PSSFSS—An Open-Source Code for Analysis of Polarization and Frequency Selective Surfaces

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***Abstract*—PSSFSS is a free, open-source code for analysis and design of polarization selective surfaces (PSSs), frequency selective surfaces (FSSs), radomes, reflectarray elements, and similar devices. It is written in Julia, a recently developed language for high-performance technical computing. Its speed and ease of use make PSSFSS useful and accessible to both students and working engineers. This paper describes the design of PSSFSS and provides several examples of its use, with comparisons to results from other simulation tools.**

***Index Terms*—computer code, frequency selective surface, FSS, open-source, polarization selective surface, radome, reflectarray.**

I. Introduction

PSSFSS [1] is a free, open-source code for analysis and design of polarization selective surfaces (PSSs), frequency selective surfaces (FSSs), radomes, and reflectarray elements. This paper introduces the reader to the Julia programming language in which PSSFSS is written, briefly outlines the analysis method and algorithms used in PSSFSS, describes how the program is used, and provides a few examples to illustrate the code's ease of use, speed, and accuracy.

II. The Julia Language

PSSFSS is written in Julia [2], a recently developed, free and open-source computer programming language intended for high-performance technical computing. A modern, dynamic, high-level language, Julia was specifically created to address perceived short-comings of existing languages like Matlab and Python. Although it can be used interactively and "feels" like an interpreted language, it transparently compiles code to machine language prior to execution, resulting in execution speed competitive with Fortran or C. Support for parallelism (both distributed and threaded) is built into the language, as is support for multidimensional arrays of any dimensions and types. The syntax for performing linear algebra is similar to Matlab's. Installation of Julia is a simple process on Windows, Linux, or Macintosh computers. The language fully supports Unicode, so that symbols such as μ_r, ϵ_r, and $\tan\delta$ can be used for Julia variable names, if desired.

III. Description of PSSFSS

A. Packaging

PSSFSS has been released as a registered Julia package. As such it can be installed via a single command at the Julia prompt. Package installation essentially consists of downloading the Git repository containing the PSSFSS source code, along with any other required packages. Similarly, updates published to the PSSFSS Github repository [1] can be automatically retrieved by the user with another simple Julia update command.

Besides its on-line user manual [3], PSSFSS includes a detailed, 86 page theory document [4] that derives from first principles the formulas and algorithms implemented in the code. The code is heavily commented with references to specific sections and equation numbers in the theory document to promote code transparency.

B. Analysis Methods Employed

PSSFSS solves for the surface electric and/or magnetic currents on planar FSS/PSS sheets located within a stratified medium consisting of any number of dielectric layers. Currents are represented using modified Rao-Wilton-Glisson (RWG) basis functions [5] and are determined via a periodic moment method (PMM) solution of the mixed-potential integral equation in the space domain. The potential Green's functions are computed using a wide-band expansion [6] that, for normal incidence, permits the most expensive part of matrix assembly to be performed once only, regardless of the number of analysis frequencies performed. Multiple FSS/PSS sheets are accommodated by cascading their generalized scattering matrices (GSMs). The number of Floquet modes retained in the GSMs is calculated automatically such that excluded modes must encounter at least 30 dB of attenuation between neighboring sheets.

The default method for frequency sweeps is an extremely robust, diagonal rational function interpolation ("fast sweep") algorithm. Applied to the final, composite GSM of the structure being analyzed, it eliminates the need for a full PMM solution at each frequency (a "discrete sweep"), often producing speedups of 10× to 20×. The strict termination criterion employed in PSSFSS for this algorithm makes it absolutely reliable, in the author's experience.

Additional details of the theory and implementation for PSSFSS can be found in [4].

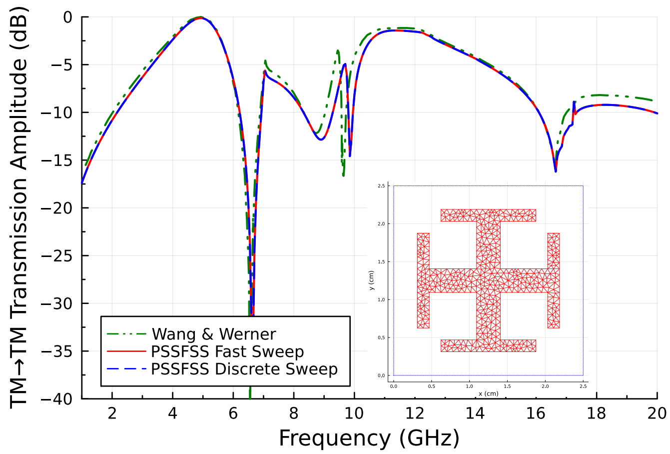
C. Program Features

Currently supported element types include rectangular strips, meanderlines, loaded and filled crosses, Jerusalem crosses, split rings, and polyrings. The latter are able to model concentric rectangular loops or polygonal rings. All element types are fully parameterized for easy specification and optimization. The user manual [3] includes a gallery of supported element types.

Available outputs include scattering parameters (magnitudes, phases, or complex) using a TE/TM, Ludwig 3, or LHCP/RHCP polarization basis, axial ratio, and others.

D. Program Usage

PSSFSS is run in a Julia script. The geometry to be analyzed is specified as a vector of two or more dielectric Layers and zero or more RWGSheets. The latter define the FSS/PSS sheets and are instantiated by calling constructors such as meander, strip, polyring, etc. After also specifying the desired scan angles (or unit cell incremental phase shifts) and frequencies to be analyzed, a call to the analyze function performs the analysis. Outputs are requested using a tiny domain-specific language implemented by the @outputs macro. For example, `@outputs s21db(L,R) ar22db(v)` will produce a matrix whose columns contain 1) transmission amplitude in dB to LHCP pol exiting port 2 due to a RHCP wave incident at port 1,




```
using PSSFSS, Plots
P = 2.5; L1 = 3P/4; L2 = P/8; w = L2; A = P/2
B = P/16; ntri = 800; units = cm;  class = 'M'
sheet = jerusalemcross(;class, w, L1, L2, P, A, B, ntri, units)
pl = plot(sheet, unitcell=true, linecolor=:red, size=(600,600))
strata = [Layer()
          sheet
          Layer(epsr=2.0, tandel=0.05, width=0.02cm)
          Layer()]
freqs = 1:0.05:20; steering = (phi=1, theta=45)
reslt = analyze(strata, freqs, steering)
T_TMdB = extract_result(reslt, @outputs s21db(tm,tm))
```

Fig. 1. Over-sized Jerusalem cross slot from [7]. The inset triangulation contains 839 triangles; a blue dashed line demarks the 2.5 cm unit cell. Below is the code used to generate the fast sweep data and plot the FSS triangulation.

and 2) reflected axial ratio in dB exiting port 2 due to an incident Ludwig 3 vertical wave at port 2. The outputs can be further post-processed and/or plotted in the same interactive or batch Julia session.

IV. Example Results

A. Over-sized Jerusalem Cross Slot

This example, taken from [7] and illustrated in Fig. 1, constitutes a severe test of the fast sweep algorithm. The unit cell is a 2.5 cm square. The FSS is etched on a 0.02 cm thick dielectric slab with $\epsilon_r = 2.0 - j0.1$. The incidence angle is $(\theta, \phi) = (45^\circ, 1^\circ)$ so that higher-order free-space Floquet modes begin propagating at 7.025, 12.292, 12.542, 14.051, 16.665, and 17.060 GHz. Fig. 1 shows that the PSSFSS fast sweep and discrete sweep plots are indistinguishable and agree well with data digitized from [7]. Below the plot is the code used to generate the PSSFSS data. Analysis was performed on a 3 GHz Core i7-9700 CPU. Fast and discrete sweeps required 195 s and 790 s respectively, a speedup of 4×. Greater speedups are usually obtained, but the many modes passing out of cut-off in this band make this case especially difficult. Here, 90 of the 381 requested analysis frequencies required a full PMM solve in the fast sweep.

B. 5-Sheet Meanderline/Strip CPSS

This example, from [8], consists of a 5-sheet, sequentially rotated, circular polarization selective surface (CPSS). The top images in Fig. 2 are the individual sheet triangulations. Each sheet shares the same unit cell, a 5.2 mm square. Sheets are etched on dielectric substrates separated from their neighbors by foam layers. Below the triangulations is a plot of computed insertion loss and transmitted axial ratio (AR) for a right-hand circular polarization (RHCP) wave normally incident on the structure, computed both by PSSFSS and CST, the latter digitized from plots in [8]. The differences are attributed to finite metalization thickness in the CST model, a feature not yet supported by PSSFSS. PSSFSS analysis of the 5-sheet

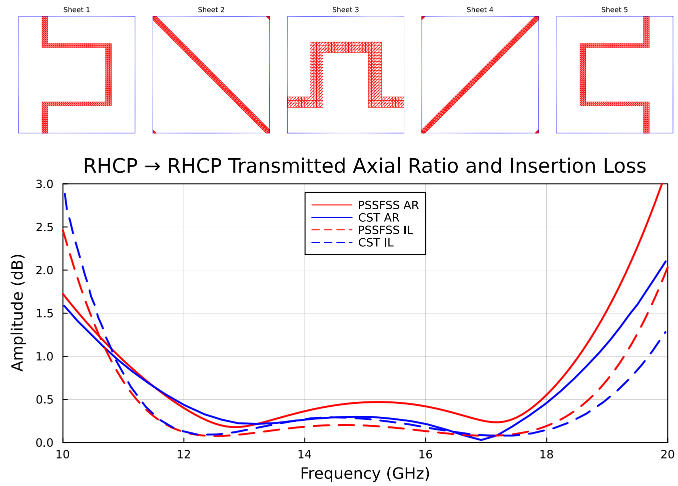


Fig. 2. 5-Sheet CPSS from [8].

composite structure at 101 frequencies required only 20 s. The speed is due to multiple factors: 1) analysis is fastest at normal incidence, 2) meanderlines and strips are triangulated using structured meshes which are exploited by PSSFSS to avoid redundant calculations, and 3) the smoothly varying GSM over this analysis bandwidth required only 13 full solutions out of 101 analysis frequencies in the fast sweep algorithm.

C. Other Examples

Due to space limitations, additional examples are omitted here but will be presented at the conference, including a design optimization.

V. Conclusions

An open-source code PSSFSS for analysis of polarization and frequency selective surfaces has been described. Written in the Julia programming language, it can be obtained, installed, and used easily and without cost. PSSFSS employs multi-threading and several novel algorithms to enhance computational efficiency. It is intended to be useful and accessible to students and working engineers who may not be specialists in computational electromagnetics.

References

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