ACE Deliverable *2.3D03*

Catalogue of Software for Reflector Surface Modelling

Project Number: FP6-IST 508009

Project Title: Antenna Centre of Excellence

Document Type: Deliverable

Document Number: WP2.3-2-02

Contractual date of delivery: 1 July 2004

Actual Date of Delivery: 31 December 2004

Workpackage: 2.3-2

Estimated Person Months: 2

Security (PP,PE,RE,CO): PP

Nature: Report

Version: 1

Total Number of Pages: 46

File name: ACE_2.3_D3_Reflector_Surface_Modelling_Software.doc

Editors: Knud Pontoppidan

Participants: TNO FEL, Chalmers University of Technology, University of Siena, Politecnico di Torino, Lund University, TICRA Engineering Consultants

Abstract

The present document is a collection of software tool descriptions for the analysis and prediction of surface reflection and transmission characteristics. The catalogue is organised in four chapters according to the surface type. Chapter 2 contains general purpose packages. Chapters 3 and 4 contain packages for non-resonant and resonant surface types, respectively. Chapter 5 contains software dedicated to special surface types..

Keyword List

FSS, Strip Grids, Wire Grids, EBG, PMC

Catalogue of Software
for Reflector Surface Modelling

Antenna Centre of Excellence

WP2.3-2 Reflector Surface Models

July, 2004 WP2.3-2-02

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This work was sponsored by the Commission of the European Communities under the 6th Framework Program, Contract no. 508009.

TABLE OF CONTENTS

1. INTRODUCTION

This document describes a number of software packages applicable to reflector antenna surfaces and radomes. Most of the packages have been developed in-house by the partners of the ACE WP2.3-2.

The description of each package follows a fixed template:

- Abstract: General and brief description on the software.
- Developing entity: Gives the coordinates of the university/institute/company where the software has been or is being developed.
- Developers: Lists the past and current developers of the software.
- Definition of the physical structure that can be analysed:
    - Software Input: Describes input files. Gives a physical level description of what data the software needs as input (rather than a detailed line by line description). If possible, the description is organised according to the input files.
    - Software Output: Describes output files. Gives a physical level description of what data/results the software produces (rather than a detailed line by line description). If possible, the description is organised according to the output files.
- User Manual: Is there is a User Manual available? Is it public domain? Where can it be found?
- Website: If applicable, gives the website where information about the software can be found.
- Operating system and programming languages: Lists the operating systems on which the software is running. Is the software in source code or is it an exe-code? If source code, gives the programming language(s) in which the software is written.
- Owner - IPR: Lists the holder of the Intellectual Property Rights.
- Availability Information on how the software can be used by others: Is it

  - only for internal use.
  - available internally for consultancy and R&D projects for external customer, but customer will not gain access to software.
  - open for partners in projects.
  - open for ACE partners.
  - open to the public.
  - commercial code, with details on terms, prices, availability of a student version.
  - freeware.
  - other terms.
- Main references: Lists main references where information about the software can be found.

The catalogue is organised in four chapters according to the surface type. Chapter 2 contains general purpose packages where several surface types are included in the same package. Chapters 3 and 4 contain packages for non-resonant and resonant surface types, respectively. Chapter 5 contains software dedicated to special surface types.

2. GENERAL PURPOSE SOFTWARE

2.1 GRASP9 (TICRA)

Abstract: The GRASP9 software is a highly advanced and versatile tool for analysing general reflector antennas and antenna farms. The package is a general tool to handle single, dual and multi-reflector configurations (beam waveguides). GRASP9 can calculate the electromagnetic radiation from systems consisting of multiple scatterers with several feeds and feed arrays.
GPAD (General Pre-processor for Antenna Design), which integrates a graphics users interface with GRASP9, provides a means for setting up and visualising the antenna system including its location on a spacecraft. A post-processor contains plotting facilities for calculated patterns.
The program is able to calculate the electromagnetic scattering from general structures composed of curved reflectors and plane triangles, rectangles, parallelograms and struts. Due to the special object structure in which the geometrical data is arranged any number of reflectors and other structures can be analysed.
The scattered field can be calculated by Physical Optics (PO) combined with the Physical Theory of Diffraction (PTD) or Geometrical Optics (GO) combined with the Geometrical Theory of Diffraction (GTD).

Further reading about GRASP9 software can be found in the references listed below. Here we shall primarily summarize the models for reflector surfaces as described in Chapter 5 of the “Catalogue of Models, Methods and Software for Reflector Surface Modelling”. The scatterers are assumed by default to be perfectly conducting, but special surface materials may be defined including a conducting surface with finite conductivity, a dielectric layer, a strip grid and a material defined by tabulated reflection and transmission coefficients. These materials may be combined in a layered structure and attached to the surfaces of a scatterer.

Developing entity: TICRA Consultant Engineers, Læderstræde 34, 1201 Copenhagen K, Denmark.

Developers: N.C.Albertsen, PhD, K. Pontoppidan, PhD, Frank Jensen PhD, P. Balling, PhD, P.H.Nielsen, PhD, R.Jørgensen, MscEE, S.B.Sørensen, PhD, P.E.Frandsen, MscEng, H.H.Viskum, PhD, M.Lumholt, PhD, T.Bondo, MScPhys, E.Jørgensen, PhD.

Definition of the physical structure that can be analysed: The surface material classes available in GRASP9 are:

Model type	**Class**
Ideal grid	ideal_grid
Strip grid	strip_grid
Wire grid	wire_grid
Dielectric Layer	dielectric_layer
Mesh	mesh
Perfect Conductivity	perfect_conductivity
Perfect Absorption	perfect_absorption
Power Splitting	power_splitting
Finite Conductivity	finite_conductivity
Tabulated	tabulated_el_prop

As mentioned above the materials may be combined in a layered structure.

Software Input:

In the present context the important input data are:

1. Input object constructors that yield one of the above types of surfaces materials/characteristics. This type of constructor appears in a GRASP9 .tor-file (TICRA object repository).

2. Tabulated electrical properties in a file. This feature is available if a user wants to utilize transmission and reflection characteristics of a surface material that have been obtained with another program or from measurements.

Input object constructors

As an example of an object constructor consider the following wire grid:

```
My_wire_grid  wire_grid
(
  displacement      :  0.1000000000     m,
  ref_coor_sys      :  ref(Reflector_coor_sys),
  ref_angle         :  45.00000000    ,
  spacing           :  0.1000000000     m,
  diameter          :  0.4000000000E-02 m,
)
```

The object name is My_wire_grid and the class name is wire_grid. Exact description of the classes listed in the table above and their attributes can be found in Grasp9 Reference Manual (can be downloaded from www.ticra.com). When an object of one of the classes in the table above is input, the object can be referenced from a scatterer (e.g. a reflector), which will then get a surface with the corresponding electrical properties.

Tabulated electrical properties in a file

The transmission and reflection characteristics of a surface material are given for plane-wave incidence on an infinite plane composed of this material. The electrical properties of a scatterer surface can be specified by tabulated reflection and transmission coefficients . Tabulated data are given as a function of the spherical coordinates theta and phi in a coordinate system with the z-axis in direction of the material surface normal.

Since electrical material properties are for a plane structure it is necessary to define a procedure for applying these to a curved surface. To this end, a coordinate system XC, YC, ZC is defined relative to the coordinate system in which the reflector is defined. An angle ALPHA (in degrees) is also defined.

A vector is formed by rotating XC an angle ALPHA in the XC-YC-plane. With ZC as the projection direction, this vector is projected onto the tangent plane of the curved reflector surface. The projected vector defines the x-axis of the coordinate system in which the tabulated data are given, and the surface normal is the z-axis.

Software Output:

GRASP9 can save any objects, which the user has created during the session in a .tor-file and this may of course also be done with object of one of the electrical properties classes. This file may then be input to the program either in another interactive session or in a batch run. The format will be that of the .tor-file as shown under software input.

The objects in .tor-files are, however, in general rarely of use to other programs. GRASP9 can, however, transform the parametric surface descriptions into actual reflection and transmission coefficients and save these values in a *Tabulated electrical properties file*. For this purpose GRASP9 has a class named *El Prop. Data Output* class, which the user can instantiate. An object of this class is referenced by an object of the class *Reflector Data Output* and is used to produce a file containing the reflection and transmission coefficients for a particular surface. The coefficients are written as functions of the incidence angles theta and phi, theta being the polar angle and phi the azimuthal angle, with respect to the surface normal, in the same format as if tabulated reflection and transmission coefficients were used to characterize a surface

User Manual: GRASP9 is described in a number of user manuals and reports. These can be found on www.ticra.com. The manuals and reports are public domain and are downloaded with the Student Edition. The manuals and reports are: "Grasp9 Technical Description", "GRASP9 batch operation", "GRASP9 Reference Manual", "GRASP9 – The Frame Design Tool" and miscellaneous tutorials.

Website: www.ticra.com.

Operating system and programming languages: GRASP9 is currently running on IBM compatible PC's and Macintosh PC's. Further, the program is running on workstations from SUN, HP and IBM plus Linux Workstations, SUN Workstations. The program is written in FORTRAN90. Public domain routines from mathematical libraries are included in the program often in modified form. No external libraries are thus needed.
GPAD, is developed using the GUI-builder XVT. The programming language is C. GPAD is running on IBM compatible PC's and Linux workstations.

Owner - IPR: TICRA is the owner of the IPR for GRASP9.

Availability Information on how the software can be used by others: The software is commercial. Please contact TICRA for further information. A free copy of the student version GRASP9-SE will be available ultimo 2004 and may then be downloaded from TICRA's homepage.

Main references: "Grasp9 Technical Description" – can be downloaded from homepage (see above).

2.2 MEN_MFSS (TNO)

Multi-mode Equivalent Network approach for Multi-layer Frequency Selective Surfaces

Abstract: The software is based on the Multimode Equivalent Network (MEN) Approach described in detail in Chapters 3 and 5 of the "Catalogue of Models, Methods and Software for Reflector Surface Modelling". The flexibility and modularity of this approach allows the analysis of several types of Frequency Selective Surfaces (FSS). These can range from single layer to multilayer FSS, based both on metallic screens (also thick

screens) and printed elements of arbitrary shape. The surfaces can be modelled as standing alone structures as well as directly integrated with array antennas. The overall structure can be planar or conformal to circular cylinders.

<u>Developing entity</u>: The software has been developed by the Antenna Group of the Integrated Front-end Solutions Department within the Physics and Electronics Laboratory of TNO (TNO-FEL) located in The Hague, The Netherlands. TNO is the Netherlands Institute for Applied Scientific Research.

<u>Developers</u>: Dr. G. Gerini, Ms. S. Monni, Dr. A. Neto

<u>Definition of the physical structure that can be analysed</u>: See abstract.

<u>Software Input</u>: The input is passed to the software via an ASCII file alternating lines of comments, describing the input fields, and the actual input lines. The input fields can be basically of two types: problem related and modelling related. The first ones are used to define the problem in terms of geometry, materials, frequency and angle. The second ones are used to define some parameters that are necessary from the modelling point of view (for example, accuracy, number of accessible modes, number of basis functions for the Method of Moment etc.). This second type of input parameters is necessarily less intuitive for the user and requires some understanding of the modelling approach. Although these parameters could be made transparent to the user and automatically tuned by the program, nevertheless, since the software is used only internally by expert users, it has been decided to avoid any automatic tuning. This, in fact, would have increased the software complexity and the computational burden. Nevertheless, it is evident that this upgrade would not require a considerable effort. Hereafter, follows a list of the input parameters

- Frequency range and number of frequency steps
- Elevation angle range and number of angular steps
- Azimuthal angle range and number of angular steps
- Flag for planar or circular cylindrical surfaces
- Geometry of the multilayer structure (periodic cell dimensions, thickness and permittivity of the dielectric sub/super-strates). If the FSS is integrated with an array of open ended waveguides, also the array geometry must be specified [type of waveguide (rectangular or circular), waveguide dimensions, array cell dimensions, slant angle (for triangular array lattices)]
- Geometry of the FSS elements

- o Polarization of the exciting field
- o Number of accessible modes (see Chapter 3)
- o Number of MoM expanding functions (see Chapter 3)
- o Number of modes to be summed in the kernel of the integral equation.

Software Output: The software can produce two main types of output. The output is always in the form of ASCII files.

- o Reflection and transmission coefficients (module and phase) as function of the frequency and/or angles (elevation and azimuth) of incidence.
- o Multimode admittance/impedance matrices - if required by the user. These are the matrices used to describe the different blocks composing the overall structure. These matrixes can be stored and reused in successive runs of the code, if the corresponding physical block has not been changed.

User Manual: The software user manual is available within TNO, but only for internal use.

Website: At the moment, no information is available on the TNO Website.

Operating system and programming languages: The software runs under Microsoft Windows 98 (or higher). The source code has been written in Fortran 90.

Owner - IPR: TNO.

Availability Information on how the software can be used by others:

- o The software is available internally for consultancy and R&D projects for external customers, but the customer will not gain access to the software.
- o The software is also “indirectly” available for partners in projects, in the sense that TNO could use the software for a joint design with other partners for an external customer. The partner will not gain access to the software.
- o The software is open, compatibly with internal needs (manpower and resources available) for ACE partners for comparisons and validation purposes. The partner will not gain access to the software.

Main references:

[1] S. Monni, G. Gerini, A. Neto, "Equivalent Network Analysis of Phased Arrays Integrated with Patch Based FSS Structures", *2002 IEEE International Antennas and Propagation Symposium*, June 2002, San Antonio, Texas.

[2] G. Gerini, S. Monni, L. Zappelli, "Optimal Choice of the EM expansion for arbitrary shaped aperture/patch FSS's in planar phased arrays", *IEEE International Symposium on Phased Array Systems and Technology 2003*, October 2003, Boston, Massachusetts.

[3] S. Monni, A. Neto, G. Gerini, "A Fast Design Methodology for Steep Roll-Off Frequency Selective Structures", *Proceedings of the 27-th ESA/ESTEC Workshop on Innovative Periodic Antennas*, Santiago de Compostela, Spain, March 2004.

[4] S. Monni, G. Gerini, "A Novel Technique for the Design of Frequency Selective Structures Integrated with a Waveguide Array", 2004 IEEE Antennas and Propagation Symposium, July 20

2.3 G1DMULT package (Chalmers)

Program for analysing planar and curved periodic structures

Abstract: The G1DMULT program package contains several computer programs for analysing radiation or scattering from arrays of metal strips or patches placed on or embedded in a planar, circular-cylindrical or spherical multilayer structure. Common for all programs is that the Green's function of the multilayer structure is provided by the G1DMULT algorithm. This means that the multilayer structure can consist of any number of substrate layers with any permeability or permittivity, in addition to ideal PEC and PMC surface layer, PEC/PMC strip grid layers representing ideal soft and hard surfaces, layers with asymptotic metal strip grids and layer with corrugations. The actual arrays of metal strips or patches, which are not homogenized and included in the Green's function, are placed periodically along the surface (in the spherical case the patches can also follow an icosahedron grid), and the patches have rectangular shape. The program solves the integral equation for the electric field by using the moment method. The elements of the moment method matrix are calculated in the spectral domain. Arrays of patches or strips as well as complete mushroom surfaces can also be analysed in an approximate way by using homogenized asymptotic boundary conditions. The numerical evaluation of elements used in moment method is made with special care. In the cylindrical case, the numerical treatment of the Bessel and Hankel functions was carefully made in order to

ensure reliable and fast evaluation of the elements needed for the moment method procedure. In the spherical case, the modified vector-Legendre transformation and normalized associate Legendre functions were implemented in order to obtain a numerically stable analysis method.

Developing entity: The program has been developed as a collaboration between Chalmers University of Technology, Sweden, and University of Zagreb, Croatia.

Developers: Zvonimir Sipus and Per-Simon Kildal.

Definition of the physical structure that can be analysed: The program analysis radiation or scattering properties of

- arrays of strips
- arrays of rectangular patches.

The strips and patches can be placed on or embedded in a planar, circular-cylindrical or spherical structure. The following types of surfaces can be included in the multilayer structure:

- ideal PEC and PMC surface layer
- PEC/PMC strip grid layer
- corrugated surface
- mushroom structure.

Software Input: Communication with the G1DMULT program is made via input/output ASCII files. In other words, the input file should be filled before running the program, and the results are written into the output files that can be graphically presented by any graphical program. The input variables are:

- the frequency points for which the structure is analysed,
- the parameters describing the multilayer structure: thickness, relative permittivity and relative permeability of each dielectric layer,

- the presence of specific surface: PEC plane (PEC tube and PEC shell in cylindrical and spherical case, respectively), PMC plane, PEC/PMC strip grid surface, corrugated surface or mushroom structure,
- the width of the patches or strips, the distances between patch/strip centres, and the way how the patch/strip array is analysed: rigorously or in an approximate way using homogenized asymptotic boundary conditions,
- the description of the source.

Software Output: The results of the G1DMULT are written into the output ASCII files that can be graphically presented by any graphical program. There are several output files containing

- complex amplitude of a reflected wave (e.g. reflection from a planar structure as a function of frequency),
- the radiation pattern (e.g. scattering from a cylinder or a sphere),
- S-parameters (e.g. self and mutual coupling of patches or dipoles placed over or embedded in a structure that has frequency selective properties).

User Manual: User Manual is not available.

Website: Website not available, please contact Per-Simon Kildal for further information (www.elmagn.chalmers.se/elmagn/antenna).

Operating system and programming languages: The program can run on any platform that has FORTRAN 90 compiler. The executable version of the program can run on PC platform.

Owner - IPR: The holders of the Intellectual Property Rights of the software are Per-Simon Kildal and Zvonimir Sipus.

Availability Information on how the software can be used by others: The program can be made available on request under certain conditions, which depends on the type of use. A license agreement must under all circumstances be signed.

Main References:

[1] Z. Sipus, P.-S. Kildal, R. Leijon, and M. Johansson, ”An algorithm for calculating Green’s functions for planar, circular cylindrical and spherical multilayer substrates,” *Applied Computational Electromagnetics Society Journal,* Vol. 13, No. 3., pp. 243-254, Nov. 1998.

[2] P.-S. Kildal, A. Kishk, and Z.Sipus, “Asymptotic boundary conditions for strip-loaded and corrugated surfaces,” *Microwave and Optical Technology Letters*, Vol. 14, pp. 99-101, Feb. 1997.

[3] Z. Sipus, S. Raffaelli, P.-S. Kildal, "Periodic strips on planar and circular cylindrical substrates: Exact and asymptotic analysis,” *Microwave and Optical Technology Letters*, Vol. 17, No. 3, pp. 173-178, Feb. 1998.

[4] Z. Sipus, R. Zentner, J. Bartolic, "Validity of approximate boundary conditions for periodic strips on cylindrical substrates,” *Proceedings of International Conference on Mathematical Methods in Electromagnetic Theory*, Kharkov, Ukraine, 1998, pp. 171-173.

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[6] Z. Sipus, N. Burum, J. Bartolic, "Analysis of rectangular microstrip patch antennas on spherical structures,” *Microwave and Optical Technology Letters,* Vol. 36, pp. 276-280, Feb. 2003.

[7] Z. Sipus, P.-S. Kildal, “Full wave analysis of mutual coupling between dipoles over different EBG surfaces: AMC, soft and hard surfaces,” *Proceedings of IEEE/URSI International Symposium on Antennas and Propagation*, Monterey, USA, 2004.

[8] A. Kishk, P.-S. Kildal, A. Monorchio and G. Manara, “Asymptotic boundary condition for corrugated surfaces, and its application to scattering from circular cylinders with dielectric filled corrugations,” *IEE Proceedings – Microwaves, Antennas and Propagation*, vol. 145, pp. 116-122, 1998.

3. SOFTWARE FOR NON-RESONANT SURFACES

3.1 MESTIS (POLITO)

Abstract: MESTIS is a software package for the analysis of a periodic arrangement of printed metallic strips. This arrangement consists of arrays of metal strips and any geometry obtained by a collection of slender strips defined by the user. The arrays can be stacked and supported by stratified dielectric media. The strips can be arranged in any skewed lattice (particular cases are square, rectangular and triangular lattices). The dielectric supports are stratified and can be losses and uniaxial anisotropic. The software is able to analyses a multiple array configuration illuminated by plane waves with a generic incidence. The structure is analyzed in the principal polarization base and its scattering properties are described in terms of Generalized Scattering Matrix. The results reported in this document act as examples to illustrate the capability of the computer codes. The software is written in standard Fortran 77 language, and it is provided with two auxiliary packages, which can be used under the matlab platform. The former, named StripView, can be used to verify the geometry of the input data. The latter, named StripResponse, can be used as a tool to view graphically the results furnished by the fortran software package.

Developing entity: IEIIT-CNR and POLITO

Owner - IPR: IEIIT-CNR

Developers: Tascone, Orta, Trinchero

Where is the software?: At IEIIT-CNR and POLITO, at TICRA

Surface type models: Strip grids containing up to three different orientations simultaneously.

Analysis model: The grids are analysed by means of the moment method, applied in the spectral domain. Unknown currents are computed simultaneously on the strips by inverting the linear system that describes the full scattering problem. In case more than one grid is present, the scattering problem is solved by means of the coupled modes formulation.

Definition of the physical structure that can be analysed: MESTIS program analyses structures consisting of a cascade of passive planar arrays supported by stratified dielectric media. All the arrays are parallel to the xy-plane and the stratification occurs along the z-axis. The geometry of the patches is any composition of slender finite-conducting strips of finite thickness. The computer code MESTIS has five predefined geometries: Single strips, Two parallel strips, Two non-parallel strips, Three non-parallel strips, Two parallel plus one non-parallel strips. The strips of different arrays cannot have different geometry. The interaction among the arrays is computed in full-wave sense. Hence, the lattice geometry of the various arrays must be the same. However, the arrays can be transversally shifted.

The dielectric support is divided in packs which are bounded by the arrays and the free-space in the case of the first and the last packs. Each pack can be formed by more than one dielectric layer with uniaxial anisotropy and with losses. The protective resin where the array is embedded is taken into account separately.

Status: Completely released, tested with comparisons against measurements and in used.

User manual: MESTIS is described in a user manual written by the authors [1].

Software input: MESTIS reads the input data from file or by keyboard. Each read instruction is preceded by a message which specifies the kind of data. The description of the input data follows the flow of the requests.

Software output: The data printed in the output File are the complex values (real, imag) of the 4x4 scattering matrix corresponding to the TE00 and TM00 Floquet modes.

At the beginning of the output file there are five rows containing the following information:

- Identification of the File (18 Characters)
- Title
- Reference values: Frequency (GHz), Theta (deg) and Phi (deg)
- Loop type (Frequency, Theta, Theta-Phi Loop)
- Loop data (initial value, final value, number of iterations)

The real and imaginary parts of the elements of the 4x4 scattering matrix corresponding to the (0,0) order the Flouquet modes follows.

The 4x4 scattering matrix is divided in four 2x2 submatrices S11, S21, S12, S22 . Each of them has the following arrangement:

TE/TE	TE/TM
TM/TE	TM/TM

and describes:

- S11 the reflection on the left hand side.
- S21 the transmission from left to right side.
- S12 the transmission from right to left side.
- S22 the reflection on the right side.

Following this order, on each row of the file, the submatrices are printed in column order (real, imag). In this way, each row contains 8 REAL numbers

In the case of Frequency or Theta loop, if N is the number of points, the number of rows is 4xN.

In the case of Theta-Phi loop, if Ntheta is the number of Theta points and Nphi those of Phi points (planes of incidence), the number of rows is 4xNthetaxNphi, and the Phi-loop is external.

Graphical interface: The output of the Fortran programs MESTIS can be plot by means a MATLAB program call StripResponse. This program read the output file, recognises the kind of loop, display the data through a graphical interface where the user can be made his choice, and organise the data in the MATLAB workspace into the array Freq, Theta, Phi and S. These arrays are available to the user for further processing.

Website: No information is available for the software on the WEB

Availability Information on how the software can be used by others: The software is not available for general public. MESTIS has been developed in the framework of a cooperation between POLITO, CNR-IEIIT and TICRA.

Main references:

[1] R. Orta, R. Tascone, D. Trinchero, “MESTIS user manual”, Politecnico di Torino, 2002

[2] R.Orta, R. Tascone , R. Zich, ``Scattering from finite extent frequency selective surfaces illuminated by arbitrary sources'', Electronics Letters, Vol.21, No.3 January 1985, pp.100-101.

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[4] S. Contu, R. Tascone , ``Scattering from passive arrays in plane stratified regions'', Electromagnetics, Vol. 5, No. 4, 1985, pp.285-306.

[5] R. Orta, R. Tascone , R. Zich, ``A unified formulation for the analysis of general frequency selective surfaces'', Electromagnetics, Vol. 5, No. 4, 1985, pp.307-329.

[6] R. Orta, R. Tascone , R. Zich, ``Efficient choice of basis functions in moment method analysis of frequency-selective surfaces'', Electronics Letters, Vol.23 No.11, May 1987, pp.586-587.

[7] R. Orta, R. Tascone , R. Zich, ``Three-dimensional periodic arrays of thin conductors'' Electromagnetics, Vol. 7, No. 2, 1987, pp.185-203.

[8] R. Orta, R. Tascone , R. Zich, ``Multiple-grid frequency-selective surfaces as periodically loaded structures'', Electronics Letters, Vol.24 No.8, Apr. 1988, pp.449-450.

[9] R. Orta, R. Tascone , R. Zich; ``Multiple dielectric loaded perforated screens as frequency selective surfaces'', IEE Proc. Vol. 135, Pt. H No. 2, Apr.1988, pp.75-82.

[10] R. Orta, P. Savi, R. Tascone , ``The effect of finite conductivity on frequency selective surface behaviour'', Electromagnetics , Vol. 10, 1990, pp.213-227.

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[16] R.Orta, P.Savi, R.Tascone, ``Numerical Green's function technique for the analysis of screens perforated by multiply connected apertures'', IEEE Trans. Antennas Propagat. , Vol. AP-44, pp. 765-776, Giugno 1996. bibitem BookFSS R. Orta, R. Tascone , Part II of the book J. C. Vardaxoglou, `` Frequency Selective Surfaces: Analysis and Design'', Research Study Press, John Wiley, 1997

[17] R. Orta, R. Tascone, R. Zich, ``Frequency selective surfaces: spectral characterization and application to multifrequency antenna systems", (invited paper), JINA 1986 - Journees Internationales de Nice sur les Antennes , Nice, November 1984, pp.168-179.

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ence on Electromagnetics in Advanced Applications, ICEAA97 , Torino, Settembre 1997, pp. 73-76.

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4. SOFTWARE FOR RESONANT SURFACES

4.1 Oresme FSS Code (LUND)

Abstract: The Oresme FSS Code computes the scattering properties of infinite, plane, multilayered dielectric structures with one or several (infinite thin) FSS's. It has been successfully verified against the Periodic Method of Moment (PMM) Code of Ohio State University. The Oresme FSS Code is based on the method of moments and the so-called V-dipole basis functions, especially developed for the Oresme FSS Code. The V-dipole basis functions are efficient entire domain basis functions that can be adapted to any FSS element consisting of straight sections and bends, like, for instance, the tripole, the four-legged loaded element, and the hexagonal loop. Notice that the element can be of either slot or wire type.

Developing entity: The method of analysis has been developed by collaboration between Chelton Applied Composites AB and Lund University. The code has been written and verified by Chelton Applied Composites AB.

Developers: Sören Poulsen, Chelton Applied Composites AB, Gerhard Kristensson, Lund University, Sten Rikte, Lund University (now with Kockums AB).

Definition of the physical structure that can be analysed: See the abstract.

Software Input: This code has a Microsoft Windows interface where the user defines the FSS geometry (except for the FSS element type, see comments below), the angles of incidence and the thickness and dielectric constant of the dielectrics. Moreover, the user is supposed to select a frequency band (given by start, stop and step frequency) over which the calculations are to be performed. All this input is directly given by the user in a Microsoft Windows Dialog. The FSS element type, however, is defined by insertion points and rotation angles of the straight sections and the bends that form the FSS element, see Ref. [2] for details. This element type input data is given by the user in the Fortran code. Notice that the user is able to change parameters, like the width or size of the FSS element, in the Windows interface.

Software Output: Calculated reflection and transmission coefficients for parallel and orthogonal polarisation are shown in a chart of the Windows dialog. The user selects whether the reflection or transmission coefficients are shown in the chart. The reflection and transmission coefficients are also stored in text files for co- and cross-polarisation.

User Manual: User Manual not available.

Website: Web site not available, please contact Chelton Applied Composites AB for further information, www.acab.se.

Operating system and programming languages: The Oresme FSS Code is running under Microsoft Windows. The code is implemented in Compaq Visual FORTRAN 6.6 and is available as source code as well as an executable file.

Owner – IPR: Chelton Applied Composites AB.

Availability Information on how the software can be used by others:
The Oresme FSS Code is available internally for consultancy and R&D projects for external customer, but customer will not gain access to software.
Main references:

[1] S. Poulsen, Scattering of electromagnetic waves from frequency selective structures, ISSN 1402-8662, Electroscience, Lund University, Sweden, 2000.

[2] S. Poulsen, Scattering from frequency selective surfaces: An efficient set of V-dipole basis function, IEEE Trans. Antennas and Propagat., Vol. 51, No. 3, March 2003.

4.2 APP 2.1 (LUND)

Abstract: The APP 2.1 Code computes the scattering properties of infinite, plane artificial puck plate (APP) structures with circular pucks. The code is based on the method of moments and a full-wave solution is obtained by solving for the unknown (magnetic) current of the apertures of the puck. The pucks, that are located in waveguide sections, consist of one or several dielectric materials stratified along the waveguide. An FSS element is etched on both end sides of the puck. An arbitrary number of dielectric layers can be added on either side of the puck structure.

Developing entity: The code has been developed, written and verified by Chelton Applied Composites AB. Lund University has supported Chelton Applied Composites AB during the development.

Developers: Sören Poulsen, Chelton Applied Composites AB, in collaboration with Anders Karlsson, Lund University.

Definition of the physical structure that can be analysed: See the abstract.

Software Input: This code has a Microsoft Windows interface where the user defines the APP geometry, the angles of incidence and the thickness and dielectric constant of the dielectrics. Moreover, the user is supposed to select a frequency band (given by start, stop and step frequency) over which the calculations are to be performed. All this input is directly given by the user in a Microsoft Windows Dialog.

Software Output: Calculated reflection and transmission coefficients for parallel and orthogonal polarisation are shown in a chart of the Windows dialog. The user selects whether the reflection or transmission coefficients are shown in the chart. The reflection and transmission coefficients are also stored in text files for co- and cross-polarisation.

User Manual: Microsoft Windows interface.

Website: Web site not available, please contact Chelton Applied Composites AB for further information, www.acab.se.

Operating system and programming languages: The APP 2.1 Code is running under Microsoft Windows. The code is implemented in Compaq Visual FORTRAN 6.6 and is available as source code as well as an executable file.

Owner - IPR: Chelton Applied Composites AB.

Availability Information on how the software can be used by others:
The APP 2.1 Code is available internally for consultancy and R&D.

4.3 AFSS (LUND)

Abstract: Transmission and reflection coefficients are determined by a mode matching technique. The fields outside the screen and in the dielectric layers are expanded in Floquet modes, while the fields inside the apertures are expanded in waveguide modes, obtained by the Finite Element Method (FEM). Scattering matrices are calculated for each layer and cascaded.

Developing entity: The software was originally developed by Björn Widenberg at Lund University, Sweden.

Developers: Björn Widenberg, Chelton Applied Composites AB, in collaboration with Anders Karlsson, Lund University.

Definition of the physical structure that can be analysed: Thick FSS, that consists of an arbitrary number of aperture layers and dielectric layers. An aperture layer is a conducting plate with a periodic array of apertures. The periodicity in the different layers must be in accord. The layers can be of any thickness and in any order, and the cross section of the apertures is arbitrary.

Software Input: The input is given in text files, which are Matlab scripts setting the relevant parameters for the program.

Geometry data for dielectric layers and aperture layers are their respective position in the structure, and their respective thickness. For the dielectric layers the complex permittivity is also added. The geometry of the apertures is constructed from general set operations in Femlab, i.e., adding and subtracting circles, ellipses, rectangles, and arbitrary polygons. Some standard shapes are available. The dielectric in the apertures also needs to be specified. The lattice is described by two lattice basis vectors.

Each layer is given a code to indicate its type: surrounding medium, dielectric layer, or waveguide layer. The boundary between each pair of layers is classified as one of the possibilities dielectric-dielectric, dielectric-aperture, and aperture-dielectric. Identical boundaries can be identified and recycled to reduce the number of scattering matrices computed.

The incident field is a plane wave, described by the angle of incidence and TE or TM polarization. The frequency loop is controlled by giving start frequency, stop frequency, and the frequency step.

The number of Floquet waves used in the computations heavily influences the computation time, and is given in the input. The number of waveguide modes needed is calculated from the number of Floquet waves.

Software Output: The primary output is the scattered fields for each frequency in the loop, i.e., reflected and transmitted fields as functions of frequency. Various post-processing routines can then be applied, which are highly customisable since all solution data are available in the computer memory. Implemented routines include the output of transmission and reflection coefficients in dB, as well as the phase, losses in the dielectrics and metallic surfaces. Surface impedance is not implemented, but is easily available.

User Manual: No manual.

Website: Not available.

Operating system and programming languages: Any platform with Matlab and Femlab. Source code.

Owner - IPR: Björn Widenberg, Chelton Applied Composites AB, bjorn.widenberg@acab.se.

Availability Information on how the software can be used by others: Available internally for consultancy and R&D projects for external customer, but customer will not gain access to software.

Main references:

B. Widenberg, S. Poulsen, and A. Karlsson. Scattering from thick frequency selective screens. Journal of Electromagnetic Waves and Applications, Vol. 14, No. 9, 2000, pp. 1303-1328.

B. Widenberg. A general mode matching technique applied to bandpass radomes. Technical Report LUTEDX/(TEAT-7098)/1-33/(2001), Lund Institute of Technology, Sweden. http://www.es.lth.se/teorel.

4.4 PB-FDTD (LUND)

Abstract: Time domain unit cell analysis of periodic structures such as phased array antennas, frequency selective surfaces (FSS) and EBG surfaces. The structure can be periodic in one or two dimensions.

Periodic boundary conditions in one dimension makes it possible to analyse edge effects and radar cross section (RCS) in array antennas, FSS's and EBG's.

The numerical technique is based on FDTD with periodic boundary conditions. Since FDTD is a time domain method, numerical data is obtained for a large frequency band in a single computation. FDTD also allows the geometry to be very complex. The non-approximate technique with periodic boundary conditions in the time domain has been developed by Henrik Holter.

The GUI for pre- (geometry drawing etc.) and post-processing is written in MATLAB.

Some articles where PB-FDTD has been used.

[1] O. Forslund, A. Karlsson, S. Poulsen, "Scattering from dielectric frequency selective structures", Radio Science, Vol. 38, No. 3, 2003.
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[4] H. Holter, T-H. Chio and D. H. Schaubert, "Experimental results of 144-element, dual-polarized endfire tapered slot phased arrays", IEEE Trans. Antennas Propagat,. November 2000.
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Developing entity: The software was originally developed by Henrik Holter at the Royal Institute of Technology, Stockholm, Sweden. The software is continuously improved (by Henrik Holter).

Developers: Henrik Holter.

Definition of the physical structure that can be analysed: Periodic structures with a complex geometry. Infinite by infinite, infinite by finite and finite by finite structures.

Software Input: The input is organized through a graphical user interface built in Matlab. The computational volume is described by the number of voxels in each spatial direction, and the physical size of the individual voxel. There are seven simulation types: 1) Ordinary FDTD (absorbing boundary conditions on all sides), 2) Unit cell broadside scan (z-direction), 3) Unit cell x-z plane scan, 4) Unit cell y-z plane scan, 5) Unit cell diagonal plane scan, 6) Finite by finite phased array calculation, and 7) Infinite by finite phased array calculation (finite in the y-direction, infinite in the x-direction).

The geometry is arbitrary within the unit cell, and can be input through the GUI using basic building blocks (lines, rectangles, wedges, boxes etc), or by first running external Matlab scripts and then manipulating the resulting geometry in the GUI. The different materials are described by their respective conductivity and relative permittivity.

The excitation pulse is a Gaussian pulse modulated with a carrier frequency, described by centre frequency and a bandwidth. The excitation can be in the form of plane waves or local (delta gap) sources.

Software Output: The program generates time domain data, which is transformed to the frequency domain by an FFT calculation. After this, a number of post-processing is available from within the GUI. The antenna impedance can be plotted in a Smith chart, with real and imaginary parts, or with magnitude and phase. Alternatives are to plot the standing wave ratio, reflection coefficient, or return loss, and the data can be output to file. The far field and RCS can be computed and plotted.

There is a special menu for FSS calculations. By specifying upper and lower Floquet surfaces, reflection and transmission coefficients for different Floquet modes can be calculated. From this information, surface impedance can be calculated. The data can be exported to the Matlab workspace for further processing.

Movies can be generated showing the time domain behavior of the fields.

User Manual: A user manual exists. It is delivered with the software.

Website: No website.

Operating system and programming languages: OS: Windows 200/XP. The software has also been used on super computers. Source code in Fortran 90/95. GUI for pre- and post-processing in MATLAB.

Owner - IPR: Henrik Holter.

Availability Information on how the software can be used by others: Commercial code. No student version. Price: USD 1000.

Main references: Henrik Holter, Stockholm, Sweden.
henrik_holter@hotmail.com

4.5 FSSS (POLITO)

Abstract: software package for the analysis of capacitive and inductive Frequency selective Surfaces (FSS). The capacitive FSS's consist of arrays of metal patches as tripoles, crossed dipoles, square loops and any geometry obtained by a collection of slender strips defined by the user. The arrays can be stacked and supported by stratified dielectric media. The inductive FSS's are perforated screens whose geometry is complementary. The patches or apertures can be arranged in any skewed lattice (particular cases are square, rectangular and triangular lattices). The dielectric supports are stratified and can be losses and uniaxial anisotropic. The software is able to analyse a multiple array configuration illuminated by plane waves with a generic incidence. The structure is analyzed in the principal polarization base and its scattering properties are described in terms of Generalized Scattering Matrix. The software is available in the original Fortran77 code. User-friendly graphical tools were written to simplify input and output management.

Developing entity: IEIIT-CNR and POLITO

Owner - IPR: IEIIT-CNR

Developers: Tascone, Orta

Where is the software?: At IEIIT-CNR and POLITO

Surface type models: Inductive or capacitive frequency selective surfaces containing a periodic arrangement of one of more dipole patches or dipole apertures.

Analysis model: Frequency Selective Surfaces (FSS) may be basically of two types, those that at low frequency are transparent (capacitive FSS consisting of an array of patches supported by dielectrics) and those that are reflecting (inductive FSS consisting of perforated screen). The behavior at the resonance frequency is complementary: the capacitive FSS are reflecting whereas the inductive FSS are transparent. Typically, the polarization and the incident direction of the electromagnetic wave influence these properties. The analysis of FSS is carried out by a spectral technique. This technique is well suited especially when dielectric supports are present. In fact, in this case, the spectral representation of the Green function is known in analytical form. This formulation allows us the introduction of a vector transmission line representation where voltages and currents are the two-dimensional Fourier transforms of the transversal electric and magnetic fields, respectively. Shunt current generators, whose strength is unknown, represent the currents induced on the metal region. The key point of this approach is the construction of a vector functional equation in the spectral domain. This equation relates the two unknown functions of the problem: the Fourier transform of the aperture electric fields (the vector voltage at the discontinuity section) and the Fourier transform of the current induced on the metal region (the vector current generator). The dielectric stratification, placed on both sides of the array are described, for each Floquet mode (propagating and evanescent), in terms of their scattering matrix. In this way, the relevant Green function is simply described by the dyadic load impedance seen by the current generator and the functional equation is obtained by means of circuit considerations. Even if the functional equation contains two unknowns, the problem can be solved. In fact, the inverse Fourier transforms of the two unknowns have complementary supports: the apertures for the transversal electric field and the metal region for the induced currents. By means of the Parseval Theorem this property yields the horthogonality between the two unknowns in the spectral domain. The horthogonality relationship can be seen as the second equation. Hence the problem can be solved by considering as primary unknown the current induced on the metallic region (patch approach) or the transversal electric field (aperture approach) according to the geometry of the discontinuity. When the metallic region has simple shape, for example strips, rings, crossed dipoles, tripoles, discs and so on, the patch approach is more convenient. Whereas the aperture approach is convenient in the case of perforated screens where the apertures have simple geometry (e.g. slots). For both the approaches the scattering problem is solved numerically in the spectral domain by the Galerkin method of moments.

The solution is given in terms of the Generalized Scattering Matrix in the Floquet mode base. Hence, it is possible to study any aspect of the scattering phenomenon: reflection and transmission coefficients, the depolarization effects, scattering of higher order harmonics and so on. On the basis of this representation, the analysis of multiple array structures can be done by cascading the Generalized Scattering Matrices of each array. Obviously, The number of Floquet modes (propagating and evanescent) involved in the interaction depends on the spacing between the arrays. A key concept in this procedure is that of accessible Floquet modes and localized Floquet modes. This is, in turn, related to the two roles played by the Floquet modes in the analysis of the FSS. On one hand, the Floquet modes are used to represent the Green's function of the problem (this operator relates quantities defined in the same section of the discontinuity). On the other hand, the Floquet modes are used to represent the scattered fields from an array that, in the case of a multiple array configuration, are to be considered as incident fields on the other arrays. It has to be remarked that the number of these Floquet modes is not necessarily the same of those used to represent the Green's function. The reason for this is that generally a finite distance exists between the array section and the one where the scattered field is of interest. Thus, a major role is played by the fact whether a mode is above or below cutoff. Hence, it is convenient to classify the Floquet modes as accessible or localized according to their attenuation between adjacent arrays being lower or higher than a specified threshold. Accessible modes, either propagating or evanescent, are responsible for the interaction through adjacent discontinuities. Localized modes are so attenuated that they do not `see' the other arrays and give rise only to energy storage if the dielectrics are lossless. In cascading the various GSM, only the accessible mode ports are involved, whereas the localized mode ports are disregarded. According to the definition of GSM, this amounts to terminate these with the input impedances of the dielectric loads. From a computational point of view, it may be convenient to decompose a multiple array FSS into single array cells where the dielectric stratifications are considered. In particular, the number of accessible modes may be different on the two sides of the array since the dielectric stratifications are generally different. The reference impedance is that of free space and the left reference plane is close to the grid, whereas the right one is close to the adjacent array. In other words, a dielectric spacer belongs always to the array located at its left. The ports corresponding to localized modes are loaded with the input impedances of the relevant dielectric stratifications. It can be noted that in the cascading procedure, the matrix to be inverted has a size that equals the number of accessible modes, since only these are responsible for the inter-array coupling. If the distance between the arrays is such that only a few Floquet modes are accessible, the cascading procedure is obviously very convenient. On the other hand, for very small spacing, a coupled equation technique is more efficient, since almost all Floquet modes, used in the characterization of each array, become accessible. These considerations explain why it is computationally very convenient to characterize each array directly in its dielectric environment, i.e. by using the application of the method of moments a Green's function that takes the dielectric structure into account. An alternative approach could be that of computing the GSM of the freestanding array and of the dielectric stratification separately and then combining them by a cascading procedure. In this case, however, being the conducting elements printed on the dielectric layers, all the Floquet modes used in the characterization would be accessible and the matrix to be inverted would be impracticably large.

Definition of the physical structure that can be analysed: The software is divided in two packages: CFSSS and IFSSS.

CFSSS program analyses structures consisting of a cascade of passive planar arrays supported by stratified dielectric media. All the arrays are parallel to the xy-plane and the stratification occurs along the z-axis. The geometry of the patches is any composition of slender conducting strips of negligible thickness. The computer code CFSSS has three predefined kind of geometry: Tripoles, Square Loops and Crossed dipoles. Furthermore, the user can be define any geometry by specifying the number of strips, their dimensions and positions. The patches of different arrays can have different geometry. The interaction among the arrays is computed in full-wave sense. Hence, the lattice geometry of the various arrays must be the same. However, the arrays can be transversally shifted.

The dielectric support is divided in packs which are bounded by the arrays and the free-space in the case of the first and the last packs. Each pack can be formed by more than one dielectric layer with uniaxial anisotropy and with losses.

IFSSS program analyses the same configurations, but the arrays of conducting patches are substituted with perforated screens with complementary geometry. The description referred to the case of capacitive structures (arrays of conducting patches), applies to the case of inductive structures (perforated screens) follows by substituting the word patch with slot.

Status: Completely released, tested with comparisons against measurements and in used.

User manual: FSSS is described in a user manual written by Riccardo Tascone [1]. The general formulation

Software input: FSSS reads the input data from file or by keyboard. Each read instruction is preceded by a message which specifies the kind of data. The description of the input data follows the flow of the requests.

Software output: The data printed in the output File are the complex values (real, imag) of the 4x4 scattering matrix corresponding to the TE00 and TM00 Floquet modes.

At the beginning of the output file there are five rows containing the following information:

- Identification of the File (18 Characters)
- Title
- Reference values: Frequency (GHz), Theta (deg) and Phi (deg)
- Loop type (Frequency, Theta, Theta-Phi Loop)
- Loop data (initial value, final value, number of iterations)

The real and imaginary parts of the elements of the 4x4 scattering matrix corresponding to the (0,0) order the Flouquet modes follows.

The 4x4 scattering matrix is divided in four 2x2 submatrices S11, S21, S12, S22 . Each of them has the following arrangement:

TE/TE	TE/TM
TM/TE	TM/TM

and describes:

- S11 the reflection on the left hand side.
- S21 the transmission from left to right side.
- S12 the transmission from right to left side.
- S22 the reflection on the right side.

Following this order, on each row of the file, the submatrices are printed in column order (real, imag). In this way, each row contains 8 REAL numbers

In the case of Frequency or Theta loop, if N is the number of points, the number of rows is 4xN.

In the case of Theta-Phi loop, if Ntheta is the number of Theta points and Nphi those of Phi points (planes of incidence), the number of rows is 4xNthetaxNphi, and the Phi-loop is external.

Graphical interface: The output of the Fortran programs FSSS can be plot by means a MATLAB program call FSSSResponse. This program read the output file, recognises the kind of loop, display the data through a graphical interface where the user can be made his choice, and organise the data in the MATLAB workspace into the array Freq, Theta, Phi and S. These arrays are available to the user for further processing.

Website: No information is available for the software on the WEB

Availability Information on how the software can be used by others: The software can be purchased by the general public. Licenses for executable files (dongle protected) or source pre-compilation files can be purchased form POLITO and CNR-IEIIT.

Main references:

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[2] R.Orta, R. Tascone , R. Zich, ``Scattering from finite extent frequency selective surfaces illuminated by arbitrary sources", Electronics Letters, Vol.21, No.3 January 1985, pp.100-101.

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[10] R. Orta, P. Savi, R. Tascone , ``The effect of finite conductivity on frequency selective surface behaviour'', Electromagnetics , Vol. 10, 1990, pp.213-227.

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[12] M. Favreau, J. M. Goutoule, R. Orta, P. Savi, R. Tascone , ``Design of a 45-degree incidence millimeter wave diplexer'', Annales des telecommunications , Vol.47, No. 11-12, pp.539-540, Novembre-Dicembre 1992.

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IEEE Trans. Antennas Propagat. , Vol. AP-44, pp. 765-776, Giugno 1996. bibitem BookFSS R. Orta, R. Tascone , Part II of the book J. C. Vardaxoglou, `` Frequency Selective Surfaces: Analysis and Design'', Research Study Press, John Wiley, 1997

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[27] R. Orta, p. Savi, R. Tascone, and R. Zich, ``Transmission line approach for the study of planar periodic structures'', 13th annual review pro-

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4.6 DAMRA (POLITO)

Abstract: software package for the analysis of capacitive and inductive Frequency selective Surfaces (FSS). The capacitive FSS's consist of arrays of metal patches having form of rings or any geometry obtained by a collection of ring strips defined by the user. The arrays can be stacked and supported by stratified dielectric media. The inductive FSS's are perforated screens whose geometry is complementary. The patches or apertures can be arranged in any skewed lattice (particular cases are square, rectangular and triangular lattices). The dielectric supports are stratified and can be losses and uniaxial anisotropic. The software is able to analyses a multiple array configuration illuminated by plane waves with a generic incidence. The structure is analyzed in the principal polarization base and its scattering properties are described in terms of Generalized Scattering Matrix. The software is available in the original Fortran77 code. User-friendly graphical tools were written to simplify input and output management.

Developing entity: IEIIT-CNR and POLITO

Owner - IPR: IEIIT-CNR

Developers: Tascone, Orta

Where is the software?: At IEIIT-CNR and POLITO

Surface type models: Inductive or capacitive frequency selective surfaces containing a periodic arrangement of one of more ring patches or ring apertures.

Analysis model: Frequency Selective Surfaces (FSS) may be basically of two types, those that at low frequency are transparent (capacitive FSS consisting of an array of patches supported by dielectrics) and those that are reflecting (inductive FSS consisting of perforated screen). The behavior at the resonance frequency is complementary: the capacitive FSS are reflecting whereas the inductive FSS are transparent. Typically, the polarization and the incident direction of the electromagnetic wave influence these properties.

The analysis of FSS is carried out by a spectral technique. This technique is well suited especially when dielectric supports are present. In fact, in this case, the spectral representation of the Green function is known in analytical form. This formulation allows us the introduction of a vector transmission line representation where voltages and currents are the two-dimensional Fourier transforms of the transversal electric and magnetic fields, respectively. Shunt current generators, whose strength is unknown, represent the currents induced on the metal region. The key point of this approach is the construction of a vector functional equation in the spectral domain. This equation relates the two unknown functions of the problem: the Fourier transform of the aperture electric fields (the vector voltage at the discontinuity section) and the Fourier transform of the current induced on the metal region (the vector current generator). The dielectric stratification, placed on both sides of the array are described, for each Floquet mode (propagating and evanescent), in terms of their scattering matrix. In this way, the relevant Green function is simply described by the dyadic load impedance seen by the current generator and the functional equation is obtained by means of circuit considerations. Even if the functional equation contains two unknowns, the problem can be solved. In fact, the inverse Fourier transforms of the two unknowns have complementary supports: the apertures for the transversal electric field and the metal region for the induced currents. By means of the Parseval Theorem this property yields the horthogonality between the two unknowns in the spectral domain. The horthogonality relationship can be seen as the second equation. Hence the problem can be solved by considering as primary unknown the current induced on the metallic region (patch approach) or the transversal electric field (aperture approach) according to the geometry of the discontinuity. When the metallic region has simple shape, for example strips, rings, crossed dipoles, tripoles, discs and so on, the patch approach is more convenient. Whereas the aperture approach is convenient in the case of perforated screens where the apertures have simple geometry (e.g. slots). For both the approaches the scattering problem is solved numerically in the spectral domain by the Galerkin method of moments.

The solution is given in terms of the Generalized Scattering Matrix in the Floquet mode base. Hence, it is possible to study any aspect of the scattering phenomenon: reflection and transmission coefficients, the depolarization effects, scattering of higher order harmonics and so on. On the basis of this representation, the analysis of multiple array structures can be done by cascading the Generalized Scattering Matrices of each array. Obviously, The number of Floquet modes (propagating and evanescent) involved in the interaction depends on the spacing between the arrays. A key concept in this procedure is that of accessible Floquet modes and localized Floquet modes. This is, in turn, related to the two roles played by the Floquet modes in the analysis of the FSS. On one hand, the Floquet modes are used to represent the Green's function of the problem (this operator relates quantities defined in the same section of the discontinuity). On the other hand, the Floquet modes are used to represent the scattered fields from an array that, in the case of a multiple array configuration, are to be considered as incident fields on the other arrays. It has to be remarked that the number of these Floquet modes is not necessarily the same of those used to represent the Green's function. The reason for this is that generally a finite distance exists between the array section and the one where the scattered field is of interest. Thus, a major role is played by the fact whether a mode is above or below cutoff. Hence, it is convenient to classify the Floquet modes as accessible or localized according to their attenuation between adjacent arrays being lower or higher than a specified threshold. Accessible modes, either propagating or evanescent, are responsible for the interaction through adjacent discontinuities. Localized modes are so attenuated that they do not `see' the other arrays and give rise only to energy storage if the dielectrics are lossless. In cascading the various GSM, only the accessible mode ports are involved, whereas the localized mode ports are disregarded. According to the definition of GSM, this amounts to terminate these with the input impedances of the dielectric loads. From a computational point of view, it may be convenient to decompose a multiple array FSS into single array cells where the dielectric stratifications are considered. In particular, the number of accessible modes may be different on the two sides of the array since the dielectric stratifications are generally different. The reference impedance is that of free space and the left reference plane is close to the grid, whereas the right one is close to the adjacent array. In other words, a dielectric spacer belongs always to the array located at its left. The ports corresponding to localized modes are loaded with the input impedances of the relevant dielectric stratifications. It can be noted that in the cascading procedure, the matrix to be inverted has a size that equals the number of accessible modes, since only these are responsible for the inter-array coupling. If the distance between the arrays is such that only a few Floquet modes are accessible, the cascading procedure is obviously very convenient. On the other hand, for very small spacing, a coupled equation technique is more efficient, since almost all Floquet modes, used in the characterization of each array, become accessible. These considerations explain why it is computationally very convenient to characterize each array directly in its dielectric environment, i.e. by using the application of the method of moments a Green's function that takes the dielectric structure into account. An alternative approach could be that of computing the GSM of the freestanding array and of the dielectric stratification separately and then combining them by a cascading procedure. In this case, however, being the conducting elements printed on the dielectric layers, all the Floquet modes used in the characterization would be accessible and the matrix to be inverted would be impracticably large.

Definition of the physical structure that can be analysed: The software is divided in two packages: CDSSS and IDSSS.

CDSSS program analyses structures consisting of a cascade of passive planar arrays supported by stratified dielectric media. All the arrays are parallel to the xy-plane and the stratification occurs along the z-axis. The geometry of the patches is any composition of conducting rings of negligible thickness. The computer code CDSSS has two predefined kind of geometry: single and double rings. Furthermore, the user can be define any geometry by specifying the number of strips, their dimensions and positions. The patches of different arrays can have different geometry. The interaction among the arrays is computed in full-wave sense. Hence, the lattice geometry of the various arrays must be the same. However, the arrays can be transversally shifted.

The dielectric support is divided in packs which are bounded by the arrays and the free-space in the case of the first and the last packs. Each pack can be formed by more than one dielectric layer with uniaxial anisotropy and with losses.

IDSSS program analyses the same configurations, but the arrays of conducting patches are substituted with perforated screens with complementary geometry. The description referred to the case of capacitive structures (arrays of conducting patches), applies to the case of inductive structures (perforated screens) follows by substituting the word patch with slot.

Status: Completely released, tested with comparisons against measurements and in used.

User manual: DAMRA is described in a user manual written by Riccardo Tascone [1]. The general formulation

Software input: DAMRA reads the input data from file or by keyboard. Each read instruction is preceded by a message which specifies the kind of data. The description of the input data follows the flow of the requests.

Software output: The data printed in the output File are the complex values (real, imag) of the 4x4 scattering matrix corresponding to the TE00 and TM00 Floquet modes.

At the beginning of the output file there are five rows containing the following information:

- Identification of the File (18 Characters)
- Title
- Reference values: Frequency (GHz), Theta (deg) and Phi (deg)
- Loop type (Frequency, Theta, Theta-Phi Loop)
- Loop data (initial value, final value, number of iterations)

The real and imaginary parts of the elements of the 4x4 scattering matrix corresponding to the (0,0) order the Flouquet modes follows.

The 4x4 scattering matrix is divided in four 2x2 submatrices S11, S21, S12, S22 . Each of them has the following arrangement:

TE/TE	TE/TM
TM/TE	TM/TM

and describes:

- S11 the reflection on the left hand side.
- S21 the transmission from left to right side.
- S12 the transmission from right to left side.
- S22 the reflection on the right side.

Following this order, on each row of the file, the submatrices are printed in column order (real, imag). In this way, each row contains 8 REAL numbers

In the case of Frequency or Theta loop, if N is the number of points, the number of rows is 4xN.

In the case of Theta-Phi loop, if Ntheta is the number of Theta points and Nphi those of Phi points (planes of incidence), the number of rows is 4xNthetaxNphi, and the Phi-loop is external.

Graphical interface: The output of the Fortran programs DAMRA can be plot by means a MATLAB program call DAMRAResponse. This program read the output file, recognises the kind of loop, display the data through a graphical interface where the user can be made his choice, and organise the data in the MATLAB workspace into the array Freq, Theta, Phi and S. These arrays are available to the user for further processing.

Website: No information is available for the software on the WEB

Availability Information on how the software can be used by others: The software is available for general public. Licenses for executable files (dongle protected) or source pre-comipled files can be purchased form POLITO and CNR-IEIIT.

Main references:

[1] R. Tascone "DAMRA user manual", CESPa-CNR, Torino, 1994

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[3] R. Orta, R. Tascone , R. Zich, ``Frequency selective surfaces: spectral characterization and application to multifrequency antenna systems'', Annales des telecommunications, Vol.40, No. 7-8, July 1985, pp.378-386.

[4] S. Contu, R. Tascone , ``Scattering from passive arrays in plane stratified regions'', Electromagnetics, Vol. 5, No. 4, 1985, pp.285-306.

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[15] R.Orta, P.Savi, R.Tascone, "Multiple Frequency-Selective Surfaces consisting of ring patches", \it Electromagnetics , Vol.15, no.4, Luglio 1995, pp.417-426.

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IEEE Trans. Antennas Propagat. , Vol. AP-44, pp. 765-776, Giugno 1996. bibitem BookFSS R. Orta, R. Tascone , Part II of the book J. C. Vardaxoglou, `` Frequency Selective Surfaces: Analysis and Design'', Research Study Press, John Wiley, 1997

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gress in Applied Computational Electromagnetics , Monterey, March 1997,pp.1472-1479.

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[29] D. Trinchero, R. Orta, R. Tascone, J.C. Vardaxoglou, ``Leaky guide periodically loaded by ring patches", X JINA 1998-International Symposium on Antennas , Nizza, 1998, pp.346-349

4.7 MultiFreSS (POLITO)

Abstract: MultiFreSS is software written in Matlab language with a user-friendly graphical interface, which allows to synthesize a general alignment of inductive or capacitive arrays, packed each other by means of a general alignment of dielectric layers.

Developing entity: IEIIT-CNR

Owner - IPR: IEIIT-CNR

Developers: Tascone, Orta, Trinchero

Where is the software?: At IEIIT-CNR and POLITO

Surface type models: General alignment of frequency selective arrays packed together with a general alignment of dielectric layers.

Analysis model: the software is based on a general synthesis algorithm that has already been used with success in the design of waveguide filters [2]. As an example, we consider an FSS made of arrays of resonant ring patches printed on a dielectric slab. The synthesis procedure yields the transmission coefficients of each array, which has to be obtained by selecting suitable values of the ring diameter, width and lattice step. However, it should be noted that the choice of these parameters must be done by controlling, at the same time, the resonance frequency of the element. In those cases where this is not possible, concentric ring configurations are used. In this way a ring controls the resonance frequency in the stop band, whereas the other one provides the right capacitive load in the pass-band. Furthermore, this configuration allows one to generate several stop bands by a suitable selection, for example, of the diameter of the outer rings of each discontinuity.

Definition of the physical structure that can be analysed: Every collection of inductive and capacitive arrays (which can be analysed by softwares FSSS, or DAMRA, or both)

Status: Released, tested and in use

User manual: No user manual is available at the moment

Software input: Graphical

Software output: Graphical

Website: No information is available for the software on the WEB

Availability Information on how the software can be used by others: The software is available for general public (requires a matlab runtime license).

Main references:

[1] R. Tascone, P. Savi, D. Trinchero, R. Orta, “A procedure for the design of microwave filters based on a distributed parameter model”, in 1997 IEEE MTT-S Dig Int. Microwave Symp. Dig., pp. 643-646, 1997.

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[3] R. Orta, R. Tascone , R. Zich, ``Frequency selective surfaces: spectral characterization and application to multifrequency antenna systems'', Annales des telecommunications, Vol.40, No. 7-8, July 1985, pp.378-386.

[4] S. Contu, R. Tascone , ``Scattering from passive arrays in plane stratified regions'', Electromagnetics, Vol. 5, No. 4, 1985, pp.285-306.

[5] R. Orta, R. Tascone , R. Zich, ``A unified formulation for the analysis of general frequency selective surfaces'', Electromagnetics, Vol. 5, No. 4, 1985, pp.307-329.

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rence on Electromagnetics in Advanced Applications (ICEAA01). Torino, Italy.

4.8 MoM/BI-RME: Analysis of Capacitive and Inductive Dichroic mirrors (A.C.I.D.) (Univ. of Pavia)

Abstract: This software applies to the analysis of inductive and capacitive frequency selective surfaces (FSS). In the case of inductive FSS, the structure consists of a metal screen perforated periodically with arbitrarily shaped holes. In the case of capacitive FSS, the structure consists of an array of arbitrarily shaped metal patches, printed on a dielectric substrate. The analysis is performed under the approximation of an infinite array, illuminated by a uniform plane wave incident at an arbitrary angle, with arbitrary polarization. The code is based on a numerical technique named the MoM/BI-RME method. It consists in the formulation of an integral equation, which is solved by the Method of Moments (MoM) with entire-domain basis functions. In the case of array elements with an arbitrary shape, the entire-domain basis functions are calculated numerically by the Boundary Integral-Resonant Mode Expansion (BI-RME) method. Due to this approach, the software is very efficient, and the wideband analysis of a frequency selective surface requires typically seconds or tens of seconds on a standard PC.
This software consists of two modules: the former is named "FSS" and applies to the analysis of inductive frequency selective surfaces, the latter is named "PAT" and applies to the analysis of capacitive frequency selective surfaces.

Developing entity:
Department of Electronics, University of Pavia
Via Ferrata, 1 – 27100 Pavia (Italy)

Developers:
Maurizio Bozzi (maurizio.bozzi@unipv.it)
Luca Perregrini (luca.perregrini@unipv.it)

Definition of the physical structure that can be analysed:
In the case of inductive FSS, the structure consists of one or two metal screens with a finite thickness, perforated periodically with arbitrarily shaped holes. In the case of the two-screen configuration, the hole shape in the two screens can be different, but both screens must have the same periodicity. Metal losses are not included in the analysis.
In the case of capacitive FSS, the structure consists of a periodic array of metal patches with an arbitrary shape, located in a stratified dielectric medium. Infinitely thin metal patches are considered in the analysis. Both dielectric and metal losses are accounted for.

Software Input:
The input/output files of this software are standard ASCII files.
The module “FSS” requires two input files:

- the <filename>.apb file describes the shape of the apertures through segments and arcs.
- the <filename>.fss file contains all the information about the periodicity (dimensions of the unit cell and skew angle), the direction of incidence of the impinging plane wave, the thickness of the metal screen(s), and possibly their spacing, and the frequency range of analysis. Moreover, two accuracy parameters (related to the convergence of the MoM and of the Green’s function, respectively) must be provided.

The module “PAT” requires similar inputs. Also in this case:

- the <filename>.apb describes the shape of the metal patches through segments and arcs.
- the <filename>.pat file contains the information about the periodicity of the structure, the thickness, relative permittivity and loss tangent of the dielectric layers, the resistivity of the metal patches, the direction of incidence of the impinging plane wave, and the frequency range of analysis. Similarly to the previous case, two accuracy parameters (related to the convergence of the MoM and of the Green’s function, respectively) must be provided.

Software Output:
The code produces a variety of output files in ASCII format, which contain the reflection and transmission coefficient of the fundamental TE and TM Floquet modes. In particular, amplitude and phase of both co-polar and cross-polar contributions are reported.

User Manual:
A User Manual is available, and can be provided by the software developers upon request.

Website:
Information on the software can be found at the website of the Microwave Lab, University of Pavia (http://microwave.unipv.it).

Operating system and programming languages:
The software runs on PCs under Windows operating system. It is written in FORTRAN language, but is distributed in the form of an executable file.

Owner - IPR:
The holder of the Intellectual Property Rights is the Department of Electronics, University of Pavia.

Availability Information on how the software can be used by others:
The software A.C.I.D. is a commercial code. A license can be provided for unlimited internal use. The price of each module of the software ("FSS" and "PAT") is 10000.00 EUR + VAT (if applicable).
A demo version of the code FSS, limited to a plane wave with normal incidence, is available and can be downloaded from the website of the Microwave Lab, University of Pavia (http://microwave.unipv.it/software/).

Main references:
The basic theory of the MoM/BI-RME method and some applications of the software in the microwave and millimeter-wave region can be found in the following journal papers:

[1] M. Bozzi, L. Perregrini, J. Weinzierl, and C. Winnewisser, "Efficient Analysis of Quasi-Optical Filters by a Hybrid MoM/BI-RME Method," *IEEE Transactions on Antennas and Propagation*, Vol. AP-49, No. 7, pp. 1054-1064, July 2001.

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5. SOFTWARE FOR SPECIAL SURFACES

5.1 RIMACS (POLITO)

Abstract: RIMACS (Reflection and Inter-modulation Analysis of Carbon Fibre Surfaces) can be used to analyse the reflection characteristics and the non linear behavior of carbon-fibre-reinforced plastics (CFRP), extracting intermodulation products and higher harmonics contributions. It is written in FORTRAN 77 language and its output is printed on as standard ascii file.

Developing entity: POLITO

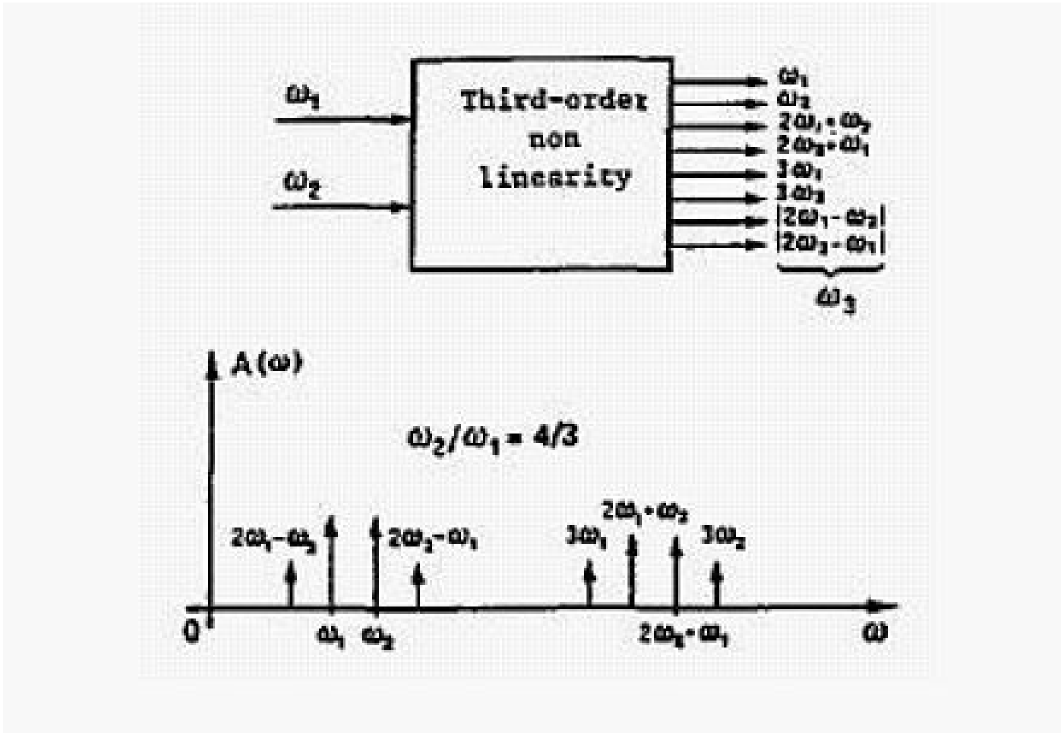
Owner - IPR: POLITO

Developers: G. Ghione, M. Orefice

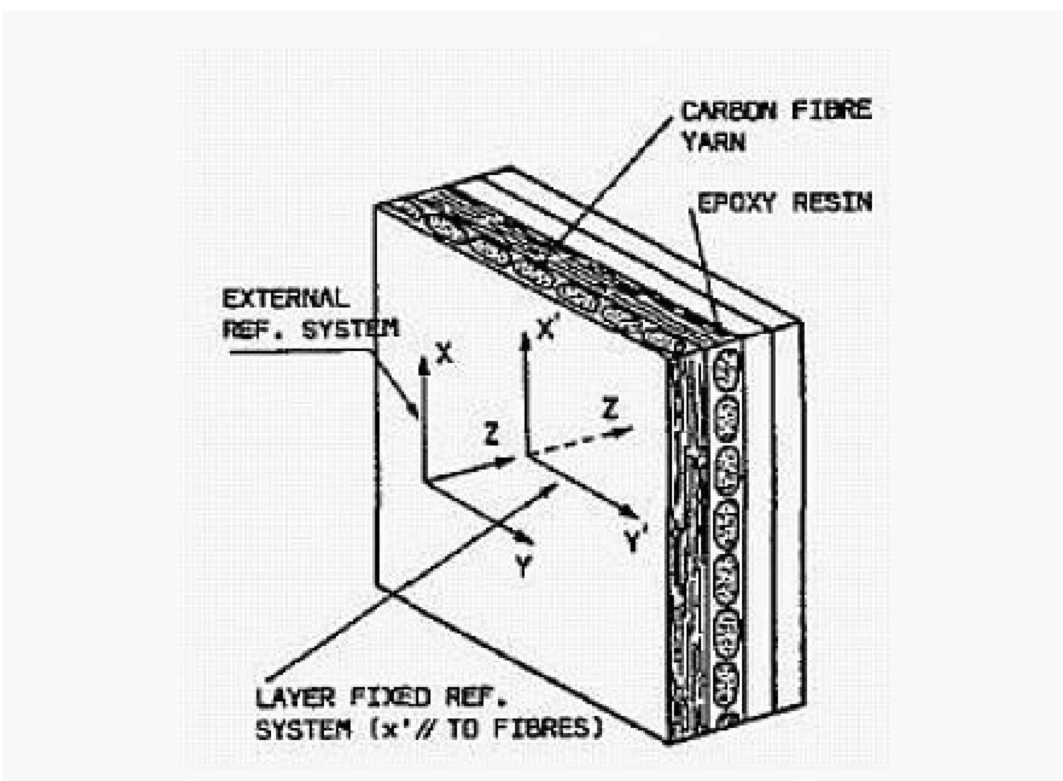
Where is the software?: At POLITO

Surface type models: CFRP planar layers.

Analysis model: the software is based on a perturbative formulation. It is assumed that only a small fraction of the incident power is converted into higher harmonics, so that the non linearity can be studied in a perturbative manner. Assuming that the field-current characteristic of the graphite is cubic, only the third order harmonics and IMPS are generated, according to the scheme of the following Figure.



Definition of the physical structure that can be analysed: a general alignment of non-isotropic lossy dielectric layers packed simulating a general alignment of CFRP layers.



<u>Status</u>: Released, tested, but no longer in use

<u>User manual</u>: No user manual is available at the moment

<u>Software input</u>: Ascii data file, with the layers characteristics

<u>Software output</u>: Ascii data file, with reflection and intermodulation characteristics

<u>Website</u>: No information is available for the software on the WEB

<u>Availability Information on how the software can be used by others</u>: The software is available for general public and can be purchased from POLITO

<u>Main references</u>:

[1] G. Ghione, M. Orefice, "Intermodulation products generation from carbon Fibre Reflector Antennas", in 1985 IEEE AP-S, 1985.