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ABSTRACT

Three computer programs for calculating particle orbits with linearized vertical motion in general cyclotron magnetic fields are described in detail. The first program is used for finding properties of equilibrium orbits and small oscillations about them. The second program is a very flexible routine for determining the history of a particle under various conditions, including acceleration. Flexibility is achieved through the use of options such as a resonance-hunt routine, harmonic-bump routines, and an equilibrium-orbit-search routine. The third program, the deflector program, allows various combinations of electrostatic, magnetic, and regenerative extractors to be used.

THREE COMPUTER PROGRAMS FOR CALCULATING CYCLOTRON ORBITS†

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1. Introduction

This report concerns a system of IBM 704 orbit programs that has been found to be a very useful tool in the design and testing of the 88-inch cyclotron at Berkeley. The theory used in the equilibrium-orbit code [1] was devised by Gordon†† and Welton [2]; the program was written by Arnette†† and the author††† at the Oak Ridge National Laboratory. The second program, for computing general cyclotron orbits, was designed by Welton [3]. The third program, for designing deflector configurations, was designed by Garren [4]. These latter two codes were programmed by the author.

Each of these programs requires a set of magnetic fields stored on a polar grid on magnetic tape in a format as described in detail in ref. [1].

2. The Equilibrium-Orbit Code

2-1 THE FUNCTIONS OF THE CODE

The equilibrium-orbit code will be mentioned only briefly, since it was reported in some detail at a previous conference [5].

The essential functions of the equilibrium-orbit code are to find the radius and radial momentum of the equilibrium orbit, and to compute the

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† Work done under the auspices of the U.S. Atomic Energy Commission.

†† T. I. Arnette and M. M. Gordon are now at Michigan State University.

††† The author is now at the Lawrence Radiation Laboratory, Berkeley.

focusing frequencies and the time for the particle to make one revolution. Also, an essential byproduct of the equilibrium-orbit search is the information on small-amplitude radial and axial oscillations needed to enable one to conveniently determine nonlinear orbit properties. This last feature is used by the general orbit code to be discussed later.

The equilibrium-orbit code can be used to generate a table of equilibrium-orbit properties for determining the isochronization and focusing properties of various magnetic-field configurations. Tables of equilibrium-orbit properties are essential for orienting various other studies, such as deflection studies, which require the other two orbit codes.

2.2 OUTPUT

The table of equilibrium-orbit properties may be printed in equal increments of one of three independent variables: the magnitude of the particle momentum p, the total relativistic particle energy E, or velocity β. Any one of five different output formats is possible, each one being some variation of the example in fig. 1. The first three columns will contain p, E, and β, the order being determined by the choice for independent variable. The fourth column gives the time, normalized to one for convenience, for the particle to traverse one revolution. Columns six, seven, and eight give the axial frequency, radial frequency, and kinetic energy, respectively. The remaining columns give the radius, radial momentum, average radius, and radial amplitude of the equilibrium orbit.

2.3 TIMING

The equilibrium-orbit code takes approximately 7 sec to generate one line of output corresponding to one equilibrium orbit, if twenty integration steps per sector are used.

3. The General Orbit Code

3.1 INTRODUCTION

The general orbit code computes the orbit of a particle in a cyclotron magnetic field with allowances for several operating modes. In each of the operating modes the user has the option of tracing the particle outward from the starting point or inward toward the center.

The operating modes are numerous and are determined by the user's choice of routines available, as described in section C. below as well as his choice of equations to be integrated.

3.2 THE EQUATIONS INTEGRATED

The equations of motion–for a particle in a magnetic field in cylindrical coordinates r, θ, z–which are integrated by the Runge-Kutta method are:

$$r' = \frac{rp_r}{Q} ,$$

$$p_r' = Q - rB(r,\theta) ,$$

$$z' = \frac{rp_z}{Q} ,$$

$$p_z' = [r \frac{\partial B}{\partial r} - \frac{p_r}{Q} \frac{\partial B}{\partial \theta}] z ,$$

$$r_e' = \frac{r_e p_{re}}{Q} ,$$

$$p_{re}' = Q_e - r_e B_e(r_e, \theta) ,$$

$$t' = \frac{r\sqrt{p^2 + 1}}{Q} ,$$

where

prime means $\frac{\partial}{\partial \theta}$

$r(\theta)$ = radius as a function of θ for the orbit to be calculated,

$p_r(\theta)$= radial momentum as a function of θ,

$Q(\theta) = (p^2 - p_r^2)^{1/2}$

p = the magnitude of the particle momentum,

$z(\theta)$ = the axial displacement,

$p_z(\theta)$= the axial momentum,

$t(\theta)$ = time from $\theta = 0$,

$r_e(\theta)$= the value of $r(\theta)$ a particle will have if started on the equilibrium orbit and given acceleration,

$p_{re}(\theta)$= the radial momentum associated with $r_e(\theta)$,

$Q_e(\theta) = (p^2 - p_{re}^2)^{1/2}$,

N = number of sectors,

$B(r,\theta)$= magnitude of z component of magnetic field in the median plane.

The following units are used:

Speed in units of c, the velocity of light in a vacuum,

Momentum in units of m_0c , where m_0 is the particle rest mass,

Energy in units of m_0c^2,

Time in units of $a = c/\omega_0$,

Field in units of $b = m_0c\ \omega_0/e$.

It is convenient to take ω_0 to be the synchronous angular velocity, or $2\pi f$, where f is the rf frequency.

3.3 PRINCIPAL ROUTINES USED

A. Equilibrium-Orbit Routine. As mentioned earlier, the equilibrium-orbit code is incorporated in the general orbit code as a subroutine. It is entered to find equilibrium orbits to be used as operating points around which orbits of interest may be initiated. It is an integral part of the resonance-hunt routine, and is used to compute the details of small-amplitude oscillations by the ellipse initial conditions and curve-plotting routines.

B. Resonance-Hunt Routine. The resonance-hunt routine finds the momentum that will cause the operating point in the (ν_r, ν_z) plane to fall a given distance from a specified resonance line. By using a simple difference formula, an iterative procedure is followed to determine p so that the relationship $k = m\nu_r + n\nu_z$ is satisfied. Here ν_r and ν_z are the radial and axial focusing frequencies, respectively, m and n are integers specifiying the resonance of interest, and k is a constant used in defining the resonance line.

C. Ellipse Routine. The ellipse routine computes the initial conditions, $x(\theta)$ and $p_x(\theta)$, using the formulas

$$x(\theta) = \sqrt{\frac{J_x}{\pi E}}\,(A\cos\psi_x + B\sin\psi_x)\,,$$

$$p_x(\theta) = \sqrt{\frac{J_x}{\pi E}}\,(C\cos\psi_x + D\sin\psi_x)\,,$$

where

θ = the starting angle,

x, p_x are the deviations from the equilibrium orbit of the radial coordinate and momentum,

J_x = an input number which determines the x-amplitude (Action).

ψ_x = an input number which determines the phase.

The coefficients A, B, C, D, and E are dependent on the details of the small-amplitude oscillations computed by the equilibrium-orbit code. The reader is referred to ref.[2]) for explicit definitions of these coefficients. Exactly parallel equations are used to compute the $z(\theta)$, $p_z(\theta)$ initial conditions. It will be observed that, with these definitions, if the amplitude is sufficiently small to allow neglect of nonlinear effects, the ellipse defined is just an invariant ellipse.

D. Curve-Plotting Routins. With the curve-plotting routine the user can plot $x(\theta)$, $p_x(\theta)$ or $\sqrt{\frac{J_x}{\pi}} \cos \psi_x$ and $\sqrt{\frac{J_x}{\pi}} \sin \psi_x$ at a preset value of θ.

E. Harmonic-Field Bump Routines. Provision for three bump subroutines have been made, two of which have been written and checked out. The field component is computed as needed, and is used to modify the stored fields during the integration procedure. Both routines use the same form for the bump, i.e.,

$$B_R = A(r) \cos (n\theta + \gamma) + B(r) \sin (n\theta + \gamma),$$

where

B_R = the field bump to be added to the magnetic field,

θ = independent variable,

n = field harmonic desired,

γ determines the phase of the bump.

A(r) and B(r) determine the radial amplitude of the bump. The only difference in the two subroutines is that the radial coefficients, A(r) and B(r), are specified in tabular form in one and analytic form in the other. The analytic formula for both A(r) and B(r) is the cubic polynomial of the form

$$a(r) = a_0 + a_1 r + a_2 r^2 + a_3 r^3.$$

F. Acceleration Routine. The energy gain per gap crossing is computed by

$$\Delta E = \frac{\delta}{q}\left[(1-\epsilon)\cos(\theta-\omega t) + \epsilon\cos 3(\theta-\omega t)\right] ,$$

where

δ = the energy gain per turn,

q = the number of acceleration gaps,

ωt = the phase angle with respect to the rf,

where t is time from $\theta = 0$ deg,

ϵ = an input constant.

The acceleration may be phase independent, i.e., $\Delta E = \frac{\delta}{q}$, if desired—in which case the equation for the time is not integrated.

If it is necessary to have a reference point for plotting or for other output, the equations of motion for a particle having the initial conditions of the equilibrium orbit are integrated. The same acceleration is given the reference particle that is given the orbital particle. If such a reference is not needed, the equations of motion are not integrated.

G. Modified Gap-Crossing Routine. This routine modifies the acceleration at the two gaps of a conventional dee structure so that

$$\Delta E_1 = F_1(r)\,\Delta E, \quad \Delta E_2 = F_2(r)\,\Delta E,$$

where ΔE_1, ΔE_2 are the energies gained at the first and second gap crossings, respectively, $F_1(r)$, $F_2(r)$ are tabular input parameters computed independently, and ΔE is the energy gain described in subsec. F above. This modification is needed only in the central portion of the cyclotron, thus a cutoff radius is part of the input. It is used to take account of the larger intervals of time the particles spend crossing the acceleration gap at small radii, during which the E field changes, so that the particles see a different effective accelerating field.

3.4 OUTPUT

A. Printed Tables. Tables (see fig. 2) will be printed as a function of θ starting at any Runge-Kutta step, at equal intervals (divided by the Runge-Kutta step size) of θ.

B. Binary Output. If the main purpose of the run is for extended curve plotting, provision is made to write all of the information computed at each Runge-Kutta step in binary form on magnetic tape to be processed by a special curve-plotting routine. Such a curve-plotting routine is not now available.

C. C.R.T. Plots. Phase plots at a specified Runge-Kutta step may be made as described in subsec. 3.3-D.

3.5 TIMING

The time for one revolution is a function of the particular operating mode and the size of the integration step. It ranges from a minimum of 5 sec in the simplest case to a maximum of approximately 18 sec in the more extensive cases. These times are figured on the basis of twenty Runge-Kutta steps per sector.

4. The Deflector Code

4.1 INTRODUCTION

The deflector code was planned to facilitate the design of a cyclotron deflection system[6]). The code calculates particle orbits in the cyclotron with the magnetic field so modified as to simulate the action of electrostatic channels, and/or magnetic channels, and /or regenerative field bumps for resonant extraction. The program will simulate multiple channels in any combination of the above channels.

With the exception of the equations for r_e' and p_{re}', the equations of motion are the same as in the general orbit code. The program first calculates and records the path that a particular orbit with given initial values of r and p_r,

called the reference ray, will take in the presence of the modified magnetic field. Using this it calculates the shape and position of the elements of the channels defined by the input parameters (fig. 3). It now shoots a barage of particles at the deflector and records what happens.

4.2 CALCULATION OF THE REFERENCE RAY AND CHANNEL WALLS

A. The Reference Ray. The reference ray particle is started (usually on or near an equilibrium orbit) at the angle θ_i and is integrated until the angle θ_f is reached (see fig.3). Outside the pie-shaped area where the deflector is located, determined by radial lines at θ_0 and θ_1, the particle experiences the magnetic field

$$\tilde{b}(r,\theta) = b(r,\theta) + b_R(r,\theta) ,$$

whereas inside the angles θ_0 and θ_1 it sees a field

$$\tilde{b}(r,\theta) = b(r,\theta) + b_R(r,\theta) + b_M[x_c(\theta)] + b_E(\theta),$$

where

$b(r,\theta)$ = the cyclotron magnetic field without the deflector,

$b_R(r,\theta)$ = the component of field due to a harmonic bump; the code presently has the same two bump routines as described in the general orbit code,

$b_M[x_c(\theta)]$ = the component of field due to the influence of the magnetic channel; it is a function of the distance x_c of the particle from the channel,

$b_E(\theta) = -\dfrac{\sqrt{1+p_c^2}}{p_c}\,\epsilon(\theta)$ = the magnetic field equivalent to the electric field, where p_c is the magnitude of the particle momentum and $\epsilon(\theta) = [\mathcal{E}_0 + \mathcal{E}_1(\theta-\theta_0) + \mathcal{E}_2(\theta-\theta_0)^2]/B_0$, when $\mathcal{E}_0$, $\mathcal{E}_1$, $\mathcal{E}_2$ are input parameters specifiying the electric field and B_0 is a normalizing constant—usually the value of the magnetic field at the center of the cyclotron.

B. Channel Walls.

(1). Computed. If $r_c(\theta)$ and $p_{rc}(\theta)$ denote the reference-ray radius and radial momentum, $d(\theta) = \frac{V}{|\epsilon(\theta)|}$ (where V is the voltage on the deflector) is the channel width, and σ_E, σ_M are the thicknesses of the electric and magnetic channel walls, respectively, then the radii of the channel walls (see fig. 3) are given by

$$T_+(\theta) = r_c(\theta) + [(1 - u)d(\theta) + \sigma_E]\ p_c/q_c,$$

$$B_+(\theta) = r_c(\theta) + (1 - u)d(\theta)\, p_c/q_c,$$

$$T_-(\theta) = r_c(\theta) - u\, d(\theta)\ p_c/q_c\ ,$$

$$B_-(\theta) = r_c(\theta) - [ud(\theta)\ \sigma_E + \sigma_M]\, p_c/q_c,$$

where $q_c = \sqrt{p_c^{\,2} - p_{rc}^{\,2}}$ and u is an input number specifiying the fractional part of $d(\theta)$ that the wall $T_-(\theta)$ is from the reference ray. Thus, the parameter u allows the channel to be shifted with respect to the reference ray.

(2). Input Directly. The program has the option whereby the coordinates of the channel walls may be input directly. Provision is made so that the walls may be adjusted to different positions by changing four numbers, one at the end of each channel wall. This feature is only available for the electric channel.

(3). The Acceptance Test.

(a) Initial Conditions for barage. The program as now written requires that the initial conditions for each particle be punched on a separate card. A simple subroutine could be written to put the particles on a grid and save the card punching. Several different ways of specifying initial conditions are available, but as a rule they are set relative to the r, p_r coordinates of the equilibrium orbit of the same momentum, for which purpose the equilibrium-orbit code is used as a subroutine.

(b) Field Specifications. The particle will see the field component b_R as described in the general orbit-code descriptions of the harmonic-bump routine, during its entire history. It will see the magnetic equivalent of the electric field $b_E(r,\theta) = \frac{-\sqrt{p^2+1}}{p}\,\epsilon(\theta)$ only while it is inside the channel (see fig. 3). It is assumed that the fringe effects are negligible, and that the particle orbit is perpendicular to the electric field lines. The particle experiences the effect of the magnetic channel only when it is above or below the bar of iron defining the channel. The magnetic channel component b_M is a function of the distance of the particle from the channel $x(r,\theta) = u\,d(\theta) + \sigma_E + [r(\theta) - r_c(\theta)]\,q_c/p_c$.

For each iron shape this effect must be measured and fit to an analytic curve, such as $b_M[x(r,\theta)] = \frac{F_0}{x} + \frac{F_1}{x^2}$. With some difficulty the code could be modified to pick up this number from a table.

(c) Particle History. The particle is tracked and its history recorded from some initial starting position until one of several events takes place. If it hits a channel wall the integration stops, and its position and the wall encountered is recorded. If it passes through the channel it is stopped at the angle θ_f (see fig. 3), and the information for a restart is recorded. If it completes a specified number of revolutions and has not encountered a wall or entered the channel, it is stopped at θ_f and its coordinates recorded for a restart. If the run is a multichannel study, and all of the particles have been tracked, the information defining the next channel is called for and the surviving particles are continued from θ_f.

4.3 OUTPUT

A. Off-line. The input parameters for each run are output on tape 6. The detailed information about each particle is output at each integration step on tape 6 in decimal form (fig. 4), or on tape 4 in binary form for future

machine processing. The user has the choice of printing the detailed information starting at the initial point or delaying until the particle has entered the channel.

B. On-line. The same detailed information that is printed off-line on tape 6 is printed on-line at the angles θ_i, θ_0, θ_1, and θ_f (figs. 3 and 4), as well as information as to what part of the deflector structure, if any, has been hit.

4.4 TIMING

If 20 Runge-Kutta steps per sector are used, the deflector code takes about 15 sec/revolution with the abbreviated output and approx 25 sec/revolution with the extended output.

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FIGURE CAPTIONS

Fig. 1. Equilibrium-orbit-code output format.

Fig. 2. General orbit-code output format.

Fig. 3. A channel configuration.

Fig. 4. Deflector-code output format.

P	E	BETA	TIME	COS	NU Z	NU R	KE	R	PR	R AVE	AMP
.0300	1.0004	.0300	.99713	.9730	.1112	1.0106	.42	.03043	-.00000	.02988	.00055
.0400	1.0008	.0400	.99596	.9537	.1459	1.0133	.75	.04072	-.00000	.03976	.00095
.0500	1.0012	.0499	.99521	.9401	.1660	1.0153	1.17	.05100	-.00000	.04961	.00137
.0600	1.0018	.0599	.99469	.9315	.1778	1.0172	1.69	.06127	-.00000	.05945	.00180
.0700	1.0024	.0698	.99427	.9268	.1838	1.0193	2.30	.07153	-.00000	.06927	.00224
.0800	1.0032	.0797	.99389	.9230	.1886	1.0214	3.00	.08176	-.00000	.07905	.00268
.0900	1.0040	.0896	.99349	.9203	.1919	1.0236	3.79	.09197	-.00000	.08881	.00312
.1000	1.0050	.0995	.99307	.9185	.1940	1.0261	4.68	.10215	-.00000	.09852	.00358
.1100	1.0060	.1093	.99263	.9176	.1952	1.0288	5.66	.11230	-.00000	.10819	.00405
.1200	1.0072	.1191	.99216	.9172	.1957	1.0319	6.73	.12242	-.00000	.11782	.00454
.1300	1.0084	.1289	.99166	.9173	.1956	1.0352	7.89	.13250	-.00000	.12739	.00504
.1400	1.0098	.1386	.99112	.9174	.1954	1.0387	9.15	.14255	-.00000	.13691	.00556
.1500	1.0112	.1483	.99056	.9178	.1949	1.0425	10.50	.15255	-.00000	.14637	.00609
.1600	1.0127	.1580	.98997	.9183	.1943	1.0466	11.93	.16251	-.00000	.15577	.00664
.1700	1.0143	.1676	.98935	.9190	.1935	1.0509	13.46	.17243	-.00000	.16510	.00721
.1800	1.0161	.1772	.98871	.9198	.1926	1.0554	15.08	.18229	-.00000	.17437	.00780
.1900	1.0179	.1867	.98804	.9206	.1915	1.0602	16.78	.19211	-.00000	.18356	.00840
.2000	1.0198	.1961	.98736	.9216	.1903	1.0652	18.58	.20187	-.00000	.19269	.00902
.2100	1.0218	.2055	.98666	.9226	.1891	1.0704	20.46	.21157	-.00000	.20174	.00966
.2200	1.0239	.2149	.98595	.9238	.1876	1.0759	22.44	.22121	-.00000	.21071	.01032

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Fig. 1

RUN NUMBER 61661

REV	THETA	KE	GAMMA	P	R	PR	X	PX	Z	PZ
	60.00	.091	-23.93	.00982950	.00751780	-.00237611	.00125240	-.00125240	.00000000	.00000000
	90.00	.091	-16.05	.00982950	.00681907	-.00113438	.00062537	-.00183798	.00000000	.00000000
	120.00	.091	-6.55	.00982950	.00668589	.00041405	-.00005371	-.00193114	.00000000	.00000000
	150.00	.091	2.36	.00982950	.00711640	.00185275	-.00081774	-.00150867	.00000000	.00000000
	180.00	.091	8.54	.00982950	.00810993	.00279241	-.00157539	-.00068186	.00000000	.00000000
	210.00	.091	10.35	.00982950	.00956568	.00298458	-.00198907	.00032706	.00000000	.00000000
	240.00	.160	9.19	.01305411	.01108213	.00274250	-.00174175	.00123823	.00000000	.00000000
	270.00	.160	11.37	.01305411	.01254310	.00312709	-.00104309	.00183857	.00000000	.00000000
	300.00	.160	9.84	.01305411	.01416806	.00264462	.00001667	.00196356	.00000000	.00000000
	330.00	.160	5.26	.01305411	.01542444	.00144502	.00111153	.00156663	.00000000	.00000000
	360.00	.160	-.95	.01305411	.01586823	-.00005016	.00183502	.00077849	.00000000	.00000000
1	30.00	.160	-7.10	.01305411	.01536960	-.00151152	.00193797	-.00020602	.00000000	.00000000
1	60.00	.229	-10.41	.01560973	.01415833	-.00238830	.00144054	-.00116941	.00000000	.00000000
1	90.00	.229	-6.88	.01560973	.01321441	-.00158967	.00071242	-.00181726	.00000000	.00000000
1	120.00	.229	-1.83	.01560973	.01278547	-.00032055	-.00012623	-.00197346	.00000000	.00000000
1	150.00	.229	3.53	.01560973	.01294611	.00104290	-.00096757	-.00160915	.00000000	.00000000
1	180.00	.229	7.90	.01560973	.01366654	.00208560	-.00166399	-.00080562	.00000000	.00000000
1	210.00	.229	10.26	.01560973	.01481331	.00256027	-.00197767	.00021840	.00000000	.00000000
1	240.00	.297	10.89	.01780595	.01613034	.00266715	-.00173453	.00113834	.00000000	.00000000
1	270.00	.297	12.14	.01780595	.01759063	.00300656	-.00104450	.00175389	.00000000	.00000000
1	300.00	.297	10.80	.01780595	.01911323	.00241151	-.00002178	.00194136	.00000000	.00000000
1	330.00	.297	7.44	.01780595	.02015808	.00112901	.00103353	.00161298	.00000000	.00000000
1	360.00	.297	3.12	.01780595	.02042611	-.00020788	.00176462	.00090382	.00000000	.00000000
2	30.00	.297	-1.03	.01780595	.01993477	-.00143617	.00196494	-.00002357	.00000000	.00000000
2	60.00	.367	-3.29	.01978669	.01882379	-.00231159	.00159590	-.00101781	.00000000	.00000000
2	90.00	.367	-1.17	.01978669	.01779246	-.00180584	.00088000	-.00175082	.00000000	.00000000
2	120.00	.367	2.31	.01978669	.01719983	-.00066708	-.00000166	-.00199482	.00000000	.00000000
2	150.00	.367	6.30	.01978669	.01720517	.00067592	-.00089340	-.00171944	.00000000	.00000000
2	180.00	.367	9.79	.01978669	.01777615	.00170499	-.00162768	-.00096484	.00000000	.00000000
2	210.00	.367	11.99	.01978669	.01875342	.00224435	-.00197221	.00006054	.00000000	.00000000
2	240.00	.436	12.95	.02154913	.01995247	.00256947	-.00178751	.00098550	.00000000	.00000000
2	270.00	.436	13.94	.02154913	.02140443	.00300921	-.00116063	.00163629	.00000000	.00000000
2	300.00	.436	12.80	.02154913	.02291231	.00235620	-.00018654	.00192183	.00000000	.00000000
2	330.00	.436	10.04	.02154913	.02387216	.00097931	.00086783	.00159683	.00000000	.00000000

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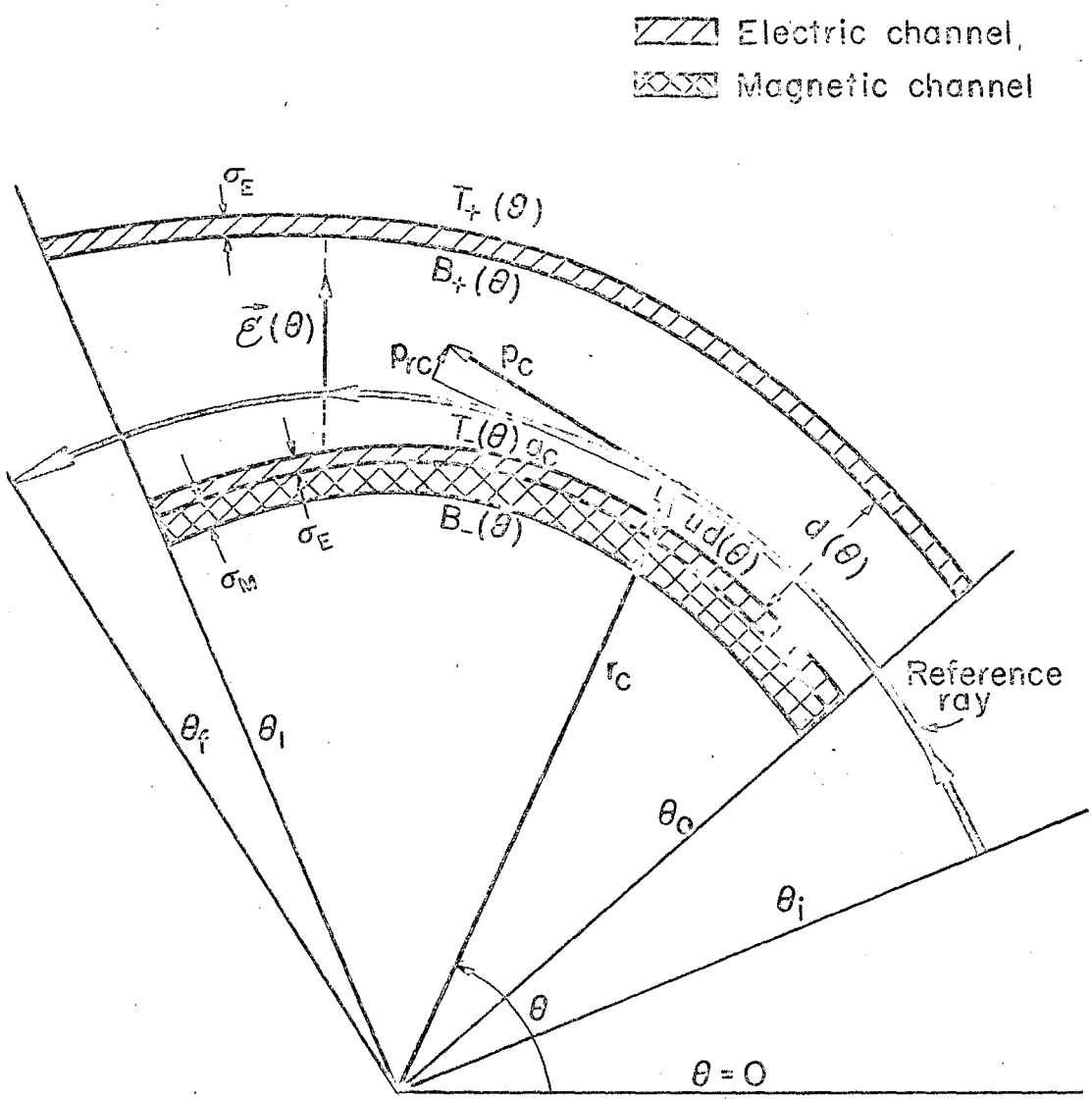
Fig. 2



MU-26344
UCRL-10083
Fig. 3

ORBIT 38, CHANNEL 1

REV	EV	THETA	KE	P	R	PR	X	PX	Z	PZ
							.00000000	-.00037147		
6		90.000	64.3866	.26420547	.25876066	.01482853	.00041385	-.00011560	.00000000	.00000000
6		96.000	64.3866	.26420547	.26031735	.01526135	.00040204	-.00010948	.00000000	.00000000
6		102.000	64.3866	.26420547	.26189913	.01520725	.00039179	-.00008511	.00000000	.00000000
6		108.000	64.3866	.26420547	.26347291	.01495122	.00038451	-.00005063	.00000000	.00000000
6		114.000	64.3866	.26420547	.26502314	.01459174	.00038120	-.00000815	.00000000	.00000000
6		120.000	64.3866	.26420547	.26654073	.01416821	.00038283	.00004321	.00000000	.00000000
6		126.000	64.3866	.26420547	.26801911	.01369670	.00039038	.00010302	.00000000	.00000000
6		132.000	64.3866	.26420547	.26945314	.01318874	.00040497	.00017301	.00000000	.00000000
6		138.000	64.3866	.26420547	.27084013	.01272596	.00042787	.00025610	.00000000	.00000000
6		144.000	64.3866	.26420547	.27222301	.01335675	.00046131	.00036690	.00000000	.00000000
6		150.000	64.3866	.26420547	.27385889	.01735858	.00050847	.00048990	.00000000	.00000000
6		156.000	64.3866	.26420547	.27607544	.02336023	.00056867	.00058586	.00000000	.00000000
6		162.000	64.3866	.26420547	.27901652	.02987150	.00064101	.00067953	.00000000	.00000000
6		168.000	64.3866	.26420547	.28274221	.03655719	.00072804	.00079646	.00000000	.00000000
6		174.000	64.3866	.26420547	.28731549	.04353694	.00083506	.00095240	.00000000	.00000000
6		180.000	64.3866	.26420547	.29283902	.05112246	.00097023	.00116168	.00000000	.00000000
6		186.000	64.3866	.26420547	.29948160	.05973887	.00114515	.00143463	.00000000	.00000000
6		192.000	64.3866	.26420547	.30749864	.06973795	.00137544	.00177578	.00000000	.00000000
6		198.000	64.3866	.26420547	.31723922	.08133799	.00168430	.00220466	.00000000	.00000000
6		204.000	64.3866	.26420547	.32909485	.09376399	.00210201	.00267317	.00000000	.00000000
6		210.000	64.3866	.26420547	.34368623	.10880369	.00266452	.00312304	.00000000	.00000000
6		216.000	64.3866	.26420547	.36201308	.12623344	.00342551	.00351980	.00000000	.00000000
6		222.000	64.3866	.26420547	.38547963	.14555818	.00447138	.00381336	.00000000	.00000000
6		228.000	64.3866	.26420547	.41613425	.16590971	.00593955	.00392667	.00000000	.00000000
6	C	228.000	64.3866	.26420547	.41613425	.16590971	.00593955	.00392667	.00000000	.00000000

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Fig. 4