3-4. List of Symbols and Abbreviations

In the following list the English alphabet precedes the Greek alphabet and lower case letters precede upper case letters. In general, upper case letters are used for quantities expressed in decibels.

a — an effective earth's radius that allows for average refraction of radio rays near the surface of the earth, (1) and (3.1).

a_1, a_2 — effective earth's radii for the terrain between the transmitting or receiving antennas, respectively, and the corresponding horizon, (3.29a).

a_3, a_4 — effective earth's radii for the terrain between horizons at distances d_3 and d_4 respectively, (3.29b).

A — attenuation relative to free space, expressed in decibels. Attenuation below free space is written as positive values of A.

A_{cr} — a predicted reference value of attenuation below free space, expressed in decibels.

A_d — the diffraction attenuation in dB, (13), (16), and section 3-2.

A_{do} — the diffraction attenuation in dB equivalent to A_{ed}, but computed assuming a smooth spherical earth, (3.47).

A_e — attenuation below free space in dB defined by (11), to simplify (10).

A_{ed} — estimated diffraction attenuation below free space in dB, extrapolated to zero distance, (15) and (3.38).

A_{es} — estimated scatter attenuation below free space in dB, extrapolated to zero distance, (17) and (3.49).

A_{fo} — an estimate of attenuation due to surface clutter, (3.38c).

A_k — an estimate of knife-edge diffraction attenuation, (13).

A_{k3}, A_{k4} — an estimate of knife-edge attenuation computed at distances d_3 and d_4, respectively, (3.27).

A_L — diffraction attenuation in dB, computed at the distance d_L.

A_{Ls} — diffraction attenuation in dB, computed at the distance d_{Ls}, (3.17c).

A_r — an estimate of the diffraction attenuation over the bulge of the earth, (13), and subsection 3-2.

A_{r3}, A_{r4} — the diffraction attenuation A_r computed at distances d_3 and d_4, respectively, (3.28).

A_s — forward scatter attenuation in dB, (18).

A_{sx} — forward scatter attenuation computed at $d = d_{xo}$, (3.48).

$\hat{A}_s$ — an estimate of the forward scatter attenuation, (3.43).

A_{xo} — an estimate of the diffraction attenuation over a smooth earth, computed at d_{xo}, (3.47).

$A(v)$ — an estimate of knife-edge diffraction as a function of the parameter v, (3.26).

A_o, A_1 — attenuation below free space computed at the distances d_o and d_1, respectively, (10) and (3.18).

A_{ot}, A_{1t} — estimates of attenuation below free space computed at the distances d_o and d_1, respectively, using two-ray optics, (3.18).

A_3, A_4 — predicted diffraction attenuation computed at distances d_3 and d_4, respectively, (3.25).

A_5, A_6 — predicted scatter attenuation computed at distances d_5 and d_6, respectively.

$\hat{A}_5, \hat{A}_6$ — estimates of scatter attenuation computed at distances d_5 and d_6, respectively, (3.43).

$\hat{A}_{50}$ — a preliminary estimate of scatter attenuation computed over a smooth earth at the distance d_5, (3.46).

$A(0.5)$ a long-term median estimate of attenuation relative to free space for any particular set of data.

b_h, b_v parameters used in computing the theoretical plane earth reflection coefficients for horizontal and vertical polarization, respectively, (3.10).

$B_{1,2,3,4}$ parameters used in computing the modified distances $x_{1,2,3,4}$, (3.32).

c phase angle relative to π radians of an effective reflection coefficient, (3.2).

c_h, c_v the phase angle c for horizontal and vertical polarization, respectively, (3.13) to (3.15).

d great circle path distance in kilometers.

dB decibels, $10 \log_{10}$ (power ratio).

d_i one of a series of equal distances at which terrain heights h_i are read, p. 3-2.

d_L sum of the distances d_{L1} and d_{L2} from each antenna to the corresponding horizon, (5d).

d_{L1}, d_{L2} the distances from the transmitting and receiving antenna, respectively, to their corresponding horizons, (5c).

d_{Ls} the sum of the smooth-earth horizon distances d_{Ls1} and d_{Ls2}.

d_{Ls1}, d_{Ls2} distances from the transmitting and receiving antennas, respectively, to their corresponding horizons over a smooth earth, (5a).

d_x the distance at which diffraction and scatter attenuations are equal, (3.44).

d_{xo} the distance at which diffraction and scatter attenuation would be equal over a smooth earth, (3.46c).

d_{x1}, d_{x2} estimates of the distance d_{xo}, defined by (3.46a) and (3.46b).

$\hat{d}_{xo}$ a preliminary estimate of the distance d_{xo}, (3.46a) and (3.46b).

d_o a distance chosen to approximate the greatest distance at which the attenuation below free space is zero dB, (3.16).

d_{o1} one estimate of the distance d_o, (3.16).

d_1 a distance greater than d_o but less than d_L, defined by (3.16d).

d_3, d_4 distances defined by (3.24) at which diffraction attenuation is calculated.

d_5, d_6 distances defined by (3.39) at which scatter attenuation is calculated.

e the base for natural or Naperian logarithms, $e \simeq 2.7183$, (3.21).

f radio wave frequency, expressed in megahertz (MHz) in this report.

$F(x_1), F(x_2)$ a function used in computing diffraction attenuation, (3.34).

g_{o1}, g_{o2} directive gain of each antenna in the direction of the other, (3.2) and (3.5).

g_{r1}, g_{r2} directive gain of each antenna in the direction of a point of ground reflection, (3.5).

Gp path antenna gain expressed in decibels above the unit gain of an isotropic radiator, (3.3).

$G(x_3, x_4)$ a function used in computing the diffraction attenuation at the distances d_3 and d_4, (3.37).

h subscript referring to horizontal polarization.

h_i any one of a series of equidistant heights of terrain above sea level.

h_e a height in meters used in computing the horizon distances, (5c).

h_{e1}, h_{e2} effective antenna heights of the transmitting and receiving antennas, respectively, (4) and (3.3).

h_{g1}, h_{g2} structural antenna heights above ground, (4).

h_{L1}, h_{L2} height above sea level of the horizon obstacle for the transmitter and receiver, respectively, (3.1).

h_s height of the surface of the ground above sea level, (2).

h_{s1}, h_{s2} height above sea level of the transmitting and receiving antennas, respectively, (3.1).

H_5, H_6 frequency gain function computed at the distances d_5 and d_6, respectively, (3.41).

k a coefficient used in defining effective antenna heights, (4).

k_1, k_2 coefficients that define the slope of a smooth curve of A_{cr} versus distance for distances $0 \le d \le d_{Ls}$, (10) and (3.19).

$\hat{k}_1, \hat{k}_2$ estimates of the coefficients k_1 and k_2, (3.20).

$K_h(a), K_v(a)$ parameters for horizontal and vertical polarization, respectively, used in computing diffraction attenuation, (3.33).

$\log_{10}$ logarithm to the base 10.

L_{bf} basic transmission loss in free space, (9).

L_{cr} median reference value of transmission loss (8).

m_d slope of the curve of diffraction attenuation A_d versus distance, (15b) and (3.38).

m_{do} slope of diffraction attenuation in dB/km for $\Delta h = 0$, (3.46a).

m_s slope of the curve of scatter attenuation A_s versus distance, (17b) and (3.45).

m_h, m_v parameters used in computing the magnitudes of the theoretical plane earth reflection coefficients R_h and R_v, (3.11).

N_s the surface refractivity, (2).

N_o surface refractivity reduced to sea level, fig. 1.

p parameter used in computing the theoretical plane earth reflection coefficient, (3.9b).

q parameter used in computing the theoretical plane earth reflection coefficient, (3.9a).

R_e the magnitude of an "effective" reflection coefficient, (3.5) and (3.8).

R_h, R_v the magnitude of the "theoretical" plane earth reflection coefficient for horizontal and vertical polarization, respectively, (3.12a) and (3.12b).

$\hat{R}_e$ estimate of an effective reflection coefficient, (3.5).

S_5, S_6 terms defined by (3.42) that are used in estimating the forward scatter attenuation A_s, (3.43).

v subscript referring to vertical polarization.

$v_{1.3}, v_{2.3}, v_{1.4}, v_{2.4}$ parameters used to compute the double knife-edge attenuation, (3.25) through (3.27).

w weighting factor, determined empirically as a function of radio frequency and terrain parameters, (3.23).

$w_{1,2}$ parameters used in computing rounded earth attenuations, defined by (3.35a).

w_3, w_4 estimates of w corresponding to $d = d_3$, $d = d_4$, (3.25).

x a parameter used in computing the theoretical plane earth reflection coefficient, (3.9a).

$x_{1,2,3,4}$ distances defined by (3.30) through (3.31b).

y_1, y_2 parameters used in computing the theoretical plane earth reflection coefficient, (3.14).

Δh an asymptotic value of $\Delta h(d)$ which is used to characterize the terrain, table 1, and (3).

$\Delta h(d)$ interdecile range of terrain heights above and below a straight line fitted to elevations above sea level, (3).

Δr the difference in path length of the direct and reflected ray, (3.2) and (3.3).

ϵ the permittivity or relative dielectric constant of the ground, (3.9) through (3.15).

θ angular distance for a transhorizon path, (7).

θ_e the sum of the elevation angles θ_{e1} and θ_{e2}, (6b).

θ_{e1}, θ_{e2} the angles by which the horizon rays are elevated or depressed relative to the horizontal at each antenna, (6a) and fig. 2.

θ_3, θ_4 angular distances corresponding to d_3, d_4, d_5, d_6 in (3.26),
θ_5, θ_6 (3.29), (3.40), (3.41) and (3.42).

λ radio wave length, used for example in (3.23).

σ the conductivity of the earth's surface, (3.9) and following.

σ_h the rms deviation of terrain and terrain clutter within the limits of the first Fresnel zone in the dominant reflecting plane, (3.6).

ψ the grazing angle of a ray reflected from a point on the surface of a smooth earth, (3.7).

3-5. Computer Program Listing and Sample Output

A computer program listing and a sample of the output are given in this section. The program is written in Fortran IV for a digital computer.* A list that relates program symbols to corresponding terms and equations in the report is provided as well as a brief flow chart of the program. Attenuation is computed at fixed distances in addition to the parameters required to obtain curves of A_{cr} versus d.

The sample output shows computations for paths in northeastern Ohio and in the Colorado plains and mountains that correspond to those where measurements were made. The curves of A_{cr} versus d shown in figures 3 through 8 were plotted from this output. Calculations were made at frequencies of 100, 50 and 20 MHz, for appropriate antenna heights above ground. The terrain of the area in Ohio and the Colorado plains is characterized by $\Delta h = 90$ m, while for the mountain paths $\Delta h = 650$ m. Values of surface refractivity used are $N_s = 312$ in Ohio and $N_s = 290$ in Colorado. For the longer mountain paths a somewhat lower value of N_s would be appropriate. The terrain parameters d_{L1}, d_{L2}, θ_{e1} and θ_{e2} were calculated using equations (5) and (6), and for these low, randomly located antennas we assumed $h_{e1,2} = h_{g1,2}$. In each area the first three sets at 100 MHz are for vertical polarization and the second three sets are for horizontal polarization. At frequencies of 50 and 20 MHz only vertical polarization is shown. The smooth-earth horizon distances d_{Ls}, and corresponding attenuation A_{Ls} are listed. Similarly, the distance d_x, at which diffraction and scatter attenuation are equal, and the corresponding attenuation A_{dx} are given.

*The program was written for a Control Data Corporation CDC-3600 computer and may require slight modification for use with other computers.

From this output the calculated reference attenuation A_{cr} may be obtained at any desired distance d:

For $0 \le d \le d_{Ls}$ $\quad A_{cr} = A_e + k_1 d + k_2 \log_{10} d$ dB.

For $d_{Ls} \le d \le d_x$ $\quad A_{cr} = A_{ed} + m_d d$ dB.

For $d \ge d_x$ $\quad A_{cr} = A_{es} + m_s d$ dB.

Reference List of Program Symbols

Program	Report	Equation	Program	Report	Equation
A	a	(1)	AOG	A_o	
ACR	A_{cr}	(8)	A1	A_1	(3.18b)
AD	A_d	(13)	A1, 2	$a_{1,2}$	(3.29a)
ADO	A_{do}		A3, 4	$a_{3,4}$	(3.29b)
ADX	A_{dx}		A3, 4	$A_{3,4}$	(3.25)
AED	A_{ed}	(3.38b)	B	b	(3.10)
AES	A_{es}	(18)	B1, 2	$B_{1,2}$	(3.32)
AFO	A_{fo}	(3.38c)	B3, 4	$B_{3,4}$	(3.32)
AG	A	(3.2)	C	c	(3.13) to (3.15)
AH5, 6	$\hat{A}_{5,6}$	(3.48)	D	d	
AH50	$\hat{A}_{50}$	(3.48)	DEDO	A_{od}	(3.17a)
AK3, 4	$A_{k3,4}$	(3.27c)	DED1	A_{1d}	(3.17b)
ALS	A_{Ls}	(3.17c)	DH	Δh	(3)
AR3, 4	$A_{r3,4}$	(3.28)	DHD	$\Delta h(d)$	(3)
AS	A_s	(17)	DHD3, 4	$\Delta h(d_{3,4})$	(3)
ASX	A_{sx}	(3.48)	DL	d_L	(5d)
AV13, 23	$A(v_{1.3,2.3})$	(3.27)	DLS	d_{Ls}	(5b)
AV14, 24	$A(v_{1.4,2.4})$	(3.27)	DL1, 2	$d_{L1,2}$	(5c)
AXO	A_{xo}	(3.47)	DLS1, 2	$d_{Ls1,2}$	(5a)
AO	A_o	(3.18a)	DX	d_x	(3.44)

Reference List of Program Symbols (continued)

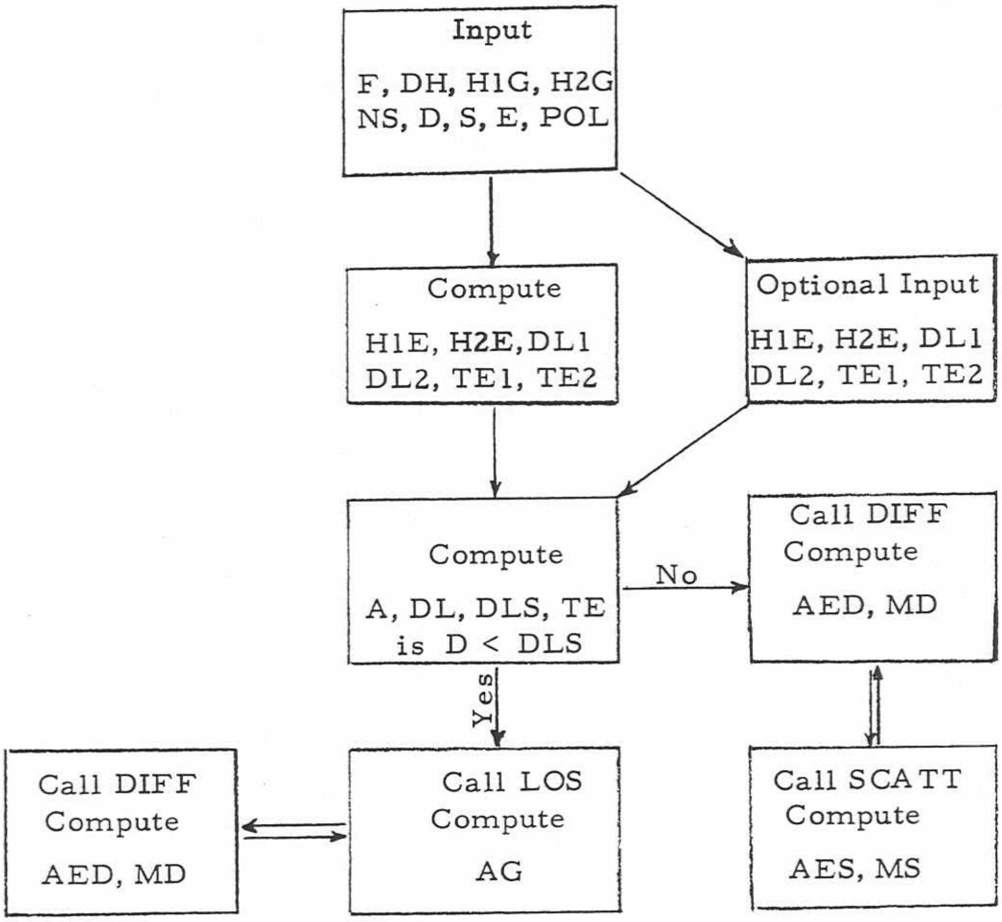
Program	Report	Equation	Program	Report	Equation
DXO	d_{xo}	(3.46)	MS	m_s	(18)
DX1, 2	$d_{x1,2}$	(3.46)	NS	N_s	(2)
DO	d_o	(3.16c)	P	p	(3.9b)
DO1, 2	$d_{o1,2}$	(3.16b)	POL	polarization	
D1	d_1	(3.16d)	PSI	ψ	(3.7)
D3, 4	$d_{3,4}$	(3.24)	Q	q	(3.9a)
D5, 6	$d_{5,6}$	(3.39)	RE	R_e	(3.5) & (3.8)
E	ϵ	(3.9) to (3.15)	S	σ	(3.9)
F	f in MHz		SH	σ_h	(3.6)
FX1, 2	$F(x_{1,2})$	(3.34)	SHDLS	$\sigma_h(d_{Ls})$	(3.38)
GX3, 4	$G(x_{3,4})$	(3.37)	SP	$\sin\psi$	(3.8a)
H1E, 2E	$h_{e1,2}$	(4b)	S5, 6	$S_{5,6}$	(3.42)
H1G, 2G	$h_{g1,2}$	figure 2	TD	θd	(3.43)
H5, 6	$h_{5,6}$	(3.41)	TE	θe	(6b)
K1, 2	$k_{1,2}$	(3.10) to (3.22)	TE1, 2	$\theta_{e1,2}$	(6a)
K1, 2	$K(a_{1,2})$	(3.33)	T3, 4	$\theta_{3,4}$	(3.25c)
K3, 4	$K(a_{3,4})$	(3.33)	T5, 6	$\theta_{5,6}$	(3.40)
M	m	(3.11)	V13, 23	$V_{1.3, 2.3}$	(3.26)
MD	m_d	(3.38b)	V14, 24	$V_{1.4, 2.4}$	(3.26)
MDO	m_{do}	(3.47)	W	w_o	(3.18)

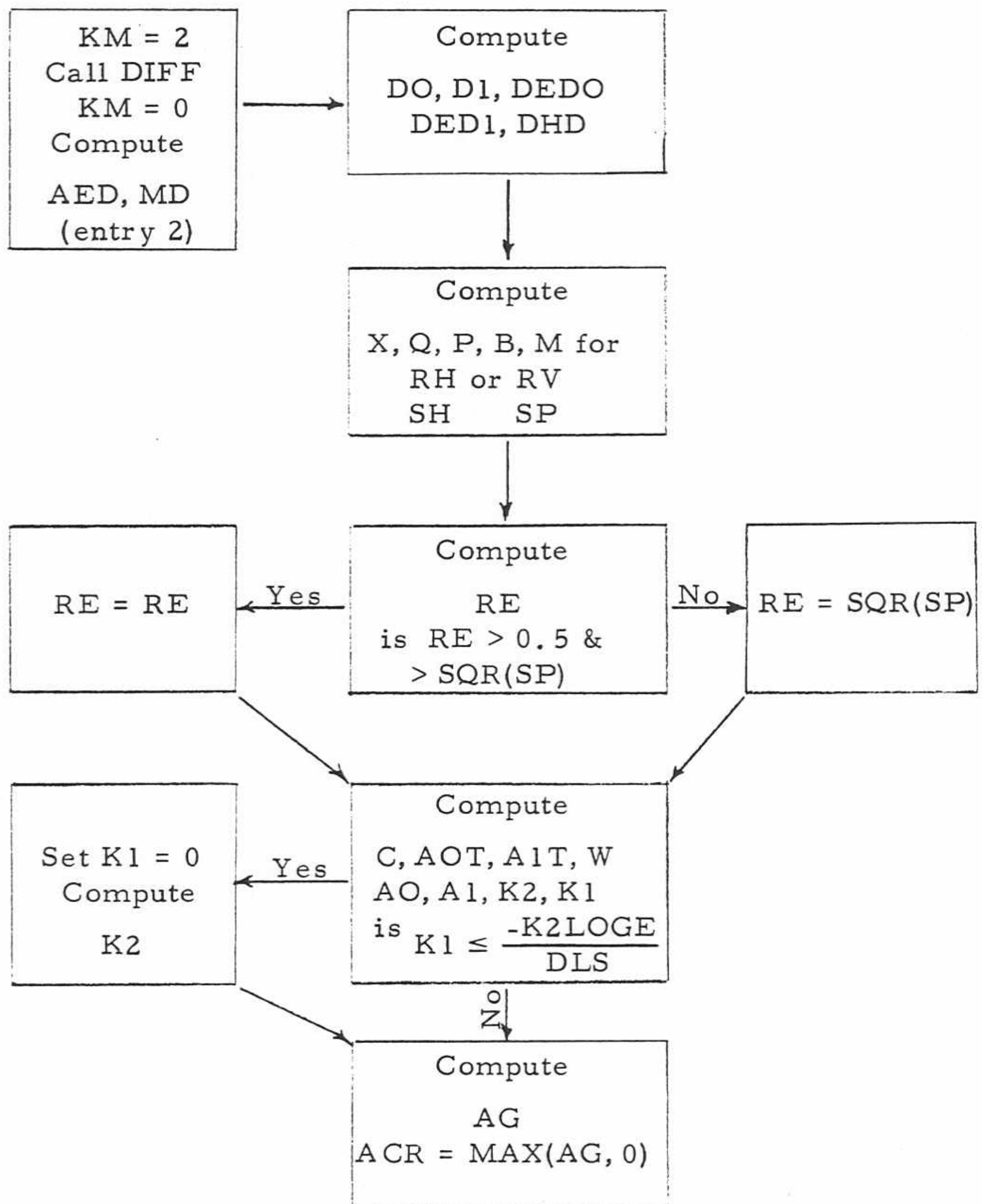
Reference List of Program Symbols (continued)

Program	Report	Equation
W1, 2	$w_{1,2}$	(3.35)
W3, 4	$w_{3,4}$	(3.23)
X	x	(3.9a)
X1, 2	$x_{1,2}$	(3.30)
X3, 4	$x_{3,4}$	(3.31)
Y1, 2	$y_{1,2}$	(3.14)

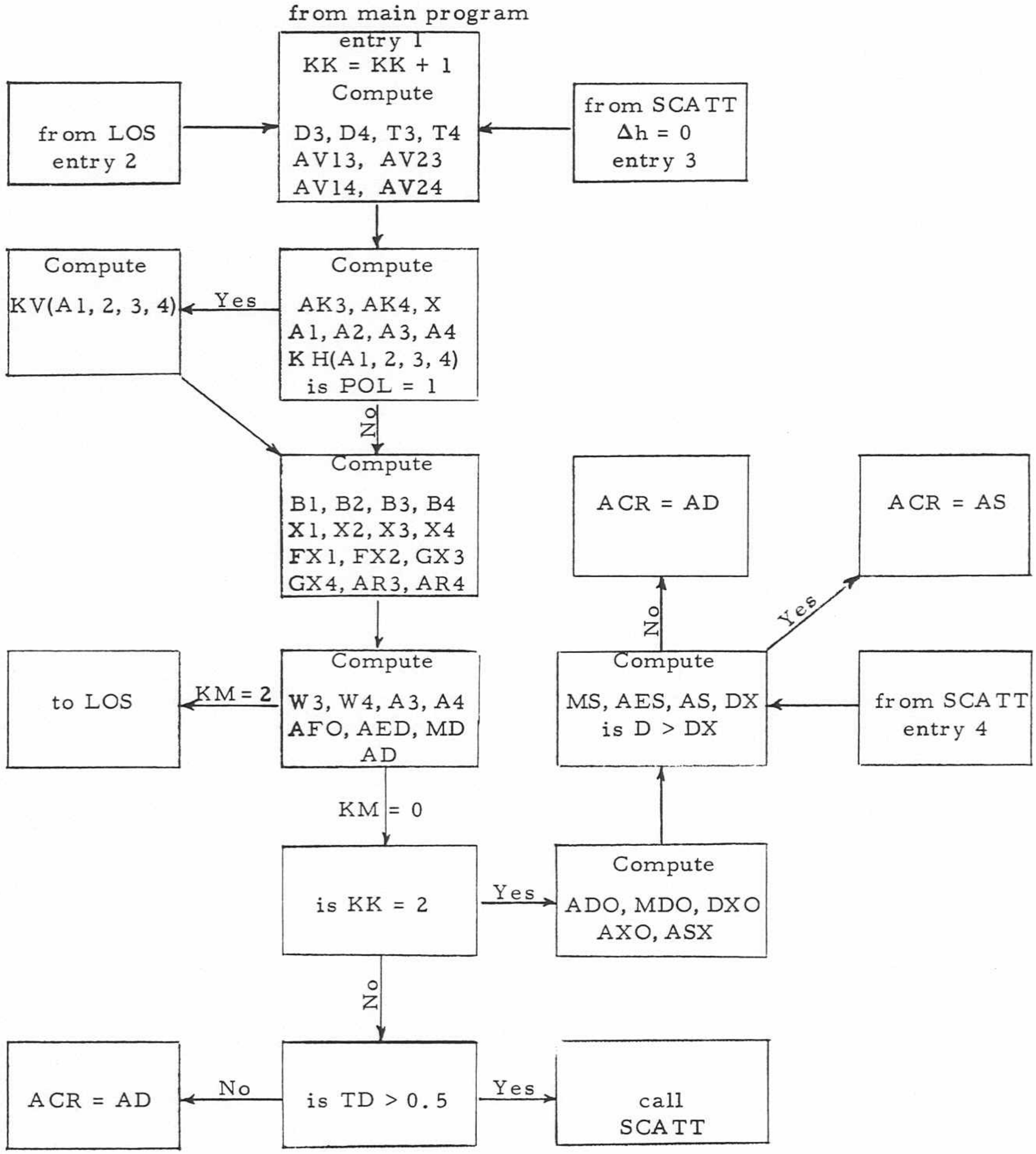
Flow Charts

Main Program




KM = 2
Call DIFF
KM = 0
Compute
AED, MD
(entry 2)
Compute
DO, D1, DEDO
DED1, DHD
Compute
X, Q, P, B, M for
RH or RV
SH SP
RE = RE
Yes
Compute
RE
is RE > 0.5 &
> SQR(SP)
No
RE = SQR(SP)
Set K1 = 0
Compute
K2
Yes
Compute
C, AOT, A1T, W
AO, A1, K2, K1
is K1 ≤ -K2LOGE / DLS
No
Compute
AG
ACR = MAX(AG, 0)

Diffraction Subroutine, DIFF



Scatter Subroutine, SCATT