Introduction to the FEKO Suite

FEKO is a simulation tool that is used for electromagnetic field analysis of 3D structures. FEKO simulations are based on the solution to Maxwell's equations by the well-known Method of Moments (MoM). This solution formulation was popularised by the Numerical Electromagnetics Code (NEC2) published by Lawrence Livermore Laboratories in 1981. The MoM implementation in NEC2 only catered for wire structures and the mistake of thinking that there is an inherent limitation in the technique is often made. FEKO is a more comprehensive implementation of the MoM which enables users to address problems involving any type of structure.

The accurate MoM, while capable of solving a wide variety of problems, uses more resources than a technique that is tailored to solving a particular problem or category of problem. There are several tools that can be implemented within the MoM to optimise the solution of a specific category of problem. A very good example is antennas on a printed substrate. For this specific problem, a special formulation of the Green's function can be used for optimal trade-off between accuracy and resource requirements. FEKO has many of these dedicated formulations implemented. This means that provision is made for very efficient solutions to some problems, as well as provision for accurate solutions for problems that do not fall into one of these special categories.

Another special category of problem that requires a special mention is the solution of electrically large problems. The most recent tool implemented in FEKO to optimise the solution of these problems is called the Multi-Level Fast Multipole Method (MLFMM). FEKO is the first commercial code to bring this tool to the market. This technique makes accurate simulations of electrically large problems possible. Before the introduction of this tool, a high frequency approximation would have had to be used to solve this kind of problem.

Two high frequency approximation techniques are available in FEKO, namely Physical Optics (PO) and Uniform Theory of Diffraction (UTD). These techniques provide solutions for problems where the requirements of the MoM and MLFMM exceed available resources. As approximation techniques, their application is not as general as the MoM and MLFMM, but they can be used successfully to solve problems that could otherwise not be addressed at all. These techniques are implemented in a hybridised form with the MoM, so that regions of the problem can still be solved with the MoM.

The MoM/FEM hybridisation allows the efficient analysis of highly inhomogeneous dielectric bodies. This hybrid formulation is specifically appropriate for problems where there is free-space region between structures. The space between the MoM region (typically the radiating structure) and the FEM region (typically the dielectric region) does not have to be meshed, resulting in a much smaller matrix and therefore less computational resource requirements.

Solution Methods	***Applications***	***Special Features***
• Method of Moments (MoM) *(Many extensions to deal with wide range of applications e.g. dielectric volumes, planar multilayered structures, dielectric and magnetic coatings, thin dielectric sheets, ground plane reflections)* • Multi Level Fast Multipole Method (MLFMM) • Finite Element Method (FEM) • Physical Optics (PO) • Uniform Theory of Diffraction (UTD)	• 3D Antenna Design • Microstrip-Antennas *(Planar and Conformal)* • Microstrip-Circuits • Antenna Placement • EMC Analysis *(including complex cable harness)* • Dielectric Bodies (e.g. SAR) • Scattering Analysis	• True Hybridisation (MoM/FEM, MoM/PO, MoM/UTD) • Parallel Processing • Out-of-core solution *(when memory requirements exceed the available RAM)* • Wide range of hardware supported (including 64-bit) • Time Domain data (TIMEFEKO manages the excitation pulse description and required FFT) • Optimisation (Variables, aim-functions and optimisation methods specified in OPTFEKO) • Import wide variety of meshed CAD • Many excitation options

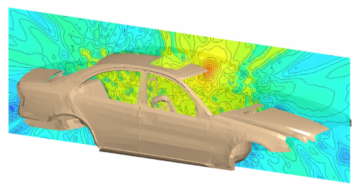
APPLICATIONS

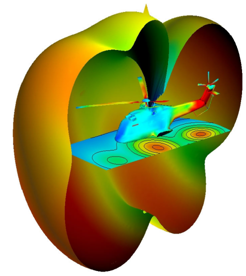
Antenna Analysis

Wire antennas, horn and aperture antennas, reflector antennas, micro-strip antennas, phased array antennas, helical antennas. Many special formulations enable the analysis of practical antenna problems.

Antenna Placement

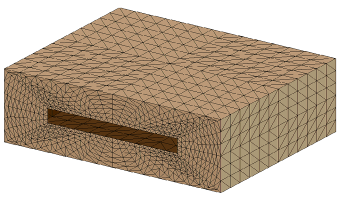
The MoM/PO or MoM/UTD hybridisations as well as the MLFMM enable the analysis of antennas mounted on electrically large platforms where the interaction with the nearby structures influences the antenna characteristics; for example UHF antennas on aircraft or ships, GSM on motor vehicles etc.

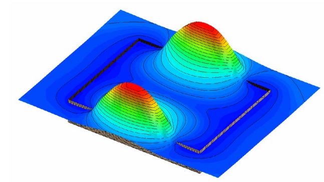




EMC

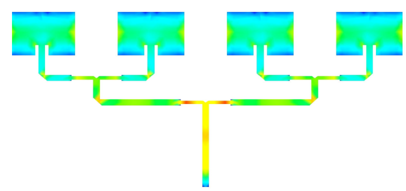
FEKO is being used extensively for EMC analysis in the motor industry and is very useful for calculating the coupling between antennas and cables. The range of EMC problems that can be solved with FEKO has been extended significantly through an interface with CableMod. For example, complex cabling problems in automobiles and aircraft can be solved.

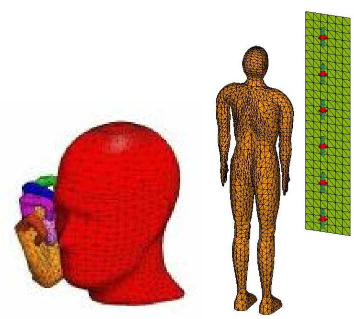




Planar Microstrip-Antennas and -Circuits

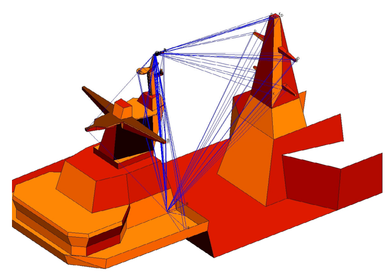
A full 3D MoM formulation for arbitrarily oriented metallic wires and surfaces within multi-layered media for the analysis of microstrip antennas. Interpolation tables are used for faster solution times.





Dielectric bodies (e.g. SAR Calculation)

Field values can be calculated inside multiple dielectric regions, each with different dielectric parameters. These fields can be used to calculate the Specific Absorption Rate (SAR). This has found a wide application in the analysis and design of mobile phones.



UTD Ray Tracing for RF Antennas

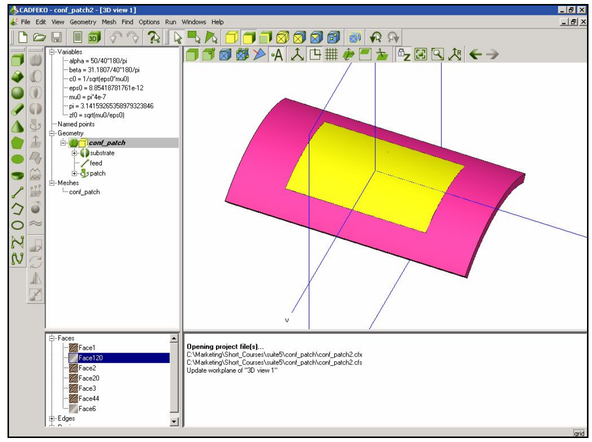
The visualisation of the UTD rays can be very informative to identify high frequency scattering and reflection points. This can be useful for the analysis of inter antenna isolation, radiation pattern distortion etc; for example RF antennas on ships or mobile phones antennas on buildings.

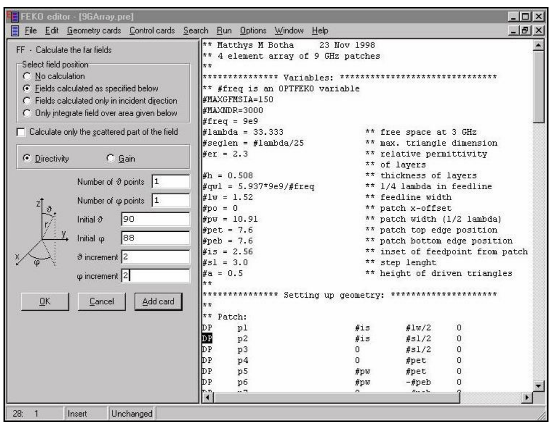
Graphical User Interface (GUI)

The FEKO GUI consist mainly of CADFEKO, EDITFEKO and POSTFEKO and is available on Windows and Linux.

CADFEKO (for interactive geometry entry and meshing)

- Canonical structures such as cylinders, polygons, spheres, cones, etc. are created through the click of a button,
- Perform Boolean operations such as splitting, unions, intersection, subtracting with these objects,
- Create complex objects using spinning, sweeping, of curves and surfaces and creating ruled surfaces between two edge curves,
- Translate, rotate, scale and mirror objects,
- Projection of points, curves and surfaces onto surfaces or solids,
- All parameters can be entered in terms of variables and/or mathematical expressions which may be modified to change the geometry,
- Models can be organised by combining objects into assemblies,
- Surface (triangle) meshes and Volume (tetrahedral) meshes,
- CADFEKO can import and mesh complex CAD models (Parasolid only).



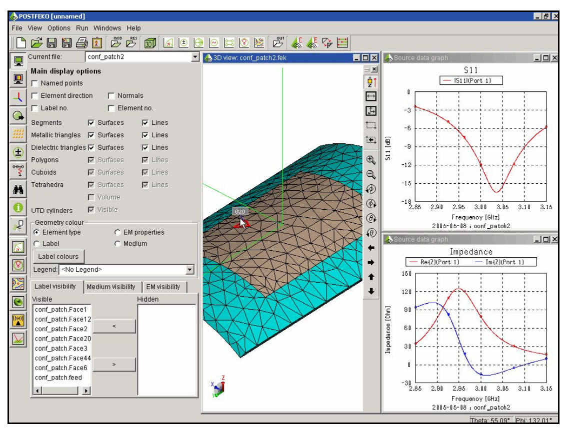


EDITFEKO (to set the solution control, excitation and output requirements)

- Easy to use card entries with dialog boxes,
- Advanced mathematical variable evaluation,
- “FOR” loops and “IF” statements are available for complex geometry and solution control.
- EDITFEKO can also be used to create and mesh simpler models using all the Geometry Cards**.**

POSTFEKO (for model validation and for data post-processing)

- POSTFEKO supports multiple views with multiple geometry (*.fek) and result (*.bof) files in a single session.
- The 3D view supports a grid that can be moved around the geometry to get dimensional information.
- Support for multiple results of the same type, for example displaying more than one near-field ortho-slice.
- Multiple and arbitrarily oriented cut-planes are supported.
- Advanced Specific Absorption Rate (SAR) display.
- UTD ray colours indicate their relative amplitudes.
- Electrical surface currents and Electric charge density.
- 2D graphs automatically display results in the appropriate units.

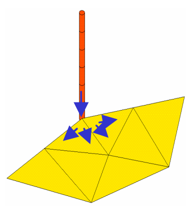


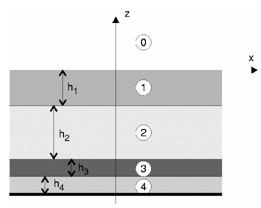
Solution Methods…

MoM (Method of Moments)

FEKO has a comprehensive implementation of the MoM. Some specific features include,

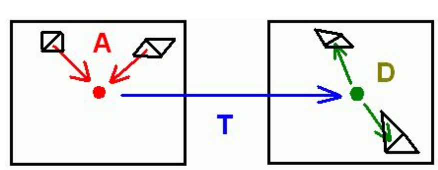
- Lumped or distributed circuit elements (R/L/C),
- Skin effect and ohmic losses,
- Special fast treatment for thin dielectric sheets,
- Dielectric or magnetic coating of wire segments and surfaces,
- Surface Equivalence Principle (SEP) for multiple homogeneous dielectric bodies which can also enclose each other,
- Volume Equivalence Principle (VEP) for smaller regions of highly inhomogeneous dielectric (cuboidal elements),
- Green's functions for the analysis of planar multi-layered media (for micro-strip antennas and circuits).





MLFMM (Multi Level Fast Multipole Method)

With the normal MoM, each basis function (triangle pair or wire-segment pair) has an influence on each of the other basis functions in the model. This leads to a quadratic growth in the number of interactions that need to be taken into account. By grouping basis functions together, the interaction between groups can be calculated and stored, rather than individual interactions. This grouping is done on multiple levels, where, at the top level the whole computational space is enclosed by one large cube. At the next level this cube is subdivided in 3-dimensions into a maximum of 8 child cubes. This process is repeated until at the finest level the cube side length is approximately a quarter of a wavelength. The interaction between any two basis functions that are not in neighbouring cubes is calculated through a process of aggregation, translation and disaggregation through the different levels. See the discussion on the solution of electrically large structures below for more detail on the advantages that this offers.



PO (Physical Optics)

The accurate "full-wave" MoM solution suffers from poor scalability i.e.

Memory (in Bytes) = $16\times N^2$

(where N=number of basis functions and for metallic surfaces $N\approx 100*(A/\lambda^2)$ *with A the surface area)*

For electrically (i.e. A/λ^2) large structures this can imply enormous computational resources requirements. In order to overcome the scalability problem the accurate MoM has been hybridised with the asymptotic high frequency techniques PO and the UTD. This implementation reduces the size of the solution matrix considerably and enables the solution of electrically large problems on small computers.

- PO current represented by triangular basis functions,
- Improved accuracy obtained through edge- and wedge-correction terms and Fock currents,
- Full hybridisation, i.e. modification of interaction matrix, which is essential for accuracy,
- Multiple reflections can be taken into account.

UTD (Uniform Theory of Diffraction)

The UTD is an asymptotic formulation where the size of the structure does not influence the memory requirements. The formulation is based on direct rays, reflections, and diffraction from edges and corners. The number of terms and ray interactions influence the run-time.

- Geometry: Flat polygonal plates or a cylinder,
- Terms: Edge and corner diffraction, double diffraction and creeping waves (cylinders). Multiple reflections,
- Full hybridisation, i.e. modification of interaction matrix, which is essential for accuracy.

FEM (Finite Element Method)

The tetrahedral (volume) element based FEM is ideal for modelling highly inhomogeneous dielectric bodies. The hybridisation of the MoM with the FEM exploits the benefits from both techniques, viz. the efficiency of the FEM for the treatment of inhomogeneous dielectric bodies, and the efficiency of the MoM for the treatment of open boundary radiating structures because no discretisation of 3D space is required. The MoM/FEM hybrid enables FEKO to solve certain classes of electromagnetic problems with optimal efficiency. A prime example of this application is the simulation of the exposure of humans to mobile phone base stations antennas.

Parallel Processing

All phases of the standard solution options are available in parallel for distributed memory systems.

Using FEKO …

PRE-PROCESSING

Geometry (CAD) / Mesh

A number of discretised (mesh) element types are required for all the different formulations offered by FEKO: Wire (segments) and Surface (triangles) are used for the MoM (also for the Surface Equivalence Principle), cuboids are required for the Volume Equivalence Principle (VEP) and tetrahedral elements are used for the FEM. These mesh elements can be obtained in a number of ways:

1. CADFEKO (Parasolid based) can be used in an interactive way to create (and mesh) complex geometries from primitive solid objects (e.g. cylinders, polygons, spheres, cones) on which Boolean operations (e.g. split, union, subtract) and other functions (e.g. spin, sweep, project) can be performed,
2. Import complicated geometries (e.g. automobile) which were created and meshed with 3rd party CAD software (e.g. NASTRAN, PATRAN, AutoCAD DXF, ANSYS, STL and FEMAP),
3. Simpler structures can be defined in the text based pre-processor (EDITFEKO). These structures can be defined parametrically using variables, making subsequent design iterations simple to handle. The optimisation utility OPTFEKO can also be used with geometries created in this way.

Obtaining a reliable mesh is a significant part of most analysis problems. EMSS and has a wealth of experience in this regard, and can offer valuable advice about choosing a CAD solution that will serve your needs as a FEKO user.

Material Parameters

When using non-perfectly conducting materials, FEKO requires the specification of material parameters. These material parameters can be easily set or changed from within the pre-processing interface – or even made parametric.

Excitation

Many excitation options are available, e.g.:

- Plane-wave (also elliptical / circular polarisation),
- Voltage source on segment, voltage source on node,
- Voltage source on edge of triangular element,
- TEM frill (magnetic ring current, for accurate impedance),
- Hertzian (electric and magnetic) dipole,
- Aperture distribution (near-field),
- Antenna radiation pattern (far-field),
- Impressed currents.

Output Parameter Specification

When using the MoM as a solution technique to Maxwell's equations, the 'solution' is complete when the currents on the entire structure are known. FEKO uses these currents to obtain output data that is more meaningful to the user's application. Many options, such as the calculation of near-fields, far-fields, input impedance and S-parameters are available.

Solution Control

FEKO provides the user with a lot of control over the solution process. The computation can be stopped at different phases, and then continued when convenient. Resource management is also controlled from FEKO. The PO and UTD approximations also have a number of features that can be set from the input file.

POST-PROCESSING

Surface and Line Currents

Surface and line currents are represented through colours on 3D objects. Vector plots and animations can be done.

Far-Fields

3D colour enriched closed surface, polar or Cartesian plots, RCS plots, directivity/gain for linear (horiz/vert) and circular (LHC/RHC) polarisation. Quantitative data can also be plotted onto 2D graphs.

Near-Fields

All three complex components of electric and magnetic fields can be displayed in 3D. FEKO allows for the values along Cartesian planes (which can be animated versus time) or iso-surfaces to be displayed. 2D quantitative data can also be plotted.

Specific Absorption Rate (SAR)

Automatic calculation of SAR is available from the computational kernel and the post-processor allows for advanced visualisation.

UTD Ray Visualisation

The rays used for UTD calculations can be visualised with the post-processor. This can be very useful for the analysis of the high frequency scattering/coupling mechanism surrounding an antenna in a complex environment.

Other

Other EM observables that can be calculated and visualised by FEKO include:

- Input impedance,
- Radiated power,
- S-parameters.

Utilities available with FEKO

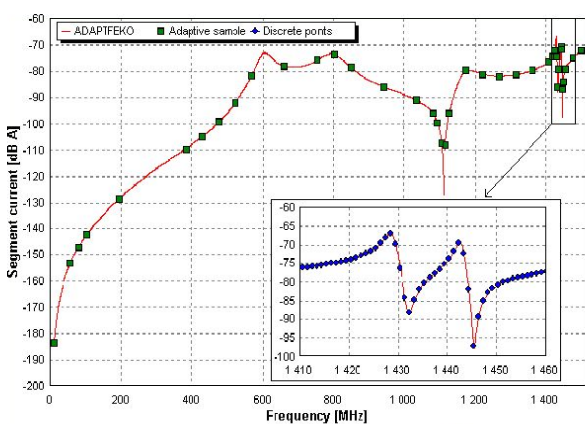
Fast Frequency analysis

As already mentioned, FEKO is based on the MoM solution to Maxwell's equations in the frequency domain. This means that a full solution is required at each frequency point of interest. For structures that have sharp frequency variations, but are used in a wider band, this is a significant problem, since many closely spaced frequency samples are required to adequately sample the frequency response.

FEKO comes with a utility that reduces this requirement dramatically. This utility calculates the response at a few selected frequency points and then automatically determines where additional samples are required. The result of this calculation is a continuous representation of the frequency dependant data.

By way of example, consider the following problem. A shielding enclosure is illuminated from the outside. The current induced on a wire segment inside the enclosure is calculated as a function of frequency. Due to the nature of the problem a very large number of discrete frequency solutions are required in order to find an accurate representation of its highly resonant frequency response. It is important to realise that no prior knowledge about the frequency response exists, making it difficult to know how many frequency samples are required. The adaptive frequency interpolation will ensure that enough samples/discrete solutions are made in order to get an accurate representation of the frequency response.

In the result obtained below, the entire frequency response is calculated with only 33 frequency sample points. Note the rapid variation at 1.4 GHz.



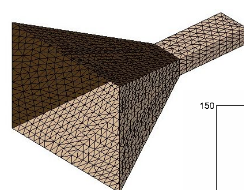
Time Domain representation

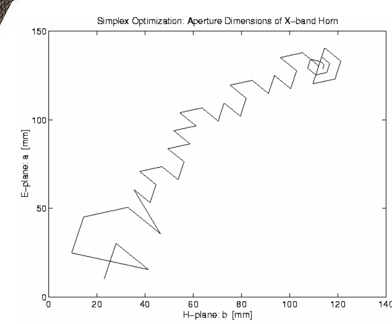
A special utility (TIMEFEKO) can be used to calculate the time domain response of a structure using the frequency domain data from FEKO and a FFT. The utility automates the process. Several input pulse forms are available (Guassian, Ramp, Double exponential, Triangle).

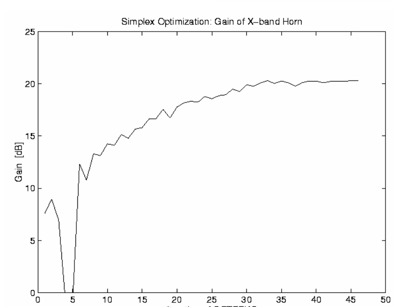
Optimisation

An optimisation utility is available to optimise a structure that has been defined using parameters in FEKO. Typically, this quantity will be a geometric property, but it is not limited to geometric optimisation only. FEKO allows for multiple aim functions, which are defined from the GUI. The aim functions that are available include input reflection minimisation, gain maximisation and radiation pattern specification.

By way of example, consider a horn where the aperture dimensions are variables which are optimised in order to maximise the gain of the antenna. Shown is a graph of the aperture dimensions as a function of iteration number, and a graph of the gain versus iteration number.



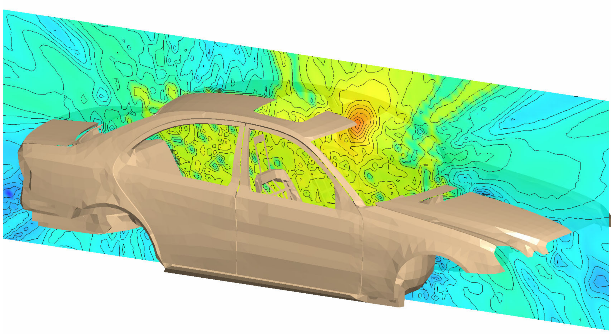




Solution of Electrically Large Problems

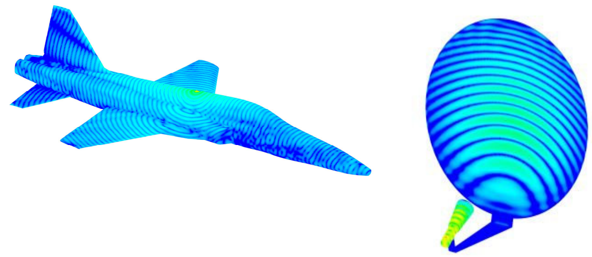
Full-wave techniques (MoM, FEM etc.) generally suffer from poor scalability. This limits the electrical size of the problems that can be solved on typical computers. When using field based solution techniques (FEM, FDTD), the discretisation of the field introduces a very small error as a wave propagates through the mesh. For very large meshes, these errors could add up, resulting in reduced accuracy in results. The error can be reduced by using a finer discretisation, but this increases the resource requirements.

The MoM does not require field discretisation, which means that the propagation distance does not degrade the accuracy of the results. With the MoM the memory required increases as the number of basis functions squared. For general structures, a basis function density of about 100 basis functions per λ^2 is recommended. For 1 GByte RAM, and using no symmetry, this translates to a surface area of approximately 82 λ^2 that can be solved in-core. Larger problems can be solved using an efficient out-of-core solver in FEKO, but this solution is slower than an in-core solution.



Whereas the memory requirements for MoM is proportional to N^2 that of the MLFMM is N*log(N) (where N=number of basis functions and for metallic surfaces $N \approx 100*(A/\lambda^2)$ with A the surface area). For large N this is a huge difference!

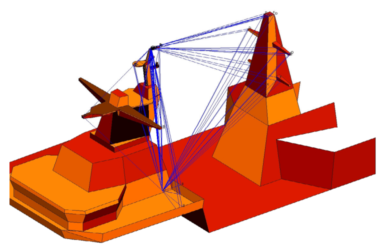
Asymptotic predictions of memory usage for the MoM with and without MLFMM			
N	MoM	MLFMM	Application
100,000	150 GB	1 GB	Military aircraft at 690 MHz Reflector antenna with aperture size 19λ
200,000	600 GB	2 GB	Military aircraft at 960 MHz Reflector antenna with aperture size 27λ
400,000	2.4 TB	4.5 GB	Military aircraft at 1.37 GHz Reflector antenna with aperture size 38λ
1 000,000	15 TB	12 GB	Military aircraft at 2.2 GHz Reflector antenna with aperture size 60λ



Although the MLFMM enables the analysis of electrically large problems this accurate full-wave method is not sufficient for the solution of electrically huge structures (e.g. aircraft or ship at 10 GHz and above).

Asymptotic high frequency techniques (PO and the UTD) offer a solution to the scalability problem for such problems. In the PO formulation the currents on the metallic surfaces are simply calculated from the incident field. With the UTD only the closed form, reflection and diffraction (edge and corner) coefficients are used in the solution. The size of the object, therefore, does not influence the memory requirement. The coefficients (terms) and the number of interactions do however influence the run-time. The UTD formulation requires that the smallest dimension of the UTD objects be at least in the order of a wavelength.

Whereas the triangles (for PO) are well suited to represent complex geometry the flat polygonal plates restrict the application of the UTD to geometries which can be modelled sufficiently with such plates (e.g. ship).



In FEKO, the generally applicable MoM has been hybridised with the Physical Optics (PO) and the Uniform Theory of Diffraction (UTD). This hybridisation enables the solution of large problems on small computers. The hybridisation allows for full wave analysis where required, and approximations to be used when applicable.

Evaluation, Licencing, Pricing and Support

Evaluation

Evaluation of FEKO can be arranged free of charge for a 45 day period. Interested parties are requested to download the software and register for evaluation at www.feko.info.

Operating Systems

The optimal platform for FEKO is usually determined by the application. FEKO is available for PC's running Windows (NT, 2000 and XP) and Linux. It is also available for distributed or shared memory parallel systems. Popular workstation hardware and operating systems are also supported. Visit the website for a list of currently supported hardware and operating systems.

Pricing

Contact EM Software & Systems-SA (Pty) Ltd or your local FEKO reseller for an official quotation.

Available Licence Types

- FEKO LITE (Limited, Licenced, but FREE version of FEKO)
- GUI Version (32 MByte limitation) **(GUI available on Windows and Linux!)**
- Classroom Licence (256 MByte limitation)
- Silver (32-bit ix86)
- Gold (64-bit Intel XEON EM64T, AMD Opteron)
- Platinum (64-bit Intel Itanium, other "UNIX Workstations" for a detailed description see www.feko.info)
- Workstation Parallel, 2 GUI versions included

Discounts

- Discounts are offered for multiple licences
- Educational discounts of 75%
- Classroom Licence: Educational Institutes can qualify to get up to 9 Classroom Licences, for free, for each purchased or rented licence.

Engineering Support Services

EMSS has a general policy of placing FEKO support at the highest priority. Typically, we respond to queries within 24 hours. Feedback regarding any aspect of FEKO, its components, the installation of the software, the documentation or anything else relating to the software is always appreciated, as we value the input of our customers highly.

Short Courses

EMSS offers short courses on FEKO which can be attended at EMSS, on-site or at a predefined venue. With these, a theoretical background on FEKO and the use thereof (pre- and post-processing) are presented and the company specific applications discussed. Please contact EMSS or a FEKO representative for more information.

Technical Support

- Support (by email, fax or telephone) is available to users, free of charge, for the first year after purchase.
- Annual engineering support and software upgrades are also available on a yearly basis to customers who have paid their maintenance and support fees (i.e. from the second year onwards).

Maintenance and Support Fees

EMSS is committed to the continued development of FEKO. Annual Maintenance and Support Fees allow further technical support and free upgrades.

- Maintenance and Support Fee is included in the first year after purchase.
- From the second year the Maintenance and Support Fee is 20% of the listed price.

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