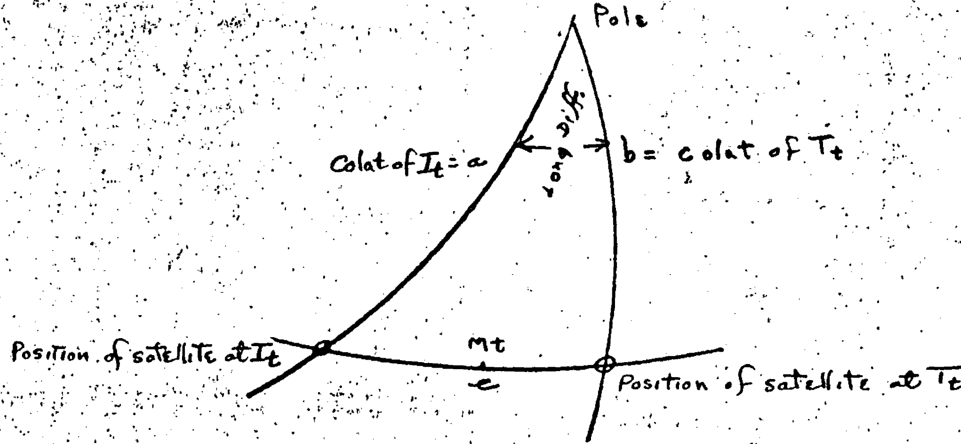
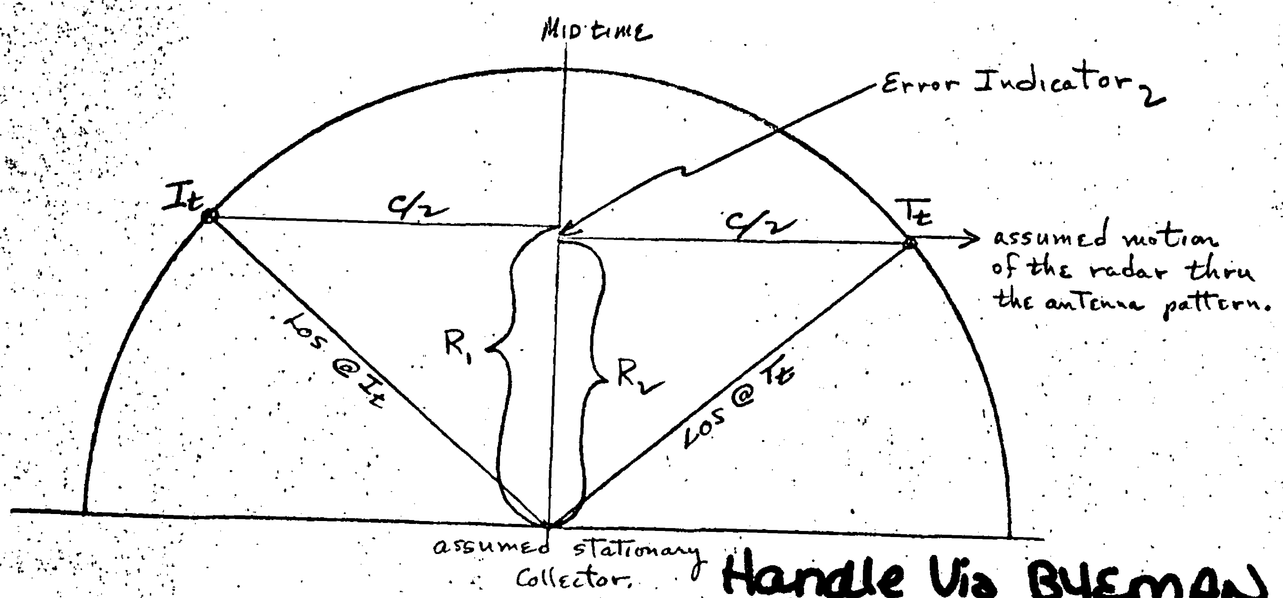


(6) To determine the great circle distance in NM the vehicle travels between two given times. Defined as c.



C = Cos-1 [Cos a Cos b + Sin a Sin b Cos (Long diff)]

(7) Considering a stationary collection vehicle, with the radar moving through the collector's pattern, C/2 = distance from the It or Tt to the Mid Time.



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(8) The range to the emitter from the vehicle at the Mid Time is a function of the elapsed time and the speed of the satellite.

$$\text{Cos } R_1 = \frac{\text{Cos }(LOS_1)}{\text{Cos } C/2} \quad \text{and COS } R_2 = \frac{\text{Cos }(LOS_2)}{\text{Cos } C/2}$$

(9) Since the LOS may vary between initial and terminal time due to altitude differences, two range figures are computed and a second error indicator estimated by, $\frac{R1 - R2}{2} = \text{Error Ind}_2$

c. Computer Solution, Single Beam Emitters, GRAB II.

(1) A vehicle position table is constructed containing, in ascending time order, the vehicle latitude, longitude and altitude. Later this table is used with an interpolation routine to determine the vehicle position at any given time within the range of the table.

(2) For every signal, entry to the program is by time of first reception (It) and time of last reception (Tt). This time is an approximation of the time the satellite crosses the radar horizon range. The approximation for initial time is subject to two errors:

(a) It will tend to be too great due to the time lag between crossing the horizon and the next illumination of the collection vehicle by the main beam.

(b) It will also tend to be too great if the satellite is not capable of receiving a signal from an emitter exactly on the radar horizon, (the satellite may have to rise slightly above the horizon).

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(c) These errors are compensated for by a programmed variable defined to be the elevation angle from the emitter to the collector at time of initial intercept.

(3) The program now calculates the vehicle position at the initial time (It), terminal time (Tt) and mean or Mid Time (Mt). The assumption is made that the vehicle is abeam the emitter at the Mid Time. Reference Attachment 4, computer program.

(4) The following computations are made:

(a) CC equals the great circle distance from the satellite position at the initial time to a position at the terminal time.

(b) XDIST equals the horizon range (LOS Distance) at the initial time.

(c) From these values, RNG is computed.

(d) ALFA equals the heading of the vehicle at the Mid time.

(e) TB equals the bearing and reciprocal bearing to the emitter at the Mid time.

(f) ANSCOLAT equals the co-latitude of the emitter.

(g) LNG equals the longitude of the emitter (ANSCOLAT and LNG are double valued).

(5) The computations are then repeated using the vehicle altitude at terminal time to determine a new horizon range.

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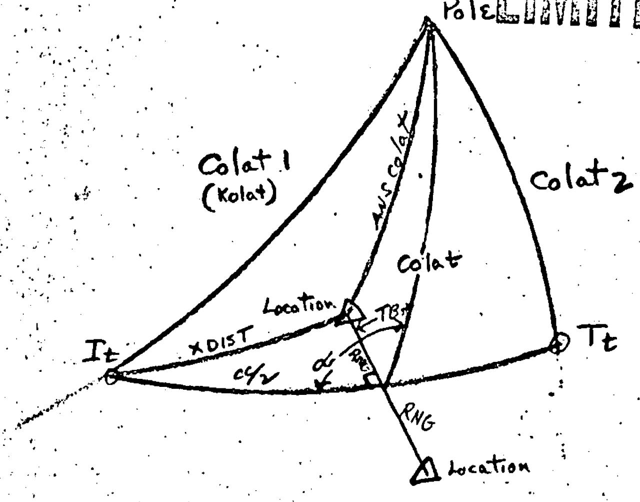

(6) The output information includes:

(a) Signal number.

(b) Two pairs of emitter location approximations.

(c) Mean time.

(d) True bearing to emitter.

(e) Initial time (It).

(f) Terminal time (Tt).

(g) Range to emitter using altitude of initial point.

(h) Range to emitter using altitude of terminal point.

7. The results of computer processing are examined by an analyst and those signals which evidence a low confidence factor (large error indicator) are eliminated from further processing. Only those signals which can be reliably located continue to be processed. Each output of the computer is manually plotted as a re-check on the analysis and measurements made up to this time. The impact points are determined and the left-right ambiguity eliminated.

8. A most probable position (MPP) is determined by the analyst by plotting each impact point on small scale map (i.e., Series 200 chart) and selecting a most probable position within the confidence circle established for each type radar located. A final location is selected by comparison of each DF impact point to all source ROB information.

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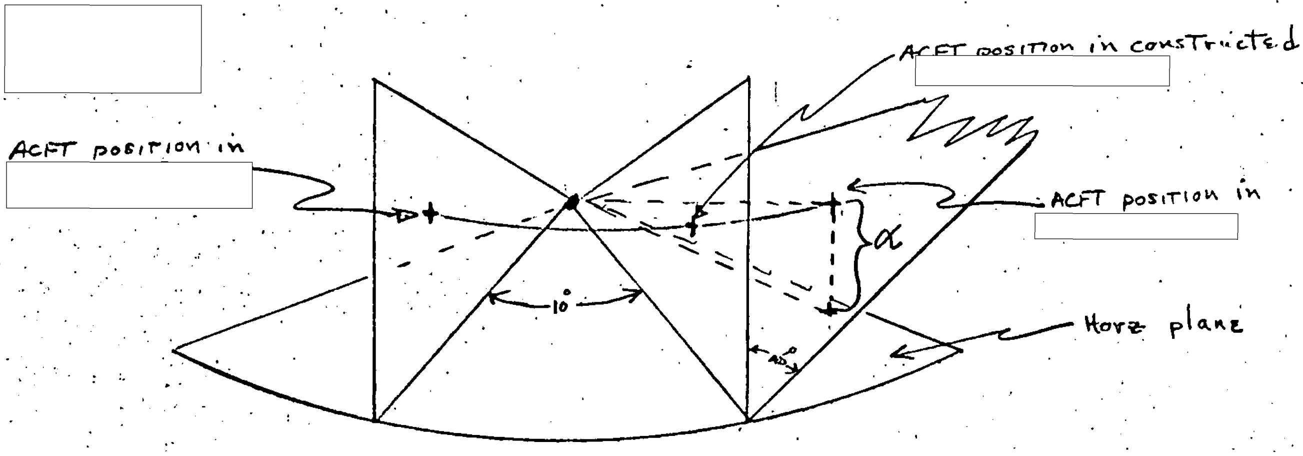
[redacted] V BEAM AND HF RANGE EQUATION DERIVATIONS

Determine elevation angle of aircraft (angle α) with respect to emitter location.

[redacted]



Assumption: [redacted]
Separation angle at horizon is 10°.

Let t = Beam separation time measured
T = Total scan time measured

α = 360 t/T - 10 degrees or

* ALPHA = 0.174533 (36.0 · t/T) - 0.174533 radians

*(Underlines refer to computer program steps as would be written in Algol)

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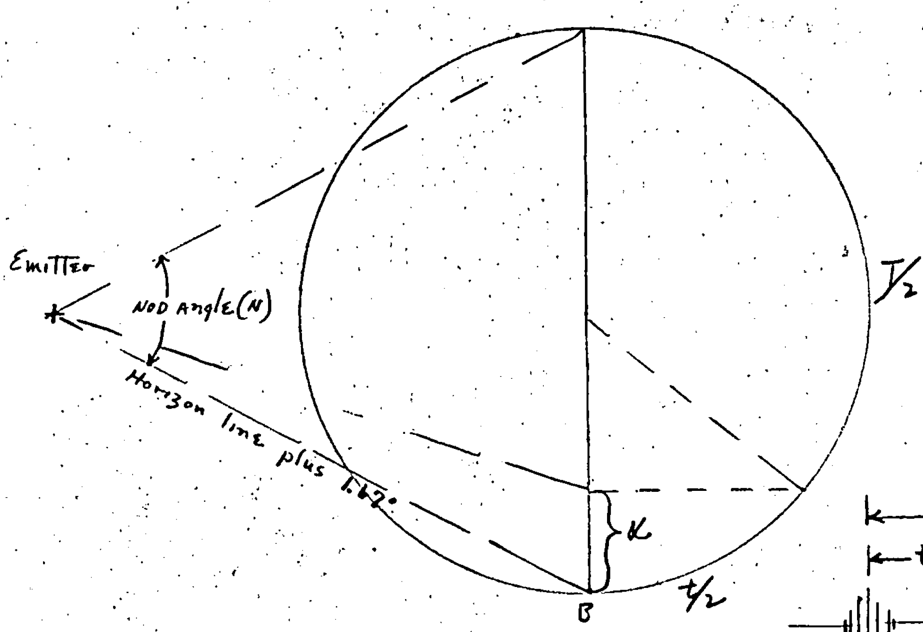
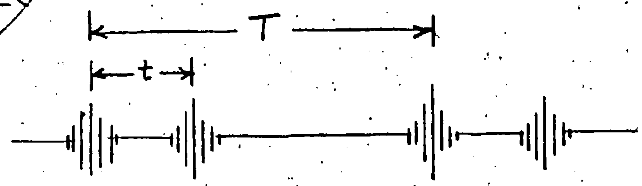
Determine α for HF



Assumption: Motion along circumference is constant, vertical component of motion defines the nod. Further assume, horizon line plus 1.67 degrees is base of circle (B).



t = illumination separation, T = complete cycle period.

α = N/2 (1 $\pm$ COS (180 t/T) degrees

Program assumes N - 21½°.

Alpha = 0.187623 (1.0 $\pm$ COS (3.1416 t/T) radians

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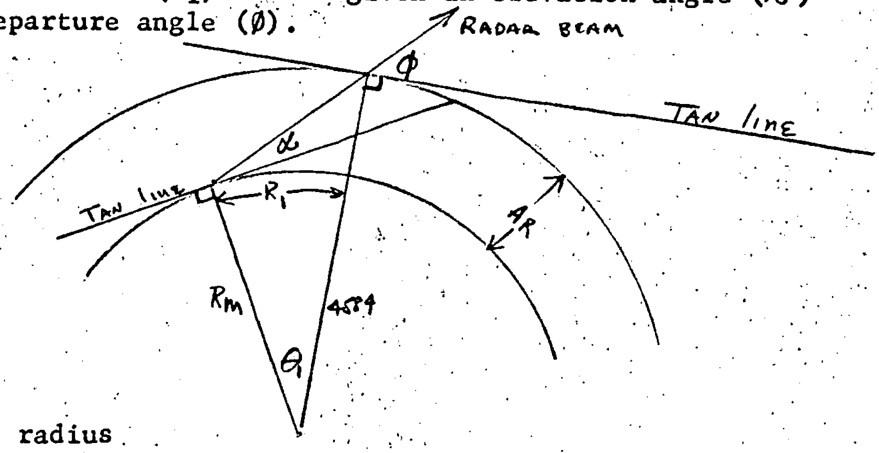
Assuming a standard refraction (4/3 earths radius) to some fixed altitude (AR), determine (R_1). When given an elevation angle (α) and cosine of departure angle (ϕ).



$R_m \doteq$ 4/3 earths radius

$$\frac{\sin(\alpha + 90)}{R_m + A_R} = \frac{\sin(90 - \phi)}{R_m} \quad \therefore \quad \frac{\cos\alpha}{R_m + A_R} = \frac{\cos\phi}{R_m}$$

$$\cos\phi = R_m \cos\alpha \,/ (R_m + A_R)$$

IF $R_m = 4584$, $A_R = 10$, then:

SinA = Sin (Alpha)
CosA = Cos (Alpha)

CPHI = 0.9978 CosA

$$\alpha + \theta_1 + \lambda = 90 \qquad \lambda + \phi = 90 \quad \therefore \quad \theta_1 = \phi - \alpha$$

$$\sin\theta_1 = \sin(\phi - \alpha)$$

$$\sin\theta_1 = \sqrt{1 - \cos^2\phi}\,(\cos\alpha) - \cos\phi\,(\sin\alpha)$$

$$R_1 = 4584 \sin\theta_1$$

Rone = 4584.0 ((SQRT (1.0 - CPHI . CPHI) CosA) - CPHI . SinA)

Note: For altitudes less than 10, set A_R = actual altitude and solve for R_1 . at low altitudes $\cos\phi \rightarrow \cos\alpha$.

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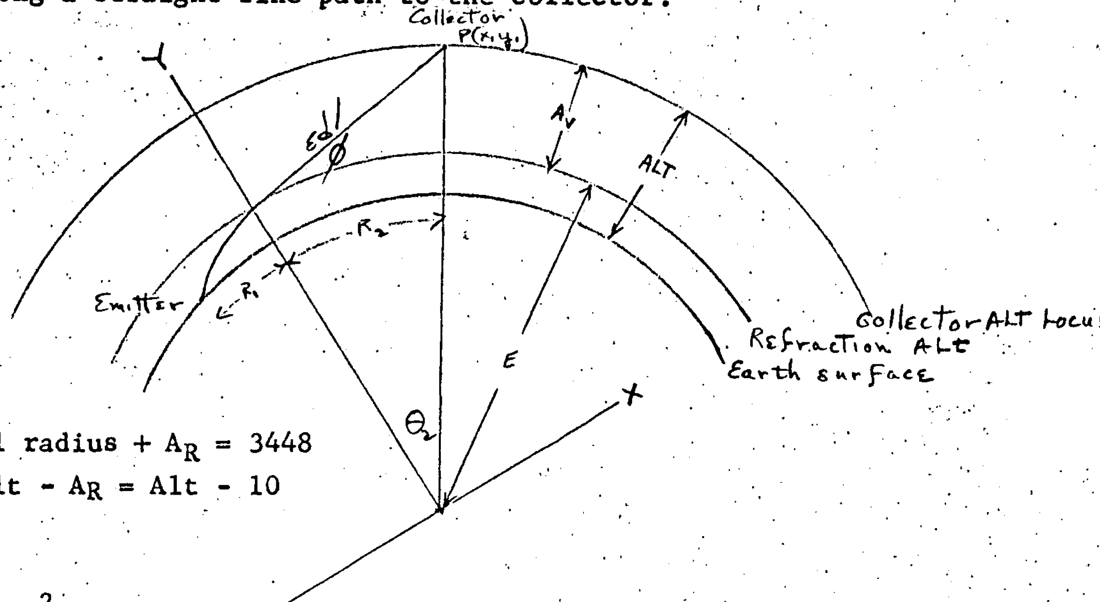
Determine range (R_2) from point of departure from refraction limit at angle Ø along a straight line path to the collector.



$E = \text{Actual radius} + A_R = 3448$

$A_V = \text{Col.Alt} - A_R = \text{Alt} - 10$

$X^2 + Y^2 = (E + A_V)^2$ Collector locus (c.l.)

$(Y - E)/X = \tan \phi \quad Y - E = X \tan \phi$ extended departure line (e.d.l.)

Solve simultaneously to determine P (X_1, Y_1)

$$Y^2 = X^2 \tan^2 \phi + 2EX \tan \phi + E^2$$

$$Y^2 = E^2 - 2EA_V + A_V^2 - X^2$$

$$X^2 (\tan^2 \phi + 1) + (2E \tan \phi) X - 2EA_V - A_V^2 = 0$$

$$X_1 = \frac{-E \sin \phi / \cos \phi + \sqrt{E^2 \sin^2 \phi / \cos^2 \phi + 1/\cos^2 \phi \; (A_V^2 + 2EA_V)}}{1/\cos^2 \phi}$$

$$X_1 = \left(-E \sin \phi + \sqrt{E^2 \sin^2 \phi + A_V^2 + 2EA_V}\right) \cos \phi \quad \text{or}$$

$$X_1 = \cos \phi \left(\sqrt{(E + A_V)^2 - E^2 \cos^2 \phi} - \sqrt{E^2 - E^2 \cos^2 \phi} \right)$$

X One = CPHI (Sort ((Alt + 34380) (Alt + 34380) - 11888704.0) CPHI . CPHI) - 3438.0 Sort (1.0 - CPHI . CPHI))

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$$Y_1 = \sqrt{(E + A_V)_1^2 - X_1^2}$$

Y one = SQRT ((Alt + 34380) (Alt + 34380) - X one . X one)

$\theta_2 = \tan^{-1}(x_1/y_1)$

Theta = Arctan (X one/Y one)

$R_2 = 3428\ \theta_2$

RTWO = 3438.0 Theta

TOTAL RANGE = $R_1 + R_2$

ANS = R one + R two

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