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User's Manual for the Lfabs System

Hugh T. Gibbons
University of Colorado Boulder

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by
Hugh T. Gibbons

Electromagnetics Laboratory
Department of Electrical and Computer Engineering
Campus Box 425
University of Colorado
Boulder, Colorado 80309-0425

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Chapter 1

Introduction

The LFabs system is a computer-aided design tool for low-frequency (30-200 MegaHertz) electromagnetic absorbers. In the LFabs system, the absorbers are assumed consist of one or more layers of non-magnetic conducting-foam absorber topped by a layer of pyramid absorbers, as shown in figure 1.1. The LFabs system finds the best possible such design subject to the constraints and specifications supplied by the user.

The LFabs system consists of three programs, CONES, LFmin and EPSILON. These programs divide the design process into two phases, for computational efficiency.

The program CONES computes and tabulates a list of approximate S-parameters for any specified pyramids. These parameters are stored in special files which can be read by LFmin and used to calculate approximate reflections from an absorbing structure. Each of these files is approximately 11 kilobytes in size, and two of them will be required for each design problem.

The program LFmin finds the best possible design within the constraints specified by the user, and reports the specifications for the design in a parametric form. The user enjoys considerable flexibility in selecting the design criteria.

The program EPSILON takes the parametric design specification for the backing layers and translates it to a more readable form.

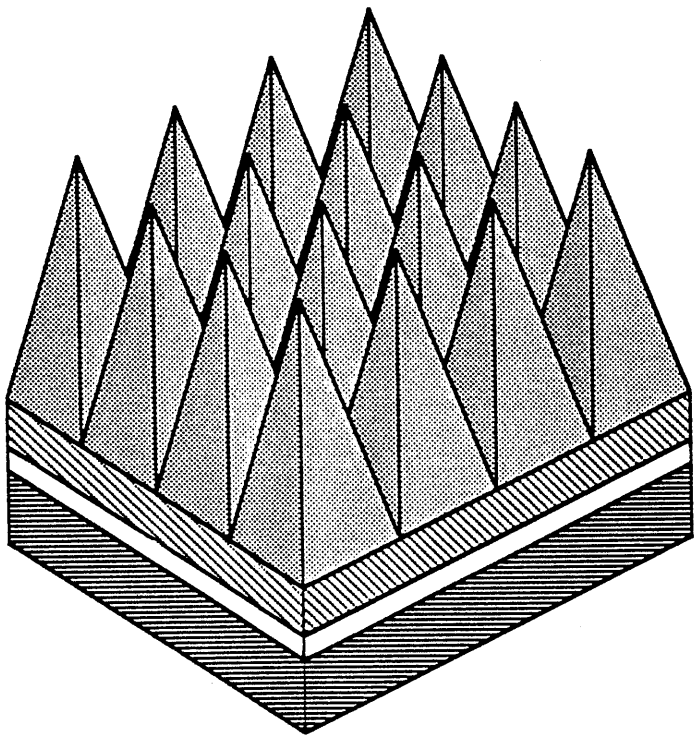

Figure 1.1: Construction of Absorbers

Chapter 2

CONES

In order to use CONES, there are several things the user should understand. In the type of absorbers envisioned by the designers of the LFabs system, the pyramids are a very important element of the design: most of the incident electromagnetic waves are absorbed in this section of the absorbers in most designs produced by LFmin. The pyramids themselves, being on top of the backing layers, provide an effective match between the (free space) effective wave impedance and the wave impedances in the backing layers; if the transition from air to absorber is too abrupt, the waves will reflect (for the most part) from the pyramids and not penetrate far enough into the lossy materials to be absorbed. This means the pyramids should consist of a material with a relative permittivity not radically different from unity in the frequency range of interest, and should be sufficiently long to provide a reasonably smooth transition. In practice, we found that the materials specified by the files C1.DAT, C3.DAT, R1.DAT-R4.DAT were reasonably good materials for pyramids. The best values for length depend on the material used and, of course, on the frequency range.

The pyramids may be assumed to be either of two types, *rectangular* pyramids, in which adjacent pyramids have bases which abut one another, or *twisted* pyramids, in which the pyramids are rotated 45 deg with respect to the array of pyramids, as shown in figure 2.1. The two different types of pyramids are supplied because they have different effective-index profiles which may render one or the other more useful for a specific purpose.

The transverse dimensions of the pyramids are considered relatively unimportant in the analysis of plane-wave propagation in these structures, and are ignored. It should be assumed by the designer, however, that these

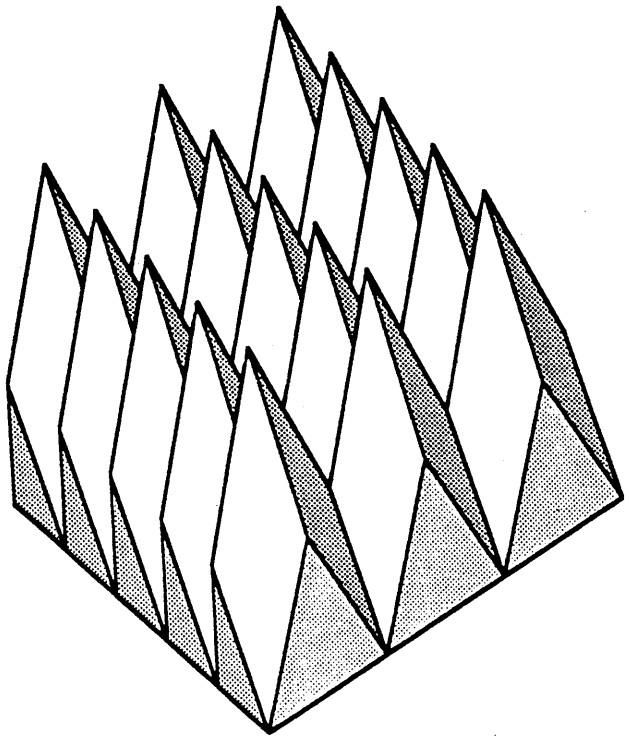

Figure 2.1: Twisted Pyramid Absorbers

dimensions are smaller than a wavelength and certainly smaller than the height of the pyramids.

2.1 Using CONES

When you run CONES, the program will prompt you for the data it needs, as described below.

The first item CONES requires is the name of the data file containing the epsilon-versus-frequency data for the material you wish to use. The format of this data should be arranged as follows: One data point is given on each line of the data file. The frequency is specified in MegaHertz, followed by the real and imaginary parts of the complex relative permittivity at that frequency. The frequency interval between consecutive points should be five MegaHertz, starting at 30 MHz and ending at 200 MHz for a total of 35 points. The permittivities may be measured values for actual materials or any theoretical values which are of interest to you. You can see how to make a e-vs.-f data file by examining any of the supplied files with the extention ".DAT".

The second item required at runtime by CONES is a name for an output file. This file will contain the results of CONES, an array of S-parameters at the various frequencies and angles of incidence in the selected polarization. Be sure to retain a record of which data you used to generate each file. If you use the name of a file already existing on your system, CONES will overwrite the old file.

Next, CONES will prompt you for the "taper length." This is the length (or height) of the pyramids in meters. CONES will also prompt you for the "backing length," which is the length of the bulk material specified by the input data file which is to be included in the pyramids you want to design. If you want to be able to consider the pyramids all by themselves, specify a backing length of zero.

The next thing you'll need to enter is the polarization. There are two polarizations, *electric* (electric field perpendicular to the plane of incidence) and *magnetic* (magnetic field perpendicular to the plane of incidence). To select the electric polarization, you need to enter an "e" or "E" in the first column, "m" or "M" for the magnetic polariztion. Characters in the second and succeeding columns of this line are ignored.

Finally, you need to select the pyramid geometry. There are two possibitities, "twisted" pyramids or "rectangular" pyramids. Enter "t" or "T"

in the first column for twisted and "r" or "R" in the first column for rectangular pyramids. Characters in the second and succeeding columns are ignored.

CONES will now go about the rather tedious task of computing the S-parameters, which involves solving the Riccati equation many times, so you will have to wait a while (maybe quite a while, depending on your system) for results. Console yourself in the meantime with the fact that it would take much longer to perform measurements of the S-parameters of a set of *physical* cones.

If your system is capable of input redirection (for example, on a unix system, MS-DOS or VMS), you can save yourself some typing by creating an input file like the one shown below. In the sample input file, lines beginning with "%" are comments.

```
***SAMPLE*INPUT*FILE****
% eps. vs. f data:
C1.DAT
% S-parameter file:
C1-2.0.m
% taper length:
2.0
% bulk length:
0.0
% polarization:
magnetic
% geometry:
twisted
************************
```

A sample input file will be provided with the CONES program.

2.2 Sample run

The following is an example of what a run of CONES looks like. In the sample run, user input is enclosed in italics.

```
***BEGIN*SAMPLE*RUN***
epsilon vs. f data file:     C1.DAT
C1.DAT
file name for S-parameters: C1-2.0.m
C1-2.0.m
taper length (m):    2.0
2.0000
bulk  length (m):    0
.0000
******* select polarization *******
   ELECTRIC or MAGNETIC      (e/m) :magnetic
m
****** select geometry type *******
SQUARE or TWISTED pyramids? (s/t) :twisted
t
****END*SAMPLE*RUN****
```

Chapter 3

LFmin

The LFmin program finds the best backing layers for a given set of pyramids whose S-parameters have been calculated in advance using CONES.

3.1 Inputs to LFmin

LFmin requires the user to specify certain parameters of the function to be minimized; this allows LFmin to be tailored to a specific design problem. For instance, in a particular anechoic chamber it may be desirable to have several types of absorber, designed to minimize reflections at certain angles, in different places on the various walls in order to get the best overall chamber performance. For this reason, it is possible to tell LFmin to sample only reflections at user-specified angles. Similaryly, the user may be very interested in the reflections at certain frequencies, so the frequency sampling points are likewise specified by the user at run time.

The objective function is an nth order norm of the vector of sampled reflections. The order n is also specified at run time. This allows the user to place an adjustable amount of weight on the dominant reflections.

The names of the files containing the S-parameters of the pyramid absorbers to be used in an optimization run are also be specified by the user, as are the names of the additional dispersion-data files for any layers composed of predefined materials, if such are desired.

Finally, it is necessary for the user to specify the initial values of the variables and their upper and lower bounds. The variables are discussed in the next section.

3.2 Variables of LFmin

Each layer of the backing is specified in terms of a number of variables; there are five variables for each layer A_1, A_2, A_3, A_4, A_5. One of these variables specifies the thickness of the layer in meters.

$$A_{1,i} = \text{thickness in meters} \tag{3.1}$$

3.2.1 Variable Permittivities:

In layers in which the user wishes to let the material properties vary, the permittivity is specified in terms of a number of variables. There are four such variables per layer. The complex relative permittivity of each layer is specified in terms of these variables as follows:

$$\epsilon'_{r,i} = A_{2,i} + 100A_{3,i}(f/30)^{A_{5,i}} \tag{3.2}$$

$$\epsilon''_{r,i} = -100A_{3,i}A_{4,i}(f/30)^{A_{5,i}} \tag{3.3}$$

These variables allow considerable flexibility in modelling the measured permittivities and conductivities of real materials.

3.2.2 Fixed Permittivties:

The user may also use fixed permittivties for each layer. In this case the user must specify a file for each such layer, from which the fixed permittivites are to be read. These files are identical to the espilon-versus-frequency data files used by the CONES program.

3.3 Using LFmin

The easiest way to use LFmin is to redirect the standard input to read from an input file. A sample input file called `LFmin.IN` is provided with the LFmin system. You can either edit `LFmin.IN` or create your own input files. In fact, LFmin was developed on a UNIX system, with input redirection in mind. If you run LFmin interactively, you'll have to enter a lot of data, so this is not recommended.

LFmin will prompt you for the data it needs. If you enter the data incorrectly, LFmin will terminate with an error.

Data are input in the following order:

[List of sampling angles for E-polarization]
[List of sampling angles for M-polarization]
[List of sampling frequencies]
[Order of norms]
[file of S-parameters for top layer in E-polarization]
[file of S-parameters for top layer in M-polarization]
[Number of backing layers]
[Scale factor]
[Lower bounds on variables for each layer (there are five!)]
[Upper bounds on variables for each layer (see above.)]
[Constraint on total length of the backing layers]
[Initial values for all variables]
[File names for epsilon-versus-frequency data for the backing layers]
(one per line for each layer; these files are used only if a fixed-material solution is requested)

3.3.1 Using Fixed Backing Materials:

To use fixed backing materials, enter a zero for the parameter A_2 for each layer (the second entry for each layer). This tells LFmin you want to use a fixed material. LFmin will look up the required values of permittivity from a file for each layer having fixed backing material, and reset the upper and lower bounds to allow no variation in the parameters used to calculate permittivity. LFmin will compute the optimal thickness for each layer of this type.

3.4 Sample Run of LFmin

```
***BEGIN*SAMPLE*RUN***

*********************************************************
*                                                       *
*       LFmin -- Version 2.0                            *
*       May 2, 1990                                     *
*                                                       *
*       Hugh Gibbons                                    *
*       Electromagnetics Laboratory                     *
*       University of Colorado                          *
*                                                       *
*       MultiLayer Backing Layer Optimizer for          *
*       Pyramid Absorbers at Low Frequencies            *
*                                                       *
*********************************************************
Enter List of Angles for E-polarization: 0,15,30,45
 .0 15.0 30.0 45.0
Enter List of Angles for M-polarization:


Enter List of Frequencies (MHz):
 30,40,60,80,100

 30.0 40.0 60.0 80.0 100.0
Order for norm? (positive integer): 2
filenames for S-parameters:
E-polarization: C1-2.0.e
M-polarization: C1-2.0.m
number of backing layers: 2
scaling factor: scale =  1.0000
lower bounds on optimization parameters:
     .000000    1.100000     .000000    1.500000     .400000
upper bounds on optimization parameters:
     .000000    2.000000     .500000    2.500000    1.500000
length constraint:   .5432
starting point for optimization:
 bl:
     .000000     .000000     .000000     .000000     .000000
     .000000    1.100000     .000000    1.500000     .400000
 bu:
     .543200     .000000     .000000     .000000     .000000
     .543200    2.000000     .500000    2.500000    1.500000
 x:
     .250000     .000000     .000000     .000000     .000000
```

```
     .250000     1.400000      .200000     1.500000      .500000
file for layer #1:
C1
file for layer #2:
C5


 Calls to E04UEF
 ---------------

      Difference Interval  = 1.0e-8
      Function Precision   = 1.0e-8
      Optimality Tolerance = 1.0e-6
      Linesearch Tolerance = 0.8e00
      Derivative Level = 2

*** E04UCF
*** NAG Library implementation ***
    HP 9000 series 300 HP-UX 6.2
    FORTRAN double precision
    (Implementation code FLH9313D)
    Mark 13B

Parameters
----------

Linear constraints.....         1       Linear feasibility.....  1.49D-08
Variables..............        10       Crash tolerance........  1.00D-02

Infinite bound size....  1.00D+10       COLD start.............
Infinite step size.....  1.00D+10       EPS (machine precision)  2.22D-16
Step limit.............  2.00D+00

Nonlinear constraints..         0       Nonlinear feasibility..  1.49D-08
Nonlinear objectiv vars        10       Optimality tolerance...  1.00D-06
Nonlinear Jacobian vars        10       Linesearch tolerance...  8.00D-01

Derivative level.......         2       Function precision.....  1.00D-08
Verify level...........         0

Major iterations limit.        50       Major print level......        10
Minor iterations limit.        50       Minor print level......         0

Difference interval....  1.00D-08       Central diffce interval  2.29D-03
```

```
Workspace provided is     IW(   400),  W(  5000).
To solve problem we need  IW(    31),  W(   411).

All objective gradient elements have been set.
Derivative level increased to    3


Verification of the objective gradients.
----------------------------------------

The objective gradients seem to be ok.

Directional derivative of the objective   -2.52843577D-03
Difference approximation                  -2.52843640D-03


  Itn ItQP      Step Nfun   Objective Bnd Lin  Nz  Norm Gf  Norm Gz  Cond
H Cond Hz  Cond T Conv
    0    3  0.0D+00    1  2.2004D-01   7   0   3  2.0D-01  2.0D-01  1.D+00
1.D+00  0.D+00 F FF
    1    3  3.9D-01    4  1.5522D-01   5   0   5  1.5D-01  1.5D-01  2.D+00
2.D+00  0.D+00 F FT
    2    1  5.4D-01    6  1.5196D-01   5   0   5  3.1D-02  3.1D-02  3.D+00
3.D+00  0.D+00 F FT
    3    1  2.1D-01    8  1.5193D-01   5   0   5  6.5D-03  6.5D-03  4.D+00
4.D+00  0.D+00 T FT
    4    1  6.0D+00   10  1.5177D-01   5   0   5  2.2D-02  2.2D-02  2.D+01
2.D+01  0.D+00 F FT
    5    2  1.0D+00   11  1.5153D-01   6   0   4  4.1D-02  4.1D-02  3.D+02
6.D+00  0.D+00 F FF
    6    1  1.0D+00   12  1.5139D-01   6   0   4  2.1D-02  2.1D-02  3.D+02
5.D+00  0.D+00 F FT
    7    1  1.0D+00   13  1.5135D-01   6   0   4  2.6D-03  2.6D-03  3.D+02
5.D+00  0.D+00 F FT
    8    2  1.0D+00   14  1.5134D-01   5   0   5  3.4D-03  3.4D-03  2.D+02
4.D+00  0.D+00 F FT
    9    1  1.0D+00   15  1.5130D-01   5   0   5  1.2D-02  1.2D-02  2.D+02
5.D+00  0.D+00 F FT
   10    1  1.0D+00   16  1.5128D-01   5   0   5  1.3D-02  1.3D-02  2.D+02
1.D+01  0.D+00 F FT
   11    1  1.0D+00   17  1.5122D-01   5   0   5  1.5D-02  1.5D-02  3.D+02
1.D+01  0.D+00 F FT
```

```
   12    1  1.0D+00   18  1.5121D-01   5   0   5  5.3D-03  5.3D-03  2.D+02
3.D+01  0.D+00 F FT
   13    1  3.9D-01   20  1.5119D-01   5   0   5  2.3D-02  2.3D-02  2.D+02
2.D+01  0.D+00 F FT
   14    1  1.0D+00   21  1.5117D-01   5   0   5  4.3D-03  4.3D-03  2.D+02
2.D+01  0.D+00 T FT
   15    1  1.0D+00   22  1.5116D-01   5   0   5  5.8D-03  5.8D-03  3.D+02
3.D+01  0.D+00 F FT
   16    1  1.0D+00   23  1.5115D-01   5   0   5  1.7D-02  1.7D-02  3.D+02
3.D+01  0.D+00 F FT
   17    1  1.0D+00   24  1.5114D-01   5   0   5  1.6D-03  1.6D-03  4.D+02
4.D+01  0.D+00 F FT
   18    1  1.0D+00   25  1.5113D-01   5   0   5  1.2D-02  1.2D-02  4.D+02
4.D+01  0.D+00 F FT
   19    1  1.0D+00   26  1.5112D-01   5   0   5  7.9D-03  7.9D-03  4.D+02
5.D+01  0.D+00 F FT
   20    1  1.0D+00   27  1.5111D-01   5   0   5  1.5D-02  1.5D-02  4.D+02
8.D+01  0.D+00 F FT
   21    1  1.0D+00   28  1.5110D-01   5   0   5  1.3D-02  1.3D-02  7.D+02
3.D+02  0.D+00 F FT
   22    1  3.6D-01   30  1.5110D-01   5   0   5  1.2D-02  1.2D-02  1.D+03
3.D+02  0.D+00 F FT
   23    1  1.0D+00   31  1.5109D-01   5   0   5  1.0D-03  1.0D-03  1.D+03
2.D+02  0.D+00 T TT

 Exit  NP phase.  INFORM =  0 MAJITS =    23   NFUN =    31   NGRAD =
31

 Varbl State      Value      Lower Bound    Upper Bound    Lagr Mult    Residual

 V  1    FR     .334441       0.000000E+00    .543200       0.0000E+00    .2088
 V  2    EQ   0.000000E+00   0.000000E+00  0.000000E+00  0.0000E+00  0.0000E+00
 V  3    EQ   0.000000E+00   0.000000E+00  0.000000E+00  0.0000E+00  0.0000E+00
 V  4    EQ   0.000000E+00   0.000000E+00  0.000000E+00  0.0000E+00  0.0000E+00
 V  5    EQ   0.000000E+00   0.000000E+00  0.000000E+00-7.8023-312  0.0000E+00
 V  6    FR   4.305736E-02   0.000000E+00    .543200       0.0000E+00  4.3057E-02
 V  7    FR    1.41297        1.10000       2.00000       0.0000E+00    .3130
 V  8    FR    .217384       0.000000E+00    .500000       0.0000E+00    .2174
 V  9    FR    1.54669        1.50000       2.50000       0.0000E+00  4.6690E-02
 V 10    LL    .400000        .400000       1.50000       4.4069E-03  0.0000E+00

 L Con State      Value      Lower Bound    Upper Bound    Lagr Mult    Residual
```

```
 L  1    FR     .377498       0.000000E+00    .543200       0.0000E+00    .1657

 Exit E04UCF - Optimal solution found.

 Final nonlinear objective value =     .1510946
 Final estimate of variables:
     .334441      .000000      .000000      .000000      .000000
     .043057     1.412965      .217384     1.546690      .400000
 Final gradient
     .000178      .000000      .000000      .000000      .000000
    -.000818      .000017     -.000427     -.000412      .004417
 ifail =  0 ; iter =  32
gamma  2 =       .15109464


****END*SAMPLE*RUN****
```

Note that the final output from LFmin is in the form of variables. On each line, LFmin prints the five variables which determine the thickness and complex permittivity used for that layer. The first layer is adjacent to the metallic wall of the chamber, with the other layers stacked on it in order. The pyramids are on top of the last layer.

3.5 Cautions on Using LFmin

3.5.1 Angle:

LFmin accepts only incident angles ranging from 0 degrees to 60 degrees in 5-degree intervals. If you attempt to use angles between these points, LFmin will round to the nearest multiple of 5 degrees. Experience has shown that for reasonable absorber designs 5 degree differences in the angle of incidence do not greatly affect the reflection coefficient. If you attempt to use angles larger than 60 degrees, LFmin will produce an error. It is not very useful to use larger angles of incidence anyway, because it is not possible to make much improvement on the reflections of waves incident at large angles (which tend to unity in magnitude, no matter what you do).

3.5.2 Frequency:

Similarly, LFmin accepts frequencies ranging from 30 MHz to 200 MHz in 5 MHz intervals. If you use frequencies between the discretization points, the

program will round to the nearest 5 MHz. Do not attempt to use LFmin outside this range, as it will produce meaningless results (by looking up the wrong element of the arrays of S-parameters).

3.5.3 The Objective Function:

The objective function to be minimized by LFmin is defined as follows:

$$F(\mathbf{x}) = S \sqrt[k]{\frac{1}{N_\theta N_f} \sum_{i=1}^{N_\theta} \sum_{j=1}^{N_f} |\Gamma(\mathbf{x}, \theta_i, f_j)|^k}$$

Where f_j and θ_i are the frequency and angle sampling points. The arbitrary scale factor, S, allows the user to scale the overall size of the objective function (which can affect LFmin's rate of convergence) and the direction of the search. By using a negative scale, the worst reflections can be found as easily as the best.

The number k is the order or power of the norm in the objective function. This number is a powerful way to control the tradeoffs made between reflections at the various sampling points. Generally, the *peak* reflections are the ones that cause the most trouble in an anechoic chamber. By choosing an order of 2 (RMS norm), the user attempts to get the lowest "overall" reflection at the expense of (maybe) an occasional high peak. Choosing a higher order k will reduce the peaks at the (possible) expense of allowing higher non-peak reflections. I would not recommend using an order higher than 20 because when the order gets too high, it approaches the *max* or infinity norm, which has discontinuities (these discontinuities disrupt the process of finding the minimum, because of the algorithm used to compute the search direction).

Chapter 4

Interpreting the Results

The LFabs system provides two programs which are useful for interpreting the results of an optimization run or evaluating the reflections from a particular design. These programs are EPSILON and REFLECT, which print the permittivity and reflection as functions of frequency.

4.1 Using EPSILON

For practical purposes, we want to know the permittivities of the layers, not the parameters used in some program. For this reason, we also provide a program to translate the parameters into complex permittivities and print the results. This program is called EPSILON.

When you run EPSILON, it will prompt you for the parameters of a layer. Simply enter a the line of the output from LFmin representing the layer for which you want to know the complex permittivity. Enter all five numbers, including the first, which represents the thickness in meters. Epsilon will report the thickness of the layer in meters and in inches, the real and imaginary parts of the permittivity, and the conductivity (in $\mho/m$) as functions of frequency.

4.2 Using REFLECT

To evaluate how "good" a design is, it is useful to know the predicted reflection coeffiecients at various frequencies and angles of incidence. The program REFLECT prints out a list of reflections from a structure specified as in LFMIN. The magnitude and phase (in degrees) of the reflection coeffi-

cients are reported for each selected angle of incidence (at frequencies from 30 MHz to 200 MHz). The user is prompted for relevant data to calculate reflections and specifies the angles of incidence to be used for the printout.

The following is a sample run of REFLECT showing inputs and outputs.

```
****BEGIN*SAMPLE*RUN****
 Enter List of Angles for E-polarization: 30
 30.0
 Enter List of Angles for M-polarization:  0,10
 .0 10.0
 cone-data for e: C1-2.0.e
 cone-data for m: C1-2.0.m
 Enter number of backing layers: 2
  Enter backing parameters
   .500000  1.400000   .050000  1.600000   .800000
   .200000   .000000  1.000000  1.000000  1.000000
 file for layer #2:
C3

  ====================================
  Angle =  30.0  E-polarized
  ====================================
  Freq.       Mag.    Phase
  ====================================
 30.0      .1999    83.
 35.0      .2130    87.
 40.0      .2255    80.
 45.0      .2208    69.
 50.0      .2052    57.
 55.0      .1817    46.
 60.0      .1558    37.
 65.0      .1334    32.
 70.0      .1186    29.
 75.0      .1119    26.
 80.0      .1111    22.
 85.0      .1115    14.
 90.0      .1104     2.
 95.0      .1059   -11.
100.0      .0982   -26.
```

105.0	.0874	-42.
110.0	.0738	-58.
115.0	.0593	-77.
120.0	.0447	-98.
125.0	.0312	-124.
130.0	.0201	-158.
135.0	.0143	149.
140.0	.0148	94.
145.0	.0183	57.
150.0	.0218	30.
155.0	.0231	7.
160.0	.0229	-12.
165.0	.0211	-33.
170.0	.0178	-54.
175.0	.0141	-75.
180.0	.0101	-100.
185.0	.0064	-133.
190.0	.0046	-180.
195.0	.0052	125.
200.0	.0072	91.

Angle = .0 M-polarized

Freq.	Mag.	Phase
30.0	.1668	92.
35.0	.2096	86.
40.0	.2270	71.
45.0	.2203	53.
50.0	.1991	35.
55.0	.1676	18.
60.0	.1323	4.
65.0	.0998	-6.
70.0	.0759	-9.
75.0	.0645	-7.
80.0	.0636	-8.
85.0	.0657	-15.
90.0	.0662	-28.

95.0	.0630	-46.
100.0	.0565	-66.
105.0	.0480	-90.
110.0	.0375	-115.
115.0	.0281	-148.
120.0	.0212	171.
125.0	.0184	124.
130.0	.0186	79.
135.0	.0198	42.
140.0	.0197	10.
145.0	.0184	-20.
150.0	.0162	-51.
155.0	.0128	-85.
160.0	.0102	-124.
165.0	.0091	-175.
170.0	.0099	134.
175.0	.0121	96.
180.0	.0143	66.
185.0	.0156	40.
190.0	.0154	19.
195.0	.0149	-2.
200.0	.0134	-20.

Angle = 10.0 M-polarized

Freq.	Mag.	Phase
30.0	.1606	92.
35.0	.2027	86.
40.0	.2207	71.
45.0	.2153	54.
50.0	.1954	36.
55.0	.1657	19.
60.0	.1318	4.
65.0	.1000	-6.
70.0	.0758	-10.
75.0	.0633	-9.
80.0	.0613	-8.
85.0	.0632	-15.

```
 90.0      .0640   -27.
 95.0      .0616   -44.
100.0      .0561   -64.
105.0      .0483   -86.
110.0      .0384  -111.
115.0      .0293  -141.
120.0      .0222  -179.
125.0      .0183   136.
130.0      .0175    91.
135.0      .0184    51.
140.0      .0184    19.
145.0      .0174   -11.
150.0      .0157   -42.
155.0      .0128   -75.
160.0      .0102  -113.
165.0      .0086  -161.
170.0      .0090   147.
175.0      .0110   107.
180.0      .0130    76.
185.0      .0145    49.
190.0      .0149    28.
195.0      .0145     7.
200.0      .0135   -12.
*****END*SAMPLE*RUN*****
```