Defence or Civil Radar – it's a Matter of Wave Propagation

Radar: Some Historical Background

"The history of radar began with the experiments of Heinrich Hertz in the late 19th century, which showed that radio waves were reflected by metallic objects. This possibility was suggested in James Clerk Maxwell's seminal work on electromagnetism. But it was not until the early 20th century that systems, able to use these principles, were becoming widely available, and it was the German inventor Christian Hülsmeyer who first used them to build a simple ship detection device, intended to help avoid collisions in fog (Reichspatent Nr. 165546). Numerous similar systems, which provided directional information to objects over short ranges, were developed over the next two decades." From Wikipedia, the free encyclopaedia.

Fig. 01: Matrix of phased array antennas (AN/FPS-115 radar)

Radar development was essentially motivated by military needs during the second world war, where radar use founded dozens of applications for instance navigation, aircraft location, enemy ship detection, anti-collision, and weather forecast.

At first radars were designed in VHF and UHF bands, then, after the magnetron development for high power transmission, microwave radars appeared. The first microwave radar was developed for aircraft detection purposes and handled tracking with a parabolic antenna. During this time, air defense reached a high level of success. Most of the radars were using pulse systems based on sending pulses of electromagnetic energy and received reflected echoes from targets. Since waves are traveling in a certain direction at light velocity, distance to target was determined from the speed of the travelling wave x time signal delay and the target position from radar direction.

Later the Doppler principles were established to determine the target velocity from frequency variation, to understand if the target is moving toward or away from the radar. With this development, radar had reached its three main detecting functions: range, speed and velocity.

Radar has been continuously developed and extended to a wide variety of object detection and tracking, such as missiles and satellites. By now it has become an integral part of most air and missile defense systems. The next radar generations were based on phased arrays antennas and electronic scanning architectures. The aim was to reduce radar weight and heavy mechanical scanning systems. Compared to full mechanical scanning systems, electronic systems are expensive and limited in terms of field of view. As an alternative, hybrid concepts have been developed using a matrix of phased array panels (fig. 01) or mixed electronic and mechanical scanning systems (fig.02).

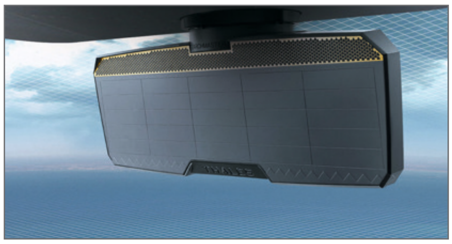


Fig. 02 Mix of electronic and mechanical scanning radar (THALES Searchmaster radar)

Other radar systems include modern detection concepts functioning as digital beam forming, switching and commutation systems, and monopulse (phase and amplitude) detection. The aim is to receive better accuracy, higher resolution, better target selection and recognition and better imaging, than the first radar concepts with simple key detection parameters could offer.

In addition to historical military use, radars also have many civil applications, for air traffic control and surveillance, altitude measurement, collision avoidance and weather forecasts – i.e. to avoid storms.

Meeting the Design Challenges

Military and civil surveillance radars require, depending on the domain covered, a high design and integration level to follow several constraints set by the industry. In the first step, the microwave circuit design has to be considered, which can be based on several technologies: i. e. microstrip (Fig. 04) and waveguides (Fig. 03). The circuit ensures the link between the generator and the antenna feeder to have the best match between generator output and antenna input. Simple and complex circuit designs are targeted depending on the radar system and the antenna architecture.

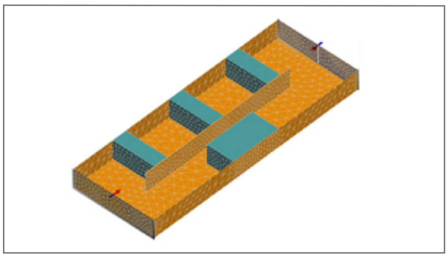


Fig. 03 Waveguide device design

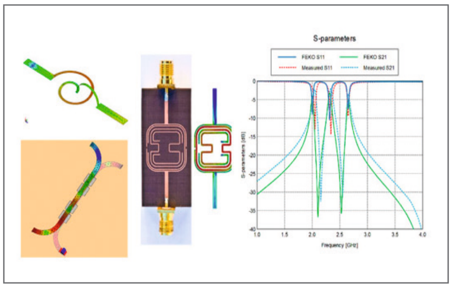


Fig. 04 Microstrip circuit design

In addition to matching, those circuits also have other purposes, ranging from filters, splitters, junctions to circulators. For the creation of the desired circuit design Altair's electromagnetic simulation suite FEKO offers several techniques for finite and infinite structures, linked to powerful local and global optimisers. From circuit design, microwave engineers can move on to the design of radar antennas. Also for this task the FEKO solver includes several tools, which can be used to design and optimize e.g. 2D antennas (Fig. 05), with additional dedicated antenna tools such as periodic boundaries, Domain Green's Functions Method (DGFM) and Method of Moments-Green's Function (MoM-GF).

In addition, 3D antennas are part of the design list of FEKO, including full-wave and asymptotic dedicated methods that ease the antenna development. Hybridization between full-wave and asymptotic methods is also a very important option to have a good trade-off between accuracy and computational aspects. Furthermore local and global optimisers can be coupled to complex 3D designs to reach the challenging radar requirements.

"Moreover, the solutions they come up with are often more efficient, more elegant, or more complex than anything a human engineer would produce. In some cases, genetic algorithms have come up with solutions that baffle the programmers who wrote the algorithms in the first place!" wrote Adam Marczyk on genetic algorithms.

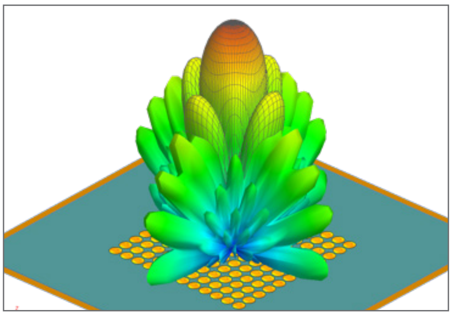


Fig. 05: 2D phased array antenna

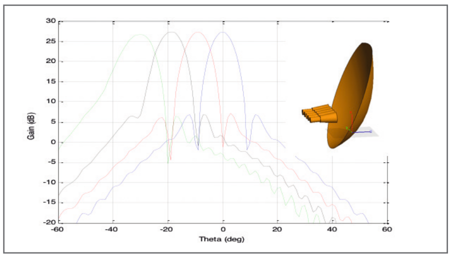


Fig. 06: 3D parabolic antenna with multi feeder

Coming from laws of nature, FEKO also includes powerful genetic and particle swarm algorithms to enable even the most complex radar antenna design (Fig. 06).

Latest techniques based on characteristic mode analysis (CMA) complete the powerful antenna tools, which help designers to follow a systematic and intelligent approach in their development efforts.

To also reach the latest radar constraints, even very complex and challenging antenna concepts can be targeted. From planar antennas and architectures, one can migrate to conformal structures for a more compact design (Fig. 07).

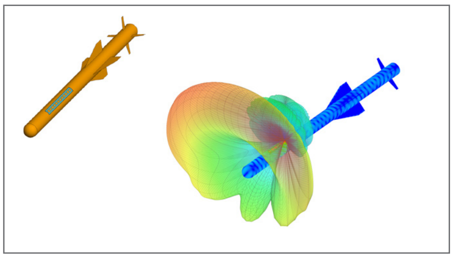


Fig. 07: Conformal patch array on missile structure

Radome Design and Radar Integration

The first radars were designed without any housing structures. When radars were implemented on aircrafts, a radome (radar dome) was developed to protect the antenna from the surrounding environment, especially from effects such as humidity, high or low temperature, bird strike, or dust.

Radomes contain dielectric materials and sometimes paint layers. Since most of the radars are designed in the microwave domain, the radome's thickness produces wavelength multiples and hence modifies the antenna patterns. Thus, radome structure and layers must be considered right from the beginning of the design process. A non optimized radome can lead to several weaknesses such as gain loss, bore sight errors (BSE), high side lobes levels, main lobe degradations and many more. In that case the radar's key parameters degrade and may lead to decrease the radar range, ghost effects, artefact detections, or angular errors detection.

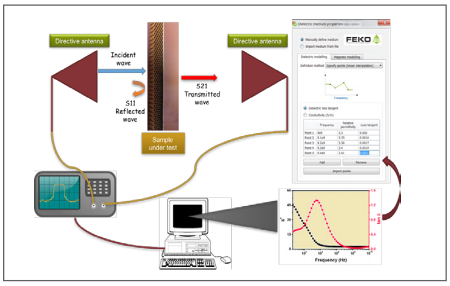


Fig. 08: Material characterization process

The first step in the development process should therefore consist in the design and optimization of the radome layers, to have a good transparency and to reduce spurious reflections towards the antenna. To handle this task very fast, tools based on MoM GF and PBC principles are available. These help the radome designers to meet the radar requirements across the scanning and the frequency range. These efficient tools also help to perform sensitivity stack studies, taking into account parameter variations such as: paintings and materials characteristics, layer thickness, etc. as well as environmental effects (due to temperature, humidity, dust,...) and support the validation of the design process.

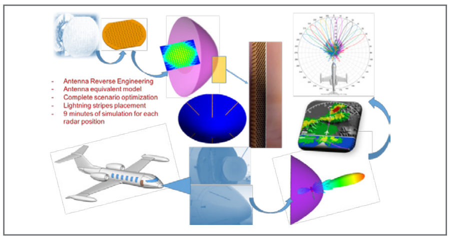
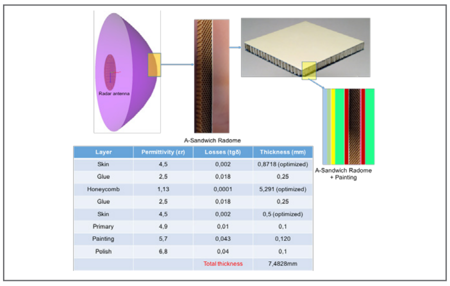


Fig.09: Weather radar design cycle from antenna to radome design

The material layer characterization process (Fig. 08) can be linked to radome tools under FEKO, to take measured S parameters data versus frequency operation band into account: Once the layers of the radome have been optimized, integration designers can perform EM simulations of the 3D radome structure, using three major numerical approaches: MLFMM (Multilevel Fast Multipole Method), RL-GO (Ray Launching Geometrical Optics), and FDTD (Finite Difference Time Domain) – depending on the radome's structure, the number of layers and the dimensions.



Layer	Permittivity (εr)	Losses (tgδ)	Thickness (mm)
Skin	4,5	0,002	0,8718 (optimized)
Glue	2,5	0,018	0,25
Honeycomb	1,13	0,0001	5,291 (optimized)
Glue	2,5	0,018	0,25
Skin	4,5	0,002	0,5 (optimized)
Primary	4,9	0,01	0,1
Painting	5,7	0,043	0,120
Polish	6,8	0,04	0,1
		Total thickness	7,4828mm

Fig.10: A-sandwich radome design

Several radome designs for different radar applications, for defence and civil domains, are targeted. These include: weather radars (Fig.09), tactical radars, on-ground tracking radars and more. In addition several radome structures, such as Monolitic and A/B/C-sandwiches (Fig. 10) with painted and unpainted configurations, are possible.

From Radar Integration to Radar Placement

To take into account the radar's environment (Fig.11), the placement of radars on platforms must also be considered beyond the integration of related radar topics.

Several techniques of antenna+radome equivalent models (near fields, far fields, spherical modes,...) can be used to reduce the simulation runtime when large electrical objects are simulated. Full wave, asymptotic and hybrid methods are used to solve complex radars and large radar placement scenarios. Dynamic parts of structures can be considered in the NGF method to reduce simulation runtime by solving only dynamically unknowns part of the MoM matrix. This feature is very useful to scan radar operations over a wide angle range.

Altair's Electromagnetic software solution FEKO covers all aspects of radar simulation, from radome design to radar integration and placement and helps to meet today's design challenges.

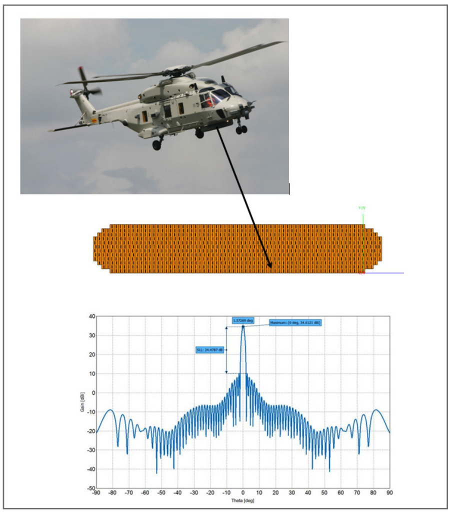


Fig. 11: Tactical radar on Naval helicopter configuration

For more information, please visit: altairhyperworks.com/FEKO

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