QUIETZONE INTERFERENCE ANALYSIS

PROGRAM

Internal Report #13 #14

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QUIETZON is a program to compute the power density expected at Green Bank from any proposed transmitter site in the Radio Quiet Zone. The program uses the coordinates of the proposed transmitter site to calculate the coordinates along the Great Circle path from the site to Green Bank. The actual elevation at each position is then extracted from the topographic data matrix.* Radio line-of-site is determined to find the elevations, with the associated distances that represent obstacles between the proposed site and Green Bank. This information is used to determine the attenuation, the total power loss, and the power density expected at Green Bank. As output, the program details the extracted profile, including the following information: Height at the source, height at the obstacle, height at Green Bank, distance from the source to the obstacle, and distance from the obstacle to Green Bank. It also gives the values calculated for the total diffraction attenuation, the forward scatter attenuation, the free space loss, the total path loss, and the power density expected at Green Bank. A 10" by 10" Calcomp plot of the path profile is also produced.

For each proposed site the following two data cards are needed:

Card 1: 'site title' maximum of 48 characters

Card 2: Antenna height (ft.) (assumes 75' if =0)

Site latitude (deg. min. sec.)

Site longitude (deg. min. sec.)

Transmitter site elevation (ft.) (calculates it from topographic data if =0)

Frequency (MHz)

Power (watts)

* See Appendix

Example:

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'Monticello Dairy'
75.    38 02 06    78 37 57    550.    152.    100.
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The following coordinate transformation equations are used in the path profile computations:

$$x = \cos \phi * \cos T$$

$$y = \sin \phi * \cos T$$

$$z = \sin T \tag{1}$$

$$T = \tan^{-1} (z/\sqrt{x^2 + y^2})$$

$$\phi = \tan^{-1} (y/x) \tag{2}$$

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where T is the latitude (positive North) and ϕ is the longitude (positive West).

In computing the great circle path coordinates, a unit sphere is assumed. The vector $\overline{S}$, from the center of the sphere to the proposed site, is determined; the vector $\overline{G}$ from the center of the sphere to Green Bank is also determined. The path vector $\overline{P}$ is then given by the following equation:

$$\overline{P} = \overline{G} - \overline{S} = (G1 - S1) + (G2 - S2) + G3 - S3) \tag{3}$$

where G1, 2, 3, and S1, 2, 3 are calculated from equations (1).

The unit vector $\overline{U}$ is given by the following equation:

$$U = \overline{P}/|\overline{P}| \text{ and } |\overline{P}| = \sqrt{p1^2 + p2^2 + p3^2}. \tag{4}$$

Theta, Θ, is the angle between the vectors $\overline{S}$ and $\overline{G}$; it is calculated from the equation:

$$\Theta = \cos^{-1} [\sin T_s \sin T_g + \cos T_s \cos T_g \cos (\emptyset_g - \emptyset_s)] \tag{5}$$

Gamma is the spacing angle which determines how frequently points are taken along the path.

$$\gamma = (\Theta/N)*n \qquad n = 0,1,2,\ldots\ldots N \tag{6}$$

N is the number of points taken; $N = \Theta/(ds * c) + 1$;
ds is the spacing of the data in seconds (30"), c is the seconds to radians conversion factor; N is truncated to the nearest integer value.

Using the following geometric relationships (See Figure 2)

$$H = \cos (\Theta/2)$$

$$B = \sin (\Theta/2)$$

$$R_n = H * \tan (\Theta/2 - \gamma)$$

$$\Delta n = B - R_n \tag{7}$$

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and $$\overline{C}_n = \overline{S} + \overline{U} * \Delta n = c1_n + c2_n \; c3_n \tag{8}$$

and applying equations (2) to equation (8) gives one the coordinate values for each T_n and $\emptyset_n$.

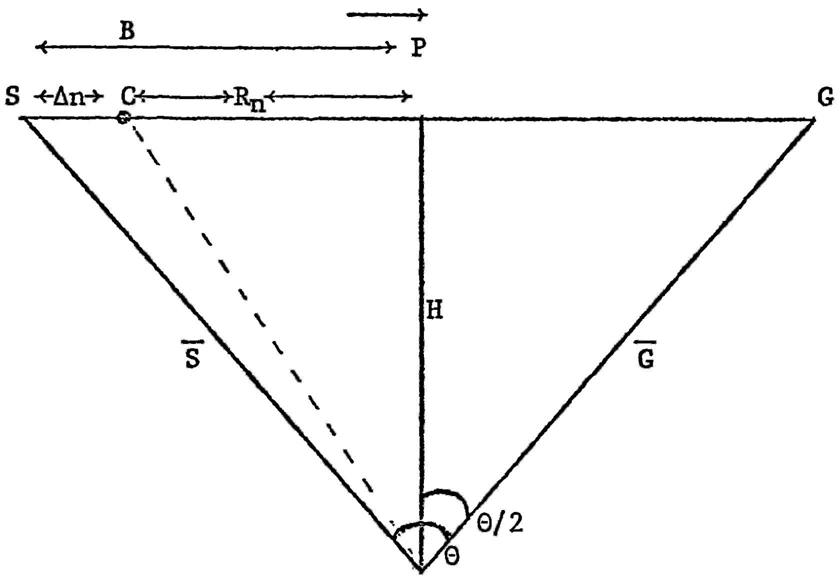


Figure 2

The elevation extraction is done by first determining the southwest coordinates of the data block, to the nearest degree, then determining the position of the coordinates in the data block. Since the coordinates may not fall on an exact position, a 4-point interpolation is performed to obtain the elevation of the desired point. The row M and column N are determined as the nearest matrix row south of the desired point, and the nearest matrix column west of the desired point. The following equations are then used for the interpolation:

$$Ea = \delta 2 * elev(m,n) + \delta 1 * elev\ (m + 1,n)$$

$$Eb = \delta 2 * elev(m,n + 1) + \delta 1 * elev\ (m + 1,\ n + 1) \qquad \text{N-S int.} \quad (9)$$

$$Ec = \Delta 2 * Ea + \Delta 1 * Eb \qquad \text{E-W int.} \quad (10)$$

See Figure 3.

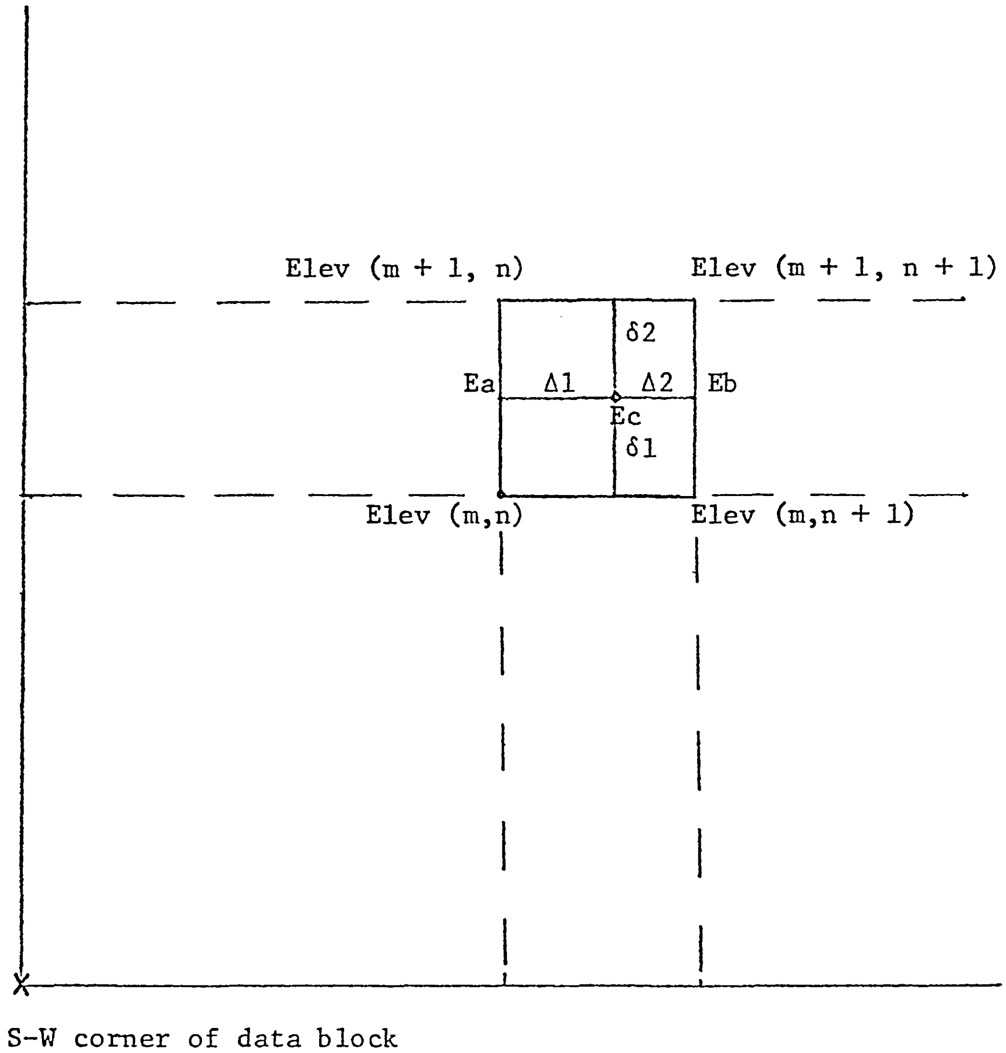

Elev (m + 1, n)
Elev (m + 1, n + 1)
δ2
Ea
Δ1
Δ2
Eb
Ec
δ1
Elev (m,n)
Elev (m,n + 1)
S-W corner of data block

Figure 3.

After the path coordinates are calculated and the elevations extracted, each point along the path is tested to determine whether or not it is an obstacle in the radio line-of-sight. Distances are too great to assume a flat earth, therefore, each elevation is reduced by an appropriate amount to account for the earth's curvature. It can be shown that this amount, Δh_n is given by:

$$\Delta h_n = R + \sqrt{R^2 + X_n^{\ 2}} \tag{11}$$

and that for distances up to 425 miles the distance, d_n, is a good approximation for X_n. A binomial series expansion of the above radical yields the following approximation for Δh_n:

$$\Delta h_n = d_n^{\ 2}/(2 * R). \tag{12}$$

R is the effective earth's radius which is equal to k*a for radio waves; a is the actual earth's radius of 6370 km; k is a function of the surface refractivity and is given by:

$$k = [1. - .04665 \exp(.005577 N_s)]^{-1} \tag{13}$$

N_s has a value of 310; this gives a value of 8639 for the effective earth's radius, which is approximately 4/3 the earth's radius.

The radio horizon corresponds to the height, ht_{max}, at the angle ρ_{max}, at the distance, d_{max}. ρ_n is the horizon ray elevation angle and is calculated as follows:

$$ht_n = elev_n - \Delta h_n$$

$$\rho_n = \tan^{-1} [(ht_n - elev_0)/d_n]$$

where $elev_0$ is the elevation at the source, including the antenna height. The geographic point which corresponds to d_{max}, ht_{max}, and ρ_{max} is then assumed to be the next source and the process is repeated to find the second obstacle. This process is repeated until no further obstacles are found in the line-of-sight to Green Bank.

The values of ρ_{max}, d_{max}, and ht_{max} are passed to two subroutines which compute the attenuation and power loss and the power density expected at Green Bank. The following equations are used for these computations.

$$v = 2.583\rho \sqrt{fD_{1t}D_{1r}/dist} \qquad (15)$$

$$A(v,0) = 6.02 + 9.11v - 1.27v^2 \qquad \text{for } v \geq 2.4 \qquad (16)$$

otherwise

$$A(v,0) = 12.953 \log 10(v).$$

$$R = .676RK^{1/3} f^{-1/6} \sqrt{dist/(d_1 * d_2)} \qquad (17)$$

$$A(0,R) = 5.86 + 6.49R\ (1. + .229R^2) + 1.46R^2 \qquad (18)$$

$$vR = 1.74\rho(f*RK)^{1/3} \qquad (19)$$

$$U(v,R) = 11.45vR + 2.19vR^2 - .206vR^3 - 6.02 \qquad vR \leq 3$$

$$U(v,R) = 13.47vR + 1.058vR^2 - .048vR^3 - 6.02 \qquad 3<vR<5 \qquad (20)$$

$$U(v,R) = 20.vR - 18.2 \qquad vR \geq 5$$

The total attenuation is then given as the sum

$$TATTEN = A(v,0) + A(0,R) + U(v,R). \qquad (21)$$

The forward scatter attenuation is computed as follows:

$$HO = (1./hte + 1./hre)/(\rho*f*Abs(.007 - .058\ \rho)) \qquad (22)$$

$$RD = \rho*dist$$

$$S = HO + 10 \log 10\ (f\rho^4) - .9 \exp\ (-RD/40) \qquad (23)$$

$$AS = S + 103.4 + .332RD - 10 \log 10 (RD) \qquad RD < 10 \qquad (23)$$

$$AS = S + 97.1 \pm .212RD - 2.5 \log 10 (RD) \qquad 10 < RD < 70 \qquad (24)$$

$$AS = S + 86.8 + .157RD + 5 \log 10 (RD) \qquad RD > 70$$

If the total attenuation is less than the forward scatter attenuation then the forward scatter equals the total attenuation.

The free space loss is calculated from

$$FSL = 32.46 + 20 \log 10 (f*dist) \qquad (25)$$

and the total path loss equals the free space loss plus the forward scatter. The power density expected at Green Bank is calculated from the following equation.

$$PDE = power/(tpl*area) \qquad (26)$$

where $Area = (c/f)^2/(4*\pi)$

ρ is the angular distance, or the angle between horizon rays in the great circle plane, and is the minimum diffraction angle

hte is the effective height at the transmitter site

hre is the effective height at the receiver site (Green Bank)

D_{1t} is the distance to the transmitter horizon

D_{1r} is the distance to the receiver horizon

dist is the total distance from the transmitter to receiver

d_1 is the distance from the transmitter to the obstacle

d_2 is the distance from the obstacle to the receiver

f is the frequency in mHz

RK is the radius of the obstacle (assumed to be 2000')

tpl is the Total Path Loss

A full discussion and justification of these equations can be found in the NBS Technical Note No. 101, Vol I and II, Transmission Loss Predictions for Tropospheric Communication Circuits, by Rice, Longley, Norton, and Barsis.

There is one CalComp plot produced for each proposed transmitter site. The plot shows the curvature of the earth from the proposed transmitter site to Green Bank and then plots the corrected path profile versus distance; both distance and height are in kms.

APPENDIX

TOPODATA is a program to decode the topographic data tape from the Electromagnetic Compatibility Analysis Center of the Department of Defense (ECAC). The tape contains the data elevations taken every 30" in the area bounded by 37°N to 40°N and 80°W to 77°W; it also has the data in the area bounded by 39°N to 40°N and 81°W to 80°W. The program is set up to incorporate the data from the missing area (37°N to 39°N and 81°W to 80°W) if it can be acquired from either ECAC or the Army Map Service.

The ECAC tape is binary 7-track tape written by a Univac 1108. Figure A-1 describes the tape record format which consists of header records followed by a data matrix. The header words contain the following information: Latitude (min), longitude (min), vertical spacing (sec), horizontal spacing (sec), number of elevations per word, security class, source, quantization factor, initial bias, minimum elevation, maximum elevation, and number of missing elevations. The data matrix is an array of compressed elevations and is 121 by 121 elements. The matrix is in the form $E_{T,\emptyset}$ where T is the latitude and $\emptyset$ is the longitude. The data is on the tape in order of increasing T and decreasing $\emptyset$. (See Figure A-2.)

The actual elevations are compressed in order to store several elevations per word. The elevations are stored in multiples of 0,3,4,5,6,7, or 9 elevations per word. The following equation is used to compress the elevations:

$$H_{i,j} = \frac{1}{QF} * (E_{i,j} - \Delta E)$$

where $E_{i,j}$ is the actual elevation in feet, ΔE is the initial bias in feet, and QF is the quantization factor. The length of the record depends on the number of elevations stored per word; the maximum record size is 4892 words.

The Univac uses a 36 bit word, the IBM a 32 bit word. When the tape is read, each 6 bits from the 7-track tape is stored in 8 bits of core. To get decoded number, it is necessary to concatenate (||) the appropriate bits, adding 0's to fill, or pad, the 32 bit integer words of the header, or 16 bit words of the data elevations.

Example: Word 1 decoding

Latitude 14 '0' bits || bits 3-8 || bits 11-16 || bits 19-24

Longitude 14 '0' bits || bits 27-32 || bits 35-40 || bits 43-48

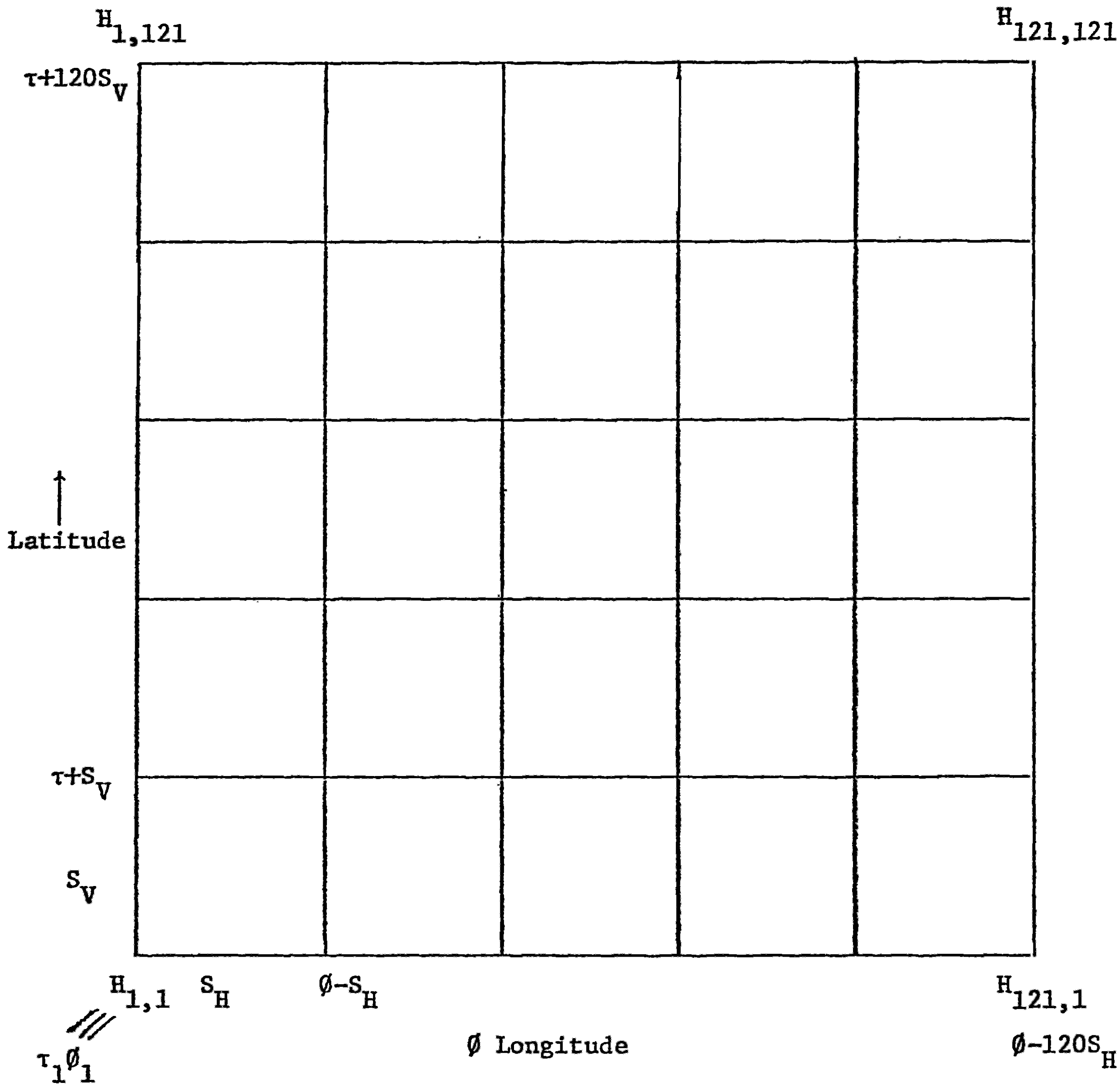
After TOPODATA copies the ECAC tape onto an IBM-readable 9-track tape, program RECOPY is run, in order to put the data matrix in row form. This is the matrix form QUIETZON uses.

	6	12	18	24 30 36 bits
X-Word 1				
X-Word 2				
Word 1	Latitude (min)			Longitude (min)
2	Vertical spacing (sec)			Horizontal spacing (sec)
3	Elev/word	Sec. Class	Source	Quantization factor
4	Initial Bias			
5	Minimum Elevation			
6	Maximum Elevation			
7	No. of missing elevations			blank
8	blank			
9	blank			
10	blank			
11	blank			
12 … 4892-max	$H_{1,1}$ $H_{1,2}$ .... $H_{2,1}$ .... $H_{3,1}$ .... $H_{121,121}$			
X-Word 1				
X-Word 2				

X-Word 1 and X-Word 2 are control words written by the Univac and are not needed for translation or processing of the data on the tape.

Security Class and Source are not needed by NRAO and are not decoded or copied with the other header words.

Figure A-1



S_V = Vertical spacing (sec)

S_H = Horizontal spacing (sec)

Figure A-2