Tijdschrift van het NERG

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DE VERENIGING NERG

Het NERG is een wetenschappelijke vereniging die zich ten doel stelt de kennis en het wetenschappelijk onderzoek op het gebied van de elektronica, signaalbewerking, communicatie- en informatietechnologie te bevorderen en de verbreiding en toepassing van die kennis te stimuleren.

BESTUUR

LIDMAATSCHAP

Voor het lidmaatschap wende men zich via het correspondentie-adres tot de secretaris of via de NERG website: http://www.nerg.nl. Het lidmaatschap van het NERG staat open voor hen, die aan een universiteit of hogeschool zijn afgestudeerd en die door hun kennis en ervaring bij kunnen dragen aan het NERG. De contributie wordt geheven per kalenderjaar en is inclusief abonnement op het Tijdschrift van het NERG en deelname aan vergaderingen, lezingen en excursies.
De jaarlijkse contributie bedraagt voor gewone leden € 43,- en voor studentleden € 24,-. Bij automatische incasso wordt € 2,- korting verleend. Gevorderde studenten aan een universiteit of hogeschool komen in aanmerking voor het studentlidmaatschap. In bepaalde gevallen kunnen ook andere leden, na overleg met de penningmeester voor een gereduceerde contributie in aanmerking komen.

HET TIJDSCHRIFT

Het tijdschrift verschijnt vijf maal per jaar. Opgenomen worden artikelen op het gebied van de elektronica, signaalbewerking, communicatie- en informatietechnologie. Auteurs, die publicatie van hun onderzoek in het tijdschrift overwegen, wordt verzocht vroegtijdig contact op te nemen met de hoofdredacteur of een lid van de Tijdschriftcommissie.

TIJDSCHRIFTCOMMISSIE

INHOUD

Deze uitgave van het NERG wordt geheel verzorgd door:
Henk Visscher, Zutphen

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Van de redactie

Michel Arts
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Voor u ligt het tweede nummer van het Tijdschrift van het NERG voor 2010. Het eerste artikel is de intreerede van prof.dr. Giampiero Gerini die hij op 14 november 2008 gehouden heeft aan de Technische Universiteit Eindhoven. Het tweede artikel is een deel van het eerste hoofdstuk van het proefschrift van dr.ir. Huib Visser. In dit artikel wordt in het kort de probleemstelling van zijn proefschrift beschreven. Tenslotte volgt een kort verslag van het TNO/NERG-symposium "Het slimme leven" dat op 12 maart jl. werd gehouden.

Met ingang van het vorige nummer is een begin gemaakt met de invoering van het elektronisch tijdschrift. Op de website van het NERG (www.nerg.nl) ziet u links onder Main Menu ook Tijdschrift staan. Als u inlogt kunt u het vorige nummer in pdf-formaat downloaden. Alle nieuwe nummers zullen voortaan ook op de website geplaatst worden. Ze zullen echter alleen voor leden toegankelijk zijn. Op de website staat ook hoe u een account kunt aanvragen als u dat nog niet heeft, maar wel lid bent van het NERG.

Het verheugt mij dat we er, na enkele jaren van minimale bezetting, weer een redactielid bij hebben. Het is Mark Bentum. Mark is universitair hoofddocent aan de Universiteit Twente en één dag in de week werkzaam bij ASTRON in Dwingeloo. Welkom bij de redactie, Mark.

Antennas in (the) evolution

Inaugural lecture
prof.dr. Giampiero Gerini,
14 November 2008

Inaugural lecture prof.dr. Giampiero Gerini. Presented on 14 November 2008 at the Eindhoven University of Technology

Introduction

Imagine that one day, all the antennas in the world suddenly stop working. In reality, the chance of a simultaneous breakdown of all these antennas is infinitesimal. It could happen if for some reason the electromagnetic laws (on which antennas are based) ceased to apply. But this would mean such catastrophic changes in the world, that the fact that antennas stopped working wouldn't be our biggest problem. It therefore takes a real effort of imagination to think of such a situation, ignoring the appeal of our rational nature and any scientific argument. This might seem inappropriate in an inaugural lecture, especially in an Engineering department. On the other hand, there is also an opposite point of view, the one of the so-called modern 'instrumentalism', which looks at science as something useful, but far away from noble arts like literature and philosophy. To present such a current of thought, I will use the critical description given by Karl Popper in his essay 'Science and Philosophy'. "There are people who think that science is, in a way, nothing more than something similar to the job of a plumber, although located at higher level. Science is very useful, but it is such that it can represent a menace for the real culture and such that it threatens the imposition of the domain of the 'quasi-illiterate' (of the 'mechanics', according to Shakespeare). It should be never mentioned together with literature, arts, philosophy. Its discoveries are pure and simple mechanic inventions, its theories are instruments. It cannot reveal, new worlds, hidden behind the surface of the every day life of the world, which is just appearance."

Like Popper, I don't agree with this point of view, and if Popper starts from there to derive his theories about science, I would simply like to take the opportunity here to mix some of the different noble disciplines: arts, history, literature and science. So please allow me to go back to my original question. What would the world be like without antennas? The impact would be much, much larger than what you can imagine. In fact, antennas are very often hidden from our eyes; we don't see them, we don't feel them, but every day they keep fulfilling their task of making our lives easier, more effective, sometimes enjoyable and very often saving the lives of thousands of people.

No more radio ('the tribal drum' as Marshall McLuhan calls it in his essay 'Understanding Media'), no more television, no more information from space (weather forecasts, monitoring of the environment, space science, telecommunications..), no more mobile phones, no more radar (on ships, airplanes and cars), no more wireless systems. As a first reaction, someone might consider this a blessing, considering the exaggerated and distorted use that is sometimes made of some of these systems. But with calm and more objective thinking, we should easily agree that the importance of antennas in our world is fundamental. Of course, this is not just due only to antennas, they do not work alone. They are good 'teammates', and they work in very close cooperation with waveguide structures, amplifiers, filters etc. etc.

In any case, the function of antennas is to convert electrical signals containing information into electromagnetic waves which are launched into the empty space surrounding us. In a way, they represent an advanced extension of our mouths. The waves propagate in space, bringing with them their important 'information loads', and sometimes they travel millions of kilometers before they reach another antenna ready to welcome them, take their message and pass it to whoever was waiting for it.

In this way the receiving antennas act as powerful extensions of our ears.

At this point, you may already be asking yourself where I am going to end up, if I am going to continue with this 'more romantic than scientific' approach. It's therefore time for a declaration of intent.

In this inaugural lecture, I want to present you with my 'vision', my program on advanced antennas. I will try to give an appealing overview of my work program, highlighting in particular those applications on which I will concentrate my research. This clearly requires the use of scientific language and technical terms, but I don't want to limit myself to a purely scientific and technical presentation, for which there are conferences and symposia organized all over the world. I would like to show the relevance and the importance of the research themes that I am proposing for society and for progress. I would like to show how the output of scientific work very often (but unfortunately not always) responds to the needs of human beings, but also influences their evolution. For this, you need more than purely scientific and technical language, so therefore I have decided that this very special occasion is the best opportunity for me to combine the rigorous and rational scientific approach with a bit of art, history and literature.

One of the factors that has had, and still has, a very strong influence on the evolution of the human race is the development of complex and articulate communication. In the beginning, our primitive ancestors used gestures and simple guttural sounds, which then evolved relatively rapidly into more complex language. Also the elaboration of a writing system, able to provide concrete support for thoughts and words, responded to the human need for communication. But there was still a limitation, due to the fact that interactive communication was only possible over very limited distances. As soon as social life passed the limit of the tribes, as soon as there was the need to explore larger areas and to interact with other groups at larger distances, this pushed human beings to explore other forms of communication: tom-tom, smoke signals, light signals.

This was already an enormous improvement which allowed simple yet effective communication over large distances, overcoming physical barriers. This can also be seen as the start of the process of contraction of distances, which nowadays, thanks to the enormous progress of communication technology, lets larger and larger numbers of people feel part of the same community. Of course, these means were soon no longer adequate for the capacity of the 'evolving man', who was able to cover larger and larger distances efficiently, to discover new territories, to maintain efficient control of larger areas. There was a need to provide an efficient and secure communication network. For thousands of years, messengers continuously put their lives in danger to bring important messages to governors and news to citizens. History and literature are full of their heroic deeds: Philippides and his epic 'Marathon'; the irresistible rides of 'The Three Musketeers' with their secret messages, in the famous novel of Alexandre Dumas senior, which so vividly impressed my childhood fantasy; or the Pony Express, the US system of mail delivery with continuous relays on horseback covering about 2900 kilometers in ten days. Once again, the importance of communication for human beings, and the effort that they put into improving it, is indisputable. Nevertheless, it took thousands of years before Guglielmo Marconi in the late nineteenth century effectively demonstrated the possibility of communicating using radio waves. Although many other researchers had been working on the wireless telegraph idea for many years before him, it was Marconi who made the first real magnificent leap into wireless technology, and who made it practical: transmitting voice and information over enormous distances without a physical connection. Starting from the pioneering experiments of Heinrich Hertz, who was the first to broadcast and receive radio waves in a laboratory, Marconi sent the first ever wireless communication over open sea in 1896: first covering up to 6.4 km on Salisbury Plain, and then reaching nearly 14.5 km across the Bristol Channel. Marconi's great triumph, however, came a few years later, in 1901, when at St. John's, Newfoundland, he received signals transmitted across the Atlantic Ocean from Poldu in Cornwall. This achievement created an immense sensation all over the world, since it demonstrated the possibility of transmitting signals over such distances, despite the opinion of many distinguished scientists that the curvature of the Earth would limit practical communications.

Wireless technology has made tremendous progress in the last decades, and it is not difficult to realize how often we make use of it, at home, at work, on holiday, wherever we are in the world. This is a discipline that involves many different aspects, and requires know-how in several fields, of which antennas is one of the most important. Wireless technology is a very strategic field for our University, with the creation of the Wireless Centre (CWT/e) of which I am proud to be part. It is also a very important and strategic field for TNO, constituting, together with electromagnetic fields and antennas, one of the basic pillars of radar, imaging, space and telecommunication systems.

These are actually the most important application areas that I will address in my talk. I will give an overview of trends and challenges in these areas, with particular attention to their implications for antennas.

Wireless

Antennas for wireless applications come in a very large variety, due to the many different uses, different environments, different platforms and the continuous expansion of the frequency range of operation. Wireless systems require large, medium and small antennas for base stations (from a few meters to a few centimeters), as well as small and very small antennas for the user terminals (down to a few millimeters). These antennas have different requirements, with different technological and design challenges. For example, antennas for base stations are often called smart antennas, since in the most advanced systems they are required to be able to adapt their radiation pattern according to the different environments. For example, to create more beams to follow different users simultaneously, to create nulls in the radiation pattern to reduce interference and disturbing signals, or at least to have the capability to electronically steer the beam to fine-tune the antenna pointing. These antennas do not necessarily need to be 'miniaturized', but they might be required to be conformal, to be shaped and adapted to particular supporting structures for reduced visual impact, for aerodynamic reasons or to meet mechanical and thermal requirements. At the same time, wireless systems serve the end-users with their portable devices. In this case, the antennas are totally different and their characteristics are dictated by totally different requirements like: very small dimensions, good efficiency for reduced power consumption, integration with the electronics for ease of manufacturability and cost reduction, and of course structural integration in the 'portable device'. The frequency range is also very rapidly changing, leading to the development of new antenna concepts and new technological solutions. This trend is mostly dictated by a couple of reasons: the constant increase in transmission capacity required by the new wireless systems, and the crowding of the lower frequency spectrum, where many different bands are allocated to different systems and services.

It is also clear that the use of higher frequencies and therefore smaller wavelengths allows the use of very small antennas, meeting the continuing trend towards miniaturization. Research groups are already looking at the use of the sub-mm wave/THz spectrum for secure communications and short-range wireless systems. By definition, submillimeter waves cover the frequency range from 300 GHz to 3 THz. Their propagation in the

atmosphere is characterized by a very high absorption rate. This aspect, which is usually regarded as a drawback, in this case on the contrary makes them suitable for extremely high-capacity shortrange secure links. In fact, very directive phased array antennas, which would still have very compact overall dimensions, could provide a point to point signal directionality, and therefore covertness, similar to that of a laser. Furthermore, the very high frequency of operation would allow enormous bandwidths. I have just mentioned sub-millimeter/THz waves. I will go back to this topic many other times, since I believe that this frequency range represents a new frontier with some of the most challenging developments in the coming years. THz technology is also one of the three main research lines of CWT/e and it will constitute an important part of my research program.

Radar

It is time now to introduce another important research area for antennas, and let me go back again to human evolution. In their evolution, human beings have developed more and more complex and faster systems of transportation. The domestication of animals like horses and the invention of the wheel, of course, have helped humans to cover larger distances in shorter times, and to reach places which they could never have reached with their own physical strength. The invention of engines meant an incredible leap forward, gradually making human senses (eyesight, hearing) not up to the task of controlling the very rapidly changing environments, and at the same time helping to quickly take essential safety decisions. As we all know, the limitations of human physical performance (we can easily find animals with much better physical performance than ourselves) have been largely compensated by the incredible evolution of the brain, and by the corresponding capacity to develop instruments, tools and in the end technology to provide powerful extensions of our senses. Radar is an excellent example. The idea of using electromagnetic waves to detect metal objects was first introduced by Christian Hulsmeyer, who in 1904 with his 'Telemobiloskop' demonstrated the feasibility of detecting the presence of a ship in dense fog. He gave his first successful demonstration on 17 May on the banks of the Rhine, in Cologne. A few days later, on 9 June, he repeated his experiment in the Port of Rotterdam, after an official invitation from Mr. J.V. Wierdsma, CEO of the Holland America Line. Many other engineers and scientists worked on the further development of Hulsmeyer's concept, which reached maturity before the Second World War. In particular, the British were the first to develop a real radar system which was effectively used as a defense against aircraft attack and for submarine detection. The use of radar information in 1940 already played an important role in the successful mission of the British fighters during the famous 'Battle of Britain', and also for the final successful result of the 'Battle of the Atlantic'. In this latter case, the final defeat of the 'U-boats' was a major achievement, and a major step towards the successful conclusion of the war, allowing an uninterrupted flow of reinforcements across the Atlantic.

In the Netherlands, the initial interest of Mr. Wierdsma was further consolidated in the following years, producing a research and development program that has created the conditions for which this country can be considered as one of the key players in this field.

The basic principle of operation of radar is based on the reflection of electromagnetic waves from objects whose electromagnetic characteristics are different from the surrounding environment. In principle, any solid object embedded in a different medium (typically air), when 'illuminated' by an electromagnetic wave, reflects back part of the energy which can then be detected. Radar systems radiate electromagnetic waves in a controlled way (in a well defined angular region and spanning the complete area of interest), and receive the energy reflected by any objects present in the area under consideration. Several types of information can be gained from the reflected signals: distance, velocity and in some cases also the type of object.

Antennas are an essential part of a radar system. Their gain, frequency bandwidth and polarization characteristics have a fundamental impact on the overall system performance. Last but not least, the structural integration of the antenna and the platform is becoming more and an issue in modern systems. Radar is not only used in land platforms, it is also mounted on board ships, aircraft and satellites, and in vehicles.

All these platforms require that the antenna is mounted in a way that satisfies specific mechanical, thermal and aerodynamic requirements. Very often, these requirements are not related to the electromagnetic performance of the antenna, and careful trade-offs are necessary.

Two types of antennas are typically used for radar systems: reflector antennas, the most traditional and widely used solutions, and phased array antennas. The latter represent the state-of-the art, and are the most flexible and advanced antenna systems, but on the other hand they are also much more complex and expensive.

A phased array consists of an array of radiating elements, typically arranged in a regular lattice. In a transmitting array, these elements are fed simultaneously with the same input signal to which a phase delay and, in same cases, an amplitude tapering is applied. Apart from the amplitude tapering, which is applied to properly shape the radiation pattern of the antenna if necessary, the phase delay between the different elements is the real basis of the phased array concept. When all the elements are fed in phase, the electromagnetic fields radiated by each element sum up coherently, producing a more directive overall pattern pointing perpendicularly (broadside) to the antenna plane. When a proper phase difference is applied to the array elements, the contributions of the different elements sum-up coherently in a main beam, which is now pointing at a certain angle from broadside. The same principles also apply to a receiving antenna. This represents a very attractive feature for a radar antenna, since it allows the radar to track targets in very rapidly varying environments, and also to change the radiation pattern accordingly, for example to reject jamming (disturbing signals), to avoid interference with other antennas, or to track more targets simultaneously.

Antenna and T/R module technologies for phased arrays have received tremendous attention in the past decades. Nevertheless, this field continuously requires new technological solutions that are able to cope with the requirements of the new generations of advanced radar systems. These requirements are:

- Low cost
- Low mass and low profile
- High efficiency
- Polarization agility and purity
- Large scanning angles
- Wide frequency bandwidths

Low cost, low mass and low profile technology

A phased array is a very powerful and versatile antenna, but it is still much more complex and expensive than a reflector antenna. Engineers and scientists are constantly required to look for innovative, low-cost technological solutions, where for example the antennas could be manufactured on typical printed circuit boards, or on multilayer semiconductor technologies used for the development of MMIC components.
This would not only allow considerable cost reduction, permitting the development of the entire front end in the same manufacturing process, but also highly integrated solutions, which are very convenient in terms of efficiency and compactness.
The choice of manufacturing processes very often poses some limitations on the type of materials and on the layouts of the structures that can actually be implemented:

- reduced flexibility in the manufacturing process (difficulty in changing the dimensions of different layers, adding or removing dielectric or metal layers etc. without requiring expensive ad hoc modifications of the process);
- the characteristics of the substrates, in particular thickness and dielectric constant (permittivity);
- the manufacturability of large panels, or the positioning and interconnection of smaller panels.

Such limitations may prevent the realization of the optimal structure to achieve the best electromagnetic performance.
In particular, the first two factors are related to an important electromagnetic phenomenon: the excitation of surface waves, which have a strong influence on the electromagnetic performance of the antenna and its efficiency. These aspects will be further discussed in the next point.

High efficiency

A planar printed antenna on a dielectric substrate with high permittivity can excite surface waves which strongly affect the performance of the antenna itself. Surface waves are electromagnetic waves guided by the overall structure which can trap inside the antenna dielectric substrate part of the energy that should be radiated, therefore reducing the antenna efficiency. Furthermore, when they arrive at the edges of the dielectric support, diffraction effects totally ruin the radiation pattern with the generation of spurious lobes.

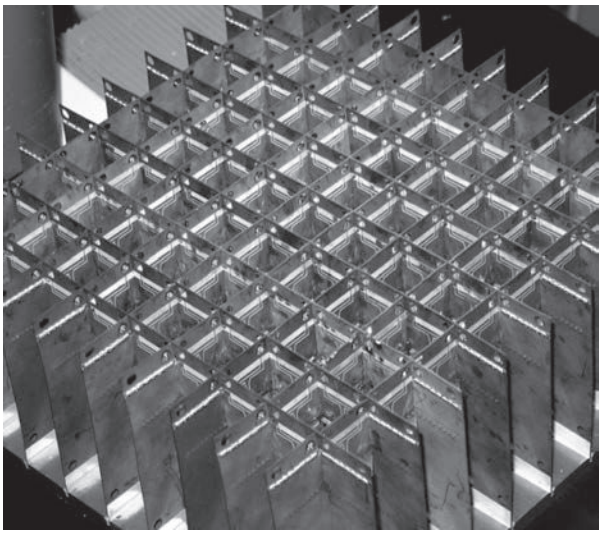
In a phased array, surface waves have the additional effect of increasing the coupling between the elements, under certain conditions causing scan blindness effect (unwanted nulls of the radiation pattern). The excitation of surface waves strongly depends on the dimensions of the slab and its permittivity. If a compromise must be found to adapt the antenna to the characteristics of the substrate for the electronic components, novel configurations must therefore be engineered to control or prevent the excitation of such waves. Technologies like Electromagnetic Band Gap (EBG) structures or Frequency Selective Surfaces (FSS) can provide innovative, low-cost solutions. These structures, which can be realized with low-cost planar technology, can be used to produce more suitable substrates for the antennas. An EBG-based substrate, for example, can be designed in such a way that it is characterized by a frequency band in which surface waves are very strongly attenuated. This creates a barrier to the propagation of these waves, and if the antenna is designed to operate in such a band, the problems I just mentioned are solved. I will explain this kind of structure in more detail in a dedicated part of this talk.

At this point, I would rather take the opportunity to stress a very important aspect in electromagnetic/antenna problems: the availability of accurate and efficient analytical models to understand and predict the physical properties of the structure under consideration. It is very often impossible or extremely timeconsuming to find optimal and innovative solutions with a trial-and-error process, based on the use of general-purpose CAD tools. Such tools are extremely powerful and user-friendly, and can simulate very complex structures, but do not always provide an easy physical interpretation of the electromagnetic behavior, and furthermore often require very long computation times. This means they are not always the best option in an initial iterative design phase, when it is necessary to have a fast response and it is fundamental to understand the most important parameters of the structure and their influence on the electromagnetic performance of the antenna. The development of these models and tools requires a deep knowledge of electromagnetic theory and the mastery of complex mathematical tools.

Polarization agility and purity, large scanning angles, wide frequency bandwidths

These are the most important parameters that characterize the performance of an array antenna. The development of array systems which can combine optimal performance for all these parameters simultaneously is a very difficult and challenging task. Often, ad-hoc solutions are proposed to specifically address one of these parameters. Or in general, they are the result of a careful trade-off based on the antenna system requirements. Nevertheless, the development of new array antenna concepts that are able to combine optimal performance with respect to all these different parameters still remains one of the main objectives of most antenna engineers. I would like to conclude this part by mentioning a novel and very promising array concept: the so-called connected array. This is currently the subject of a PhD project at this university, supported by and carried out at TNO. This concept originates from an idea of Prof. Musiake presented in his original work [1], which dates back to the 1970s. Although based on a purely theoretical concept which cannot be directly implemented in a real system, this idea has been further elaborated in other scientific works [2]-[8], leading to the concept of connected arrays. In a connected array, the radiating elements are electrically connected and not separated as in a traditional array structure. This can for example be realized with a long, periodically fed slot, or with a very long stripline which is again fed at periodic intervals. One of the most advanced demonstrators of connected array developed so far is shown in fig. 1. This demonstrator

figure 1: Hardware demonstrator of connected array of printed dipoles



has been developed at TNO within the PhD project I just referred to. A connected array can provide the best performance in terms of combined bandwidth, polarization purity and scanning capabilities. I will not go into a long and complex discussion to explain their electromagnetic model, but I would just like to highlight again how the design and optimization of these structures would be impossible without any analytic model. It is not possible to just proceed with a trial-and-error process based on generic electromagnetic CAD tools. We have therefore developed analytical models, which have provided a deep insight into the physics of the structure [9]. Although these models require the introduction of some simplifying assumptions, they are in any case invaluable instruments that provide the guidelines and the necessary know-how for the final optimized design.

Periodic structures

It is now time to introduce a new subject and I would again like to use the concept of evolution. Life originated about 3.5 billion years ago in the form of primordial organisms that were relatively simple and very small. All living things have evolved from these lowly beginnings. At present there are more than two million known species, which are widely diverse in size, shape and way of life. What has produced this incredible result? It has been produced by 'mistakes,' or mutations, which occur in the DNA molecule during replication. The result of these mutations is that daughter cells differ from the parents. Newly arisen mutations are more likely to be harmful than beneficial, because their occurrence is independent of any possible consequences. Occasionally, however, a new mutation may increase the organism's adaptation. The probability of such an event happening is greater when organisms colonize a new territory or when environmental changes confront a population with new challenges. This is also what happens to ideas and theories when they 'colonize' new communities. Periodic structures had been widely studied and adopted for many different applications in the microwave community. These applications included microwave tubes, linear accelerators, filters, artificialdielectric materials, leaky wave antennas, slot arrays, phased-array antennas, frequency-selective surfaces and so on. In the 1990s, the photonics community introduced new concepts and new terminology: photonic band gaps [10]. This terminology and the related structures were suggested mostly by the similarities observed between the stop-band performance of optical periodic structures and solid-state electronic band gaps. This terminology crept into the microwave community where it initially also created some quite strong polemics refuting the novelty of the subjects proposed. It is a matter of fact that in the end, these ideas, these mutations, stimulated new thinking with respect to novel periodic structures, or modifications of existing structures, in order to perform new functions or to improve their performance. This has strengthened the attention in the microwave/antenna community for Frequency Selective Surfaces (FSS) and their applications in combination with antennas, and has produced a variety of novel concepts which can be grouped under the widely accepted terminology of Electromagnetic Band Gap Structures (EBG) and Metamaterials.

In general, these artificial surfaces/substrates are obtained by periodically loading dielectric substrates with metal or dielectric inserts which alter the electromagnetic properties of the overall structure.

Frequency Selective Surfaces represent the first 'generation' of structures of this kind, and their main characteristic is to behave like an open filter. In simple words, FSSs can be completely transparent or opaque to electromagnetic waves in a certain frequency band, and exactly the opposite outside this band. Typical uses of FSSs are as dichroics for reflectors, beam splitters and filters in quasi-optical systems, smart radomes to reduce the RCS, and frequency selective screens to prevent problems with Electromagnetic Compatibility (EMC) and Electromagnetic Interference (EMI).
The practical example of how an FSS is used to reduce the mono-static RCS of platforms like ships and aircraft can help to illustrate the use of surfaces of this type in combination with antennas.

In this case, the FSS is designed to be transparent in the frequency band of the antennas located inside the ship's mast or the aircraft's fuselage, and to be opaque for the out-of-band signals corresponding to detecting radars. By properly shaping the FSS, the out-of-band signal is reflected back, but in a direction different from the incoming signal, where the radar is actually located. This clearly reduces the possibility of detection of the platforms from the radar, while still allowing the correct functioning of the antennas.

If the structures above are examples of widely used FSS applications, they have found new impulses from their combination with components like MEMS and diodes that can render them reconfigurable, and also from their direct integration with antennas. These novel configurations allow new applications like selective screening of rooms, smart radomes for the protection of antenna systems against jamming, and selective ground planes for dual-band antennas.

EBGs represent other very interesting examples of electromagnetic periodic structures. In this case, a dielectric substrate is loaded with an array of metal or dielectric elements in a periodic lattice, which can be realized in three-dimensional (3D) or planar (2D) technology. This periodic loading alters the characteristic of the substrate creating a band gap: a frequency band in which surface waves do not propagate. Surface waves are electromagnetic waves whose field, in normal conditions, is confined and guided by dielectric substrates. It is clear that if a substrate supporting such waves is used to support an antenna, part of the power, instead of being radiated by the antenna, couples to these surface waves and remains trapped in the substrate. As a consequence:

- the antenna efficiency is much lower;
- the radiation pattern of the antenna presents high secondary lobes due to the scattering of surfaces waves from the edges of the substrate;
- the coupling between the radiating elements of an array is strongly increased by the presence of surface waves, introducing possible scan blindness effect. A scan blindness effect is an undesired blind spot in the main direction of the antenna due to a strong destructive interaction between the array elements.

Unfortunately, it is not always possible to choose the antenna substrate characteristics in such a way that they do not support surface waves. Very often the integration of the antenna with the electronics and the use of particular multilayer dielectric technologies lead to the use of substrates which could support surface waves. It is therefore necessary to be able to block their propagation, altering the characteristics of the antenna substrate, without spoiling the overall antenna system performance. A very instructive example is given in fig. 2. In these pictures, an EBG structure in purely planar technology, developed at TNO within a project for the European Space Agency, is used in combination with an array antenna consisting of 8 dipole elements [11]. The properties of EBGs can also be used to create a mix of guidance and radiation. For example, by properly removing elements of the periodic lattice it is possible to create a defect in the band gap structure, through which the electromagnetic field can be confined and guided. This can allow the development of integrated structures, in which waveguides, filters, power dividers, antennas etc. can be realized using the same technology.

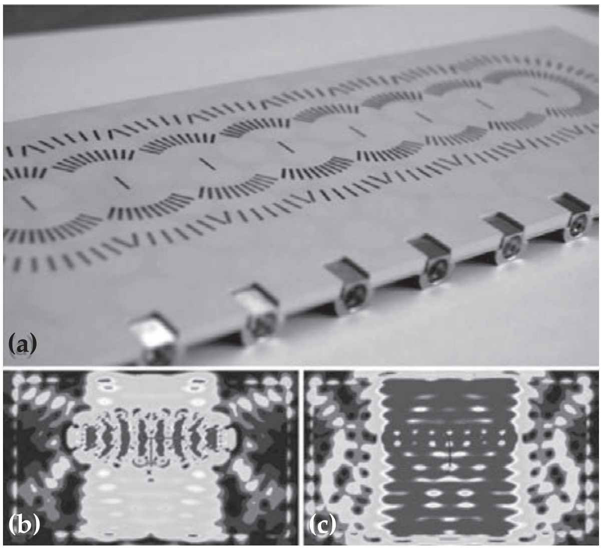


figure 2: (a) Linear phased array based on planar circularly symmetric (PCS) electromagnetic band gap (EBG) technology; field distribution inside the dielectric substrate with (b) and without (c) the EBG structure.

Another possibility connected to the modification of EBGs is given by the capability of such structures to support electromagnetic leaky waves. These waves are characterized by a very peculiar behavior: they propagate in the dielectric substrate, but at the same time they leak energy by radiation. This means that although they are guided by the substrate, like surface waves, they are not confined and they progressively radiate their energy, therefore fading away along their path. A nice combination of the different effects illustrated so far is the antenna shown in fig. 3. In this case the excitation is surrounded by an EBG sector, which prevents the propagation of surface waves and conveys the energy in the opening of the sector. This opening is filled with a modified EBG structure, which is compatible with the existence of a leaky wave. The leaky wave propagating along this altered EBG structure radiates the energy in free space, acting as an antenna.

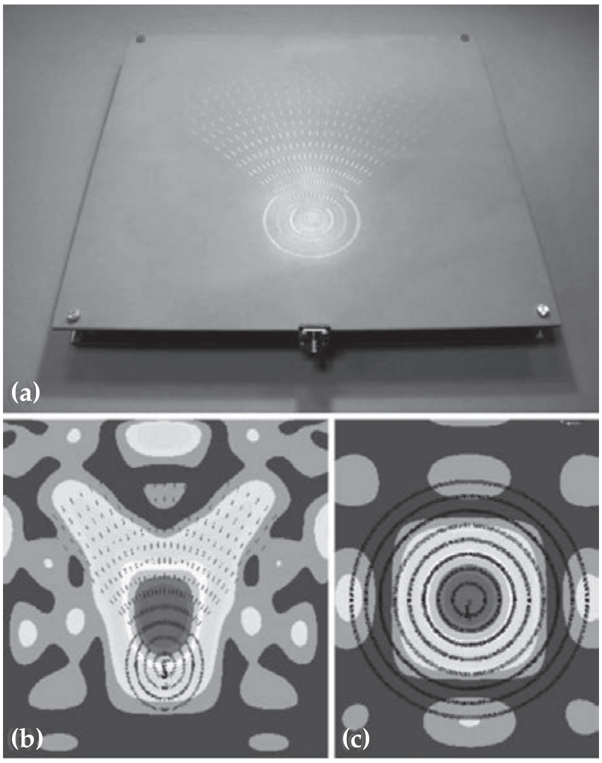


figure 3: (a) Holographic antenna based on planar circularly symmetric (PCS) electromagnetic band gap (EBG) technology; snapshot of the field distribution inside the dielectric substrate with a leaky wave sector (b) and with an entirely closed EBG structure (c).

This last structure allows me to introduce a very intriguing but not yet completely mature concept that is attracting a lot of attention in the scientific community. It is an idea with a tremendous emotional impact on our imagination: invisibility. When is something invisible? When its presence does not impede the view of what is behind it. Extending this idea from optical frequencies to lower frequencies (microwaves, mm and sub-mm waves), the object is invisible when the distribution of the impinging electromagnetic field, on the other side of the obstacle, is the same as it would have been without the obstacle itself. To achieve this, we can imagine the following solution: develop a properly engineered artificial material to cover the object. This material should allow the energy associated with the incident field to be captured, guiding it around the object and then radiating it on the other side of the object, coherently with the non intercepted field, in such a way as to reconstruct the original front wave. Actually, the principle at the base of the antenna mentioned before (combination of surface waves and leaky waves) would allow the implementation of such a concept.

The idea is definitively very intriguing, but it is also necessary very clearly to define its boundary conditions and constraints. At the moment, the main limitation of such a concept is the very limited bandwidth in which the desired effect can be obtained. This means such a concept is not yet applicable, since in most of the applications that can be envisaged, the spectrum of the signal for which the object must be rendered invisible is at least one order of magnitude larger than the available bandwidth. Nevertheless, we all know that history is full of ideas that were first considered to be simply science fiction, but after some years (sometimes more, sometimes less) proved to be feasible and are now part of our everyday life.

THz technology

At this point, I would like to introduce a completely new topic: THz technology. This is a topic of extreme interest and with tremendous development potential. I have already mentioned what this technology can offer for wireless communication, but this is just one of many applications. In the remaining part of this lecture, I will try to present an overview of the most challenging fields of application such as space science, Earth observation and security (detection of concealed objects and substances). This makes sub-mm wave technology one of the most promising fields of research and development, with an enormous impact on society and extremely interesting market perspectives. A further element which should not be neglected is that the expertise in this field in the Netherlands is remarkable, although scattered among different centers and not yet coordinated. Up to now, the real burst has come mostly from space applications, but the increasingly accurate assessments performed in recent years have shown that there are considerable opportunities in many other fields that will fuel researchers and technologists for many, many years to come.

Space science

As a first example of the application field, I will start with space science. One more time, let me go back to the evolution of the human race. We have already discussed the tremendous importance for human evolution of the development of complex and articulate communication. We have also seen the efforts put into the development of means of communicating over larger and larger distances. This, in a way, was also in response to the need for and the attraction of exploring and conquering

new territories. In fact, apart from the fascination of the unknown, the discovery and exploration of new 'worlds' was and still is also responding to the human need to ensure the availability of new resources for the survival of a constantly increasing population.
When technology allowed the 'big leap' into space, the borders of new worlds to be explored became immense. In the last few decades, both manned and unmanned missions have started the exploration of the universe. Who in this room has not at least once seen and been fascinated by the 'sparkling darkness' of the images of the first man on the Moon? Increasingly powerful telescopes and other space instruments have been developed in recent decades, and new ones are continuously being developed to extend our view into space, and our view of the Earth from space. Space science missions study the universe trying to understand our origins; Earth observation instruments help us to monitor our world. Many communications satellites have been placed in orbit to meet our never-ending need for information and communication. Antennas play an important role in all these space missions, and they are the subject of very demanding requirements. It is undisputable that space missions would be completely impossible without antennas.

As an example to illustrate some of the most challenging developments of antennas for space, I will take a new mission by the Japanese Space Agency called SPICA (Space Infrared telescope for Cosmology and Astrophysics). This represents one of the most challenging missions for the exploration of deep space proposed in the framework of the Cosmic Vision (2015-2025) plan. This particular choice is dictated by two main reasons:

- the first reason is that SPICA is supposed to operate in the THz frequency range, and this gives me the possibility to introduce one very important research subject for my professorship: sub-millimeter wave/THz technology;
- the second reason is that a PhD of Eindhoven University of Technology, under my supervision and in close cooperation with the TNO antenna group, is already working on this exciting and challenging subject in cooperation with SRON (Netherlands Institute for Space Research).

A full understanding of how the universe came into existence is only possible by observing the part of the electromagnetic spectrum in which most objects emit detectable radiation. Half of the radiation of a typical galaxy is emitted in the mid and far-infrared (MIR/FIR) range from dust and gas in the interstellar medium. These kinds of observations in the MIR/FIR are very difficult because of the very low level of the signals, which are also highly attenuated by the atmosphere. This requires the development of instruments and telescopes which must be cooled to cryogenic temperatures (in some cases down to few hundred mK;
1K = – 272 °C) to achieve the high sensitivities required, and for most of the spectrum these instruments must be operated in orbit, outside the Earth's atmosphere. Clearly this renders such missions very expensive and complex, and progress has therefore been very slow. In the last quarter of a century, only four operational observatories were available, offering limited spatial resolution and sensitivity. It is in this framework that the SPICA mission by the Japanese Space Agency comes into the picture. It will offer an improvement in sensitivity of two orders of magnitude over the most advanced existing instruments, such as Herschel (ESA mission), as well as making observations possible over the full MIR/FIR range. This huge increase in sensitivity will allow SPICA in a few seconds to make photometric images that would take Herschel hours, and in an hour to take the full FIR spectrum of an object that would take Herschel several thousand hours. One of the SPICA instruments, the FIR Imaging Spectrometer, will be developed in Europe, under the supervision of ESA, and it will require the development of an ultra-wide band (three bands of one octave each) focal plane imaging system with extremely high sensitivity.

A focal plane imaging system consists of three main parts: the focusing optics, the focal plane imaging array and the back-end. The first part consists of reflectors or lenses whose main purpose is to focus the incoming radiation into the receivers. The focal plane imaging array is a set of antennas arranged in the focal plane of the focusing system. These antennas receive the incoming signal and transfer it to the detectors. Each receiver corresponds to a pixel (resolution cell) of the image. The last part of the system is the back-end, consisting of the signal processing module which produces the final output image.

Mapping a radio-astronomical object is very time-consuming. Due to the very low level of the signal, the system has to pause for a certain time at each pixel of the image, which corresponds to the so-called integration time necessary to improve the signal-to-noise ratio. For a large image consisting of many thousands of pixels, the acquisition of the complete image might require an extremely long time. In terms of performance, a focal plane array offers a tremendous advantage compared with a single-detector system, since it decreases the acquisition time tremendously by using parallel receivers to simultaneously map multiple pixels. Coming back to the SPICA European Imaging Spectrometer, the main challenges from the antenna point of view are:

- Extremely high level of integration: the antenna and the detectors must be tightly integrated, requiring compatible technology and an optimized design to allow perfect matching of these two essential parts of the overall system.
- The antenna array must be based on innovative concepts that can achieve the very wide bandwidth requirements, while at the same time being compatible with a technological solution for the realization of very large focal plane arrays of a few thousand elements.
- Development of ad hoc analysis and design tools, which should allow accurate design of the focal plane array in all its constituent parts. Such tools should model all the relevant effects that can affect the final performance of the instrument.

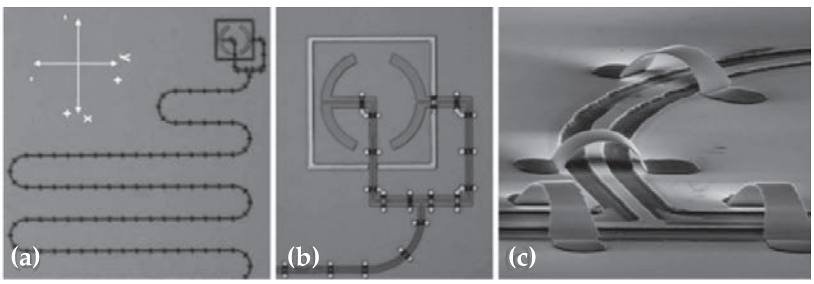
Together with a PhD student of this university and the antenna group at TNO which I have the honor and pleasure of coordinating, we have already started a cooperation with SRON on this topic. SRON is a world-leading research center with state-of-the-art know-how in the development of instruments for space science and Earth observation missions. The main objective of this cooperation is the development of demonstrators of focal plane arrays to prove the readiness of the technology for the SPICA-SAFARI instrument. This mission is considered by SRON to be of strategic importance. Fig. 4 shows the first antenna-detector system designed, manufactured and successfully tested at 670 GHz.

I have already anticipated that there are several other fields in which sub-mm/THz wave technology can play a very important role in the coming years. It is interesting to see once again how all these applications and the corresponding antenna developments respond to problems and issues raised by human progress and evolution. We all know that the first empirical discoveries of our ancestors (fire, metals etc.) up to the most recent scientific ones (engines, nuclear energy, genetic bioengineering, to name just a few), have always been subject to the dichotomy of human nature: good and evil. Each of these discoveries represented a fundamental step in human evolution, extending its potential, its control of nature and its quality of life. At the same time they also provided new ways to satisfy the desire for power and dominance over other human beings, and for wild and uncontrolled abuse of nature. Unfortunately, we all know how common it is in these days to hear news about wars, terrorist attacks, about the destruction of human lives by drugs, and about the tremendous effects on the environment of industrialization and deforestation. Sub-mm imaging systems can provide powerful tools to fight these plagues more efficiently.

Earth observation

In the last few decades, all the main space agencies have developed imaging systems at mm and sub-mm wave frequencies for Earth observation, and many new missions with more ambitious objectives are being planned.

figure 4:(a) Hardware demonstrator of 670 GHz dual slot antenna integrated with kinetic inductance detector (KID); (b) detail of the antenna and feeding network; (c) detail of the airbridges distributed along the coplanar waveguide. [Courtesy of SRON]



For example, Post EPS (EUTEMSAT Polar System) and Post MSG (Meteosat Second Generation) are new missions of the European Space Agency, which is planning the development of the next generations of meteorological satellites. These satellites will help to monitor Earth's atmosphere and provide real-time images of weather systems. In particular, Post-MSG will provide efficient monitoring of the position of weather fronts and the rapid development of local thunderstorms. GMES (Global Monitoring for Environment and Security) Sentinels is the next flagship initiative for space in Europe. It provides autonomous and independent access to information for policy-makers, particularly in relation to environment and security, such as atmospheric pollution monitoring, flood and fire risk management, forest monitoring, land cover and land use change monitoring, marine and coastal environment monitoring etc. New sub-mm wave payloads are foreseen on board all these satellites.

All these missions are of fundamental importance for the monitoring of our planet. They will help in timely and more accurately predicting the evolution of weather and environment, and in taking important decisions to save thousands of lives, and in the long term the life of our planet.

Perhaps we should recall here the historic desire of human beings to predict the future. Think, for example, of the Cumaean Sibyl, one of the most famous priestesses of the Roman and Greek world presiding over the Apollonian oracle at Cumae, a Greek colony located near Naples in Italy. Inspired by Apollo, she wrote her prophecies on leaves, which were then scattered by the wind, making her prophecies 'sibylline'. This is just one of the many examples of attempts to respond to the desire to know the future, which have accompanied the human race throughout its history. Aren't weather forecasts and predictions of environmental evolution modern examples of the same desire, but guided by a rational and scientific approach?

Security: detection of concealed objects and substances

Another field of application of sub-mm/THz waves is the detection of concealed objects and substances. For example, small and fast radiometers, based on focal plane arrays, could be used for real-time personal inspection to identify potential terrorists and smugglers carrying concealed guns, explosives or drugs. Terahertz radiation, in fact, has a few remarkable properties that make it suitable for this purpose. Many common materials and living tissues are semi-transparent and have 'terahertz fingerprints', while others give rise to much stronger reflections. This allows not only imaging of concealed objects and materials, but also precise identification of some of these substances. This can be achieved by spectroscopic techniques which identify the typical resonance lines of these materials. Such properties can also be used in non-destructive testing or non-intrusive inspections of postal packages, suspicious suitcases and bags etc. Moreover, the non-ionizing properties of terahertz radiation are inherently safe for screening applications on human beings and animals.

Last but not least, the very small field wavelengths allow the development of very compact systems making use of focal plane arrays with up to a few thousand pixels, which can operate in real-time, allowing covert operation.

Someone might observe that systems for detection of concealed objects already exist, and are used for example at some airports. These systems, which must not be confused with typical metal detectors, mostly work in the lower mm-wave frequency range (90-100 GHz) or with X-rays. The main advantages that sub-mm waves can offer with respect to these solutions are:

- Higher resolution compared with the mm waves, due to the smaller wavelengths of the sub-mm electromagnetic waves.
- Lower health risks than X-rays, due to the very low energy levels.
- Very compact, portable systems, able to operate in real time (thanks to the very small wavelengths, which allow the development of compact focal plane arrays with thousands of pixels).

As also suggested by other colleagues, the extremely well-known and poetic words of the Biblical songs of King Solomon given in the book of Ecclesiastes offer a very poignant conclusion for an overview of sub-mm/THz wave applications: "To everything there is a season, and a time to every purpose under Heaven: A time to be born, and a time to die; a time to plant, and a time to pluck up that which is planted", and so on. Indeed the tremendous amount of activities that have been carried out and attention that has arisen in the last years around the sub-mm/THz wave frequency range suggest there are considerable opportunities for the coming years. The increasingly accurate assessments performed indicate that it is time to pluck up the results. Some companies and research institutes are already developing some pioneering and some more mature systems, but this is still a field that offers huge development margins and market opportunities. Furthermore, sub-mm wave/THz imaging is a field of research and development which requires the contribution of many disciplines; not only antennas and electromagnetic periodic structures, for which I will make my modest contribution. This offers the opportunity to involve many other research groups within this university and of course in the rest of the scientific community in the Netherlands, in Europe and in the rest of the world.

Some thoughts on education

Before concluding this inaugural lecture, I would like to spend few words about education: about its role and some of the challenges that must be faced in our society.

I would like to start by citing these famous words of the Divine Poet: Dante Alighieri.

Fatti non foste a viver come bruti, ma per seguir virtute e canoscenza.
Jullie zijn niet geschapen om te leven als beesten, maar om deugd na te streven en om kennis te verwerven.
You were not made to live like brutes, but to follow virtue and knowledge. *[D. Alighieri, La Divina Commedia – Inferno – Canto XXVI – vv. 118-120]*

These are the famous words of Ulysses in the Divine Comedy of Dante Alighieri, before leaving on his last journey, encouraging his travel mates to start a new adventure, searching for new worlds and new knowledge. Dante expresses here his high consideration for knowledge, which should have no age and no limits. This is the kind of spirit that should be transmitted to our new generations: the importance of knowledge for ourselves and for the entire world. Man, as the only creature with the capability of discernment and thought, has the responsibility for the future of the world.
Children have to grow up with ideals, which should not be only easy earnings, easy life. This is something for which families, and primary and secondary schools, have a fundamental function. They form the personalities of the young generation. As a university, we have the obligation to raise these issues, we have to guide the students, also the very young ones, to the university and to a right approach to the university; we have to indicate priorities and influence political decisions. We also need to have dreams, ambitious projects. We need to make courageous choices; we need to think with a longer-term perspective and offer it to the students. We have to work for innovation ('Where innovation starts' is our motto), offer them arguments that are in line with the state-of-the-art, and of course offer them good and interesting courses and ensure a good transfer of knowledge.
With regard to this last point, it is important to highlight the necessity of a good balance between the transfer of knowledge and research; between the task of transmitting the culture and wisdom of the past, and the pursuit of new knowledge and the achievement of new perspectives. Science privileges the discovery, and science itself has been privileged since the discovery has generated the technology. As a consequence, the more the university has become researchoriented, the more it has privileged research and looked at the 'old' less as an aim in itself, but more as an instrument in the research of the 'new'. This has resulted in the fact that the transmission of knowledge, among the functions of the university, has received less attention than research. The combination of an explosive growth of specialized knowledge and the tendency of this knowledge to become obsolete has forced the University of our Century to place less importance on the transmission of knowledge. I believe that a proper balance must be found. We want the new students to be as able to master the past as their predecessors. Such a good mix has been found in the Electromagnetic group, with a good balance between state-of-the-art research, applied research and fundamental theory of electromagnetics. My first priority at the university will be the definition and activation of new PhD projects and the tutoring of these students in the fields I have mentioned in this lecture. I will try to offer them the optimal balance between fundamental knowledge, applied research and experimental validation. From this point of view, I believe that the combination of the academic environment and the applied research programs at TNO could represent an optimal melting pot for the formation and maturation of the next generations of researchers and engineers.

I also believe that the full exploitation of the diversity of our modern societies is fundamental for innovation. The participation of all segments of the population, minorities and newcomers can only bring a wider range of perspectives, leading to creative and inventive solutions. In my opinion, from this point of view, the USA is an excellent example. It is sufficient to look at how many famous scientists and how many distinguished professors who made the 'scientific' glory of that country originally came from other countries, or belonged to minorities. I am very happy and proud to see how open our university is in accepting international students, researchers and professors from other countries. This is a fantastic opportunity; we have to welcome them, offer them a chance and enrich our knowledge with their knowledge, our culture with their culture.

One last consideration and a recommendation for the present and new generations of students.
I don't think that only the 'elected' people can accept the inexorable burden of moral responsibility with dignity and a clear conscience. This was the idea of the pietistic morality, which mainly reached us through Kant. On the contrary, the ethic of the last century pretends to convince everybody to become worthy of this choice, with full acceptance of responsibilities; responsibilities accepted and proved by the daily engagement. Although this has in itself something heroically utopian, I really share this approach. You are going to be the new generations of engineers, researchers, scientists, managers. You have to be worth of this fantastic opportunity and of the role that you will play in our society. I would like to conclude with the words of Renée, one of the two main protagonists of the book: 'L'Elégance du brésson' by Muriel Barbery (2006, Editions Gallimard, Paris). "What is intelligence for, if not to serve? I am not referring to the false service that proud high state officials exhibit as sign of their virtue: an outward humility that is only vanity and contempt…I must be concerned with the progress of humanity, with the solution of crucial problems for the existence, with the welfare or the elevation of humanity…Shall we devote ourselves to teaching, to the composition of an opera, to research, to culture? It does not matter. In this context, only the intention matters: elevate the thought, contribute to the common interest…"

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Curriculum Vitae

Prof.dr. Giampiero Gerini was appointed as part-time professor in Novel Structures and Concepts for Advanced Antennas in the Department of Electrical Engineering of Eindhoven University of Technology (TU/e) on 1 June 2007.
Giampiero Gerini obtained his MSc (Laurea) degree cum laude in Electronic Engineering and his PhD in Electromagnetics in 1988 and 1992, res-

pectively, at the University of Ancona, Italy. After his PhD, he had a postdoctoral appointment at the same university, where from 1993 to 1994 he was Assistant Professor of Electromagnetics. From 1994 to 1997, he was Research Fellow at the European Space Research and Technology Centre (ESA/ESTEC), Noordwijk, the Netherlands, in the Radio Frequency System Division. Since 1997, he has been with TNO Defence Security and Safety, The Hague, the Netherlands where he is currently Chief Senior Scientist of the Antenna Unit in the Transceiver and Real-time Signal Processing Department. This position implies the coordination of the overall scientific activities of the Antenna Group, supervision of PhD students and project management of national and international projects with major European research, industrial and governmental partners.

His main research interests are phased array antennas, electromagnetic bandgap structures, frequency selective surfaces and integrated antennas at microwave, millimeter and sub-millimeter wave frequencies. The main fields of application are radar, space and telecommunication systems.

prof.dr. Giampiero Gerini

Contributie

NERG biedt de mogelijkheid uw jaarlijkse contributie te betalen via automatische incasso. Uw voordeel is een korting van € 2 op de contributie van € 43. De incasso vindt plaats rond mei/juni. Wilt u van deze mogelijkheid gebruik maken neem dan even contact op met de ledenadministratie (nergadministratie@gmail.com) voor een machtiging.

Approximate and Full-Wave Antenna Analysis for CAD

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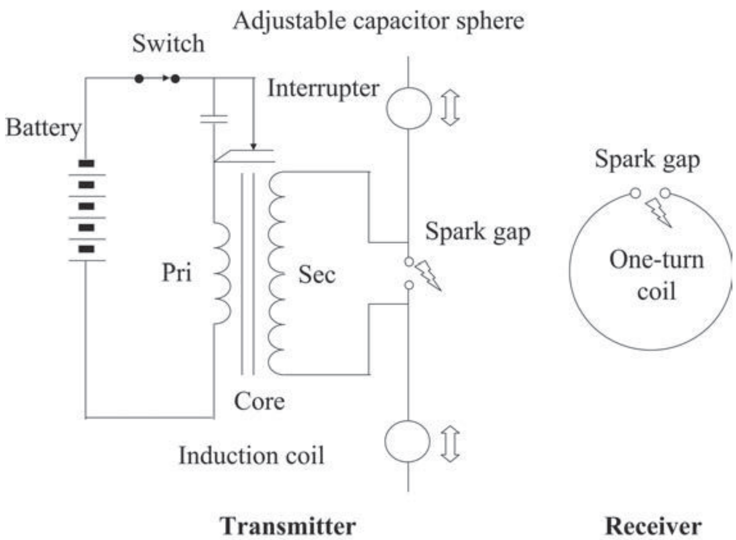
Abstract

From the moment that Heinrich Rudolf Hertz experimentally proved the correctness of the Maxwell equations in 1886, antennas have been in use. The fact that Guglielmo Marconi's success depended on the 'finding' of the right antenna in 1895, indicates the importance of antennas and thus of antenna analysis. It was however common practice up till the middle of the 1920's to design antennas empirically and produce a theoretical explanation after the successful development of a working antenna. It took a World War to evolve antenna analysis and design into a distinct technical discipline. The end of the War was also the starting point in the development of electronic computers that eventually resulted in the commercial distribution of numerical electromagnetic analysis programs. Notwithstanding the progress in numerical electromagnetic analysis, still a need exists for approximate antenna models. They are needed both in their own right and as part of a synthesis process that also involves full-wave models.

1 The history of antennas and antenna analysis

The history of antennas dates back almost entirely to the understanding of electromagnetism and the formulation of the electromagnetic-field equations. In the 1860's, James Clerk Maxwell saw the connection between Ampère's, Faraday's and Gauss's laws. By extending Ampère's law with what he called a *displacement current* term, electricity and magnetism became united into electromagnetism [1]. His monumental work *A Treatise on Electricity and Magnetism from* 1873 is still in print [2]. With light now described as and proven to be an electromagnetic phenomenon, Maxwell already predicted

Fig. 1 Hertz's open resonance system. With the receiving one-turn loop, small sparks could be observed when the transmitter discharged. From [4].



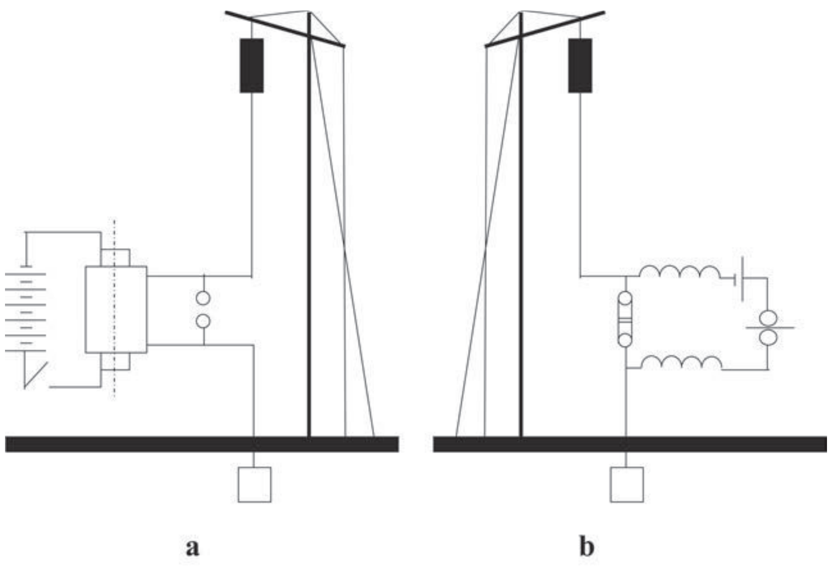
the existence of electromagnetic waves at radio frequencies, i.e., at much lower frequencies than light. It lasted until 1886 before he was proven right by Heinrich Rudolf Hertz, who constructed an open resonance system as shown in Figure 1 [3], [4].

A spark gap was connected to the secondary windings of a conduction coil. A pair of straight wires was connected to this spark gap. These straight wires were equipped with electrically conducting spheres that could slide over the wire segments. By means of moving the spheres, the capacity of the circuit could be adjusted for resonance.
When the breakdown voltage of air was reached and a spark created over the small air-filled spark gap, the current at the resonance frequency was oscillating in the circuit and emitting radio waves at that frequency (Hertz used frequencies around 50 MHz). A single-turn square or circular loop with a small gap was used as receiver. Without being fully aware of it, Hertz had created the first radio system, consisting of a transmitter and a receiver.
Guglielmo Marconi grasped the potential of Hertz's equipment and started experimenting with wireless telegraphy. His first experiments - covering the distance of the attic of his father's house - were conducted at a frequency of 1.2 GHz, for which he used, like Hertz before him, cylindrical parabolic reflectors, fed in the focal point by half-wave dipole antennas. In 1895 however, he made an important change to his system that suddenly allowed him to transmit and receive over distances that progressively increased up to and beyond 1.5 km [5]-[7]. In his own words, at the reception of the Nobel prize for physics, in Stockholm, Sweden in 1909 [7]:

> "In August 1895 I hit upon a new arrangement which not only greatly increased the distance over which I could communicate but also seemed to make the transmission independent from the effects of intervening obstacles. This arrangement [Figure 2a] consisted in connecting one terminal of the Hertzian oscillator or spark producer to earth and the other terminal to a wire or capacity area placed at a height above the ground and in also connecting at the receiver end [Figure 2b] one terminal of the coherer to earth and the other to an elevated conductor."

Marconi had enlarged the antenna. His monopole antenna was resonant at a wavelength much larger than any that had been studied before and it was this creation of long-wavelength electromagnetic waves that turned out to be the key to his success. It was also Marconi who, in 1909, introduced the term *antenna* for the device that was formerly addressed as *aerial* or *elevated wire* [7], [8].
The concept of a monopole antenna, forming a dipole antenna together with its image in the ground was not known by Marconi at the time of his invention. In 1899, the relation between antenna length and the operational wavelength of the radio system was explained to him by professor Ascoli, who had calculated that the `length of the wave radiated [was] four times the length of the vertical conductor' [9].

Fig. 2: Marconi's antennas in 1895. a. Scheme of the transmitter used by Marconi at Villa Griffone. b. Scheme of the receiver used by Marconi at Villa Griffone. From [4].



Up to the middle of the 1920's it was common practice to design antennas empirically and produce a theoretical explanation after the successful development of a working antenna [10]. It was in 1906 that Ambrose Fleming, professor at University College, London, and consultant to the Marconi Wireless Telegraphy Company, produced a mathematical explanation of a monopole-like antenna[1] based on image theory. This may be considered the first ever antenna design that has been accomplished experimentally and theoretically [10]. The first theoretical antenna description may be attributed to H.C. Pocklington, who in 1897 first formulated the frequency domain integral equation for a total current flowing along a straight thin wire antenna [11].

The invention of the *thermionic valve* or *diode* by Fleming in 1905 and the *audion* or *triode* by Lee de Forest in 1907 paved the way for a reliable detection, reception and amplification of radio signals. From 1910 onwards broadcasting experiments were conducted that resulted in Europe in 1922 in the forming of the British Broadcasting Corporation (BBC) [12]. The early antennas in the broadcasting business where makeshift antennas, derived from the designs used in point-to-point communication. Later, T-configured antennas were used for the transmitters [13] and eventually the vertical radiators became standard, due to their circular symmetrical coverage (directivity) characteristic [13], [14]. The receiver antennas, used by the public, were backyard L-structures and T-structures [4].

In the 1930's a return of interest to the higher end of the radio spectrum took place. This interest intensified with the outbreak of World War II. The need for compact communication equipment as well as compact (airborne) and high-resolution radar made it absolutely necessary to have access to compact, reliable, high-power, high-frequency sources. In early 1940, John Randall and Henry Boot were able to demonstrate the first cavity magnetron, creating 500 kW at 3 GHz and 100 kW at 10 GHz.

In that same year, the British prime minister, Sir Winston Churchill, sent a technical mission to the United States of America to exchange war-time secrets for production capacity. As a result of this Tizard Mission, named after its leader Sir Henry Tizard, the cavity magnetron was brought to the USA and the MIT Rad Lab (Massachusetts Institute of Technology Radiation Laboratory) was established. At the Rad Lab, scientists were brought together to work on microwave electronics, radar and radio, to aid in the war effort. The Rad Lab closed on 31 December 1945, but many of the staff members remained for another six months or more to work on the publication of the results of five years of microwave research and developments. This resulted in the famous 28 volumes of the Rad Lab series, many of which are still in print today [15]-[42].

For antenna analysis we have to mention the volume *Microwave Antenna Theory and Design* by Samuel Silver [26], which may be regarded as one of the first `classic' antenna theory textbooks. Soon, it was followed by several other, now `classic' antenna theory textbooks, amongst others: *Antennas* by John Kraus in 1950 [43], *Antennas, Theory and Practice* by S.A. Schelkunoff in 1952 [44], *Theory of Linear Antennas* by Ronold W.P. King in 1956 [45], *Antenna Theory and Design* by Robert S. Elliott in 1981 [46] and *Antenna Theory, Analysis and Design* by Constantine A. Balanis in 1982 [47]. Specifically for phased array antennas, we have to mention *Microwave Scanning Antennas* by Robert C. Hansen [48], 1964, *Theory and Analysis of Phased Array Antennas* by N. Amitay, V. Galindo and C.P. Wu [49], 1972, and *Phased Array Antenna Handbook* by Robert J. Mailloux [50], 1980[2] .

At the end of World War II, antenna theory was mature to a level that made the analysis possible of, amongst others, free-standing dipole, horn and reflector antennas, monopole antennas, slots in waveguides and arrays thereof. The end of the War was also the beginning of the development of electronic computers. Roger Harrington saw the potential of electronic computers in electromagnetics [51] and introduced in the 1960's the Method of Moments (MoM) in electromagnetism [52]. The origin of the MoM dates back to the work of Galerkin in 1915 [53]. The introduction of the IBM-PC[3] in 1981 considerably helped in the development of numerical electromagnetic analysis software. The 1980's may be seen as the decade of

1 The antenna was a *suspended long wire antenna*, nowadays also called *Inverted L Antenna or ILA*, used for transatlantic transmissions.

2 For the `classic' antenna theory textbooks mentioned here we refer to the first editions. Many of these books by now have been reprinted in second or even third editions.

3 4.77MHz, 16kb RAM, no hard drive.

numerical microwave circuit and planar antenna theory development. In this period the Numerical Electromagnetics Code (NEC), for the analysis of wire antennas, was commercially distributed. The 1990's, however, may be seen as the decade of the numerical electromagnetic-based microwave circuit and (planar, integrated) antenna design. In 1989 Sonnet started distribution, followed, in 1990, by HP (now Agilent) High Frequency Structure Simulator (HFSS)[4] [51]. These two numerical electromagnetic analysis tools were followed by Zeland's IE3D, Remcom's XFdtd, Agilent's Momentum, CST's Microwave Studio, FEKO from EM Software & Systems and others.

Today we have evolved from the situation in the early 1990's when the general opinion appeared to be `that numerical electromagnetic analysis cannot be trusted' to a state wherein numerical electromagnetic analysis is considered to be the ultimate truth [51]. The last assumption however is as untrue as the first one. Although numerical electromagnetic analysis software has come a long way, incompetent use can easily throw us back a hundred years in history. One only has to browse through some recent volumes of peer-reviewed antenna periodicals to encounter numerous examples of bizarre looking antenna structures designed by an iterative use of Commercially Of The Shelf (COTS) numerical electromagnetic analysis software. These reported examples of the modern variant of trial-and-error, although meeting the design specifications, are often presented without even a hint of a tolerance analysis let alone a physical explanation of the antenna operation.
The advice that James Rautio, founder of Sonnet Software, gave in the beginning of 2003 [51]

> "No single EM tool can solve all problems; an informed designer must select the appropriate tool for the appropriate problem",

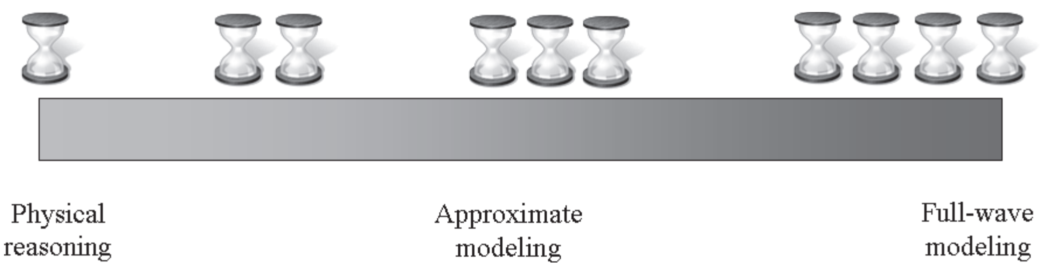
is still actual today as a benchmarking of COTS analysis programs has shown at the end of 2007 [54], [55]. Apart from the advice to choose the right analysis technique for the right structure to be analysed, these recent studies also indicate the importance of being careful in choosing the feeding model and meshing of the design to be analysed. So, notwithstanding the evolution of numerical electromagnetic analysis software, it still takes an experienced antenna engineer, preferably one having a PhD in electromagnetism or RF-technology, to operate the software in a justified manner and to interpret the outcomes of the analyses.
Having said this, we may now proceed with a discussion of how to use full-wave analysis software in antenna synthesis.

2 Antenna synthesis

Antenna synthesis will make use of a manual or automated, iterative use of analysis steps. Analysis techniques occupy a broad time consumption `spectrum' from a quick physical reasoning (`the length of a monopole-like antenna should be about a quarter of the operational wavelength') to a, in general lengthy, full-wave, numerical electromagnetic analysis. The `spectrum' of analysis techniques is shown in Figure 3, where the hour-glasses symbolically indicate the time involved in applying the analysis techniques.

For an automated synthesis, starting with mechanical and electromagnetical constraints and possibly an initial guess, we have to rely on stochastic optimisation. Since stochastic optimisation will need a (very) large number of function evaluations or analysis steps, such an optimisation scheme based on full-wave analysis, see Figure 4 is not a good idea.

Fig. 3: Analysis techniques ordered according to calculation time involved.



4 Currently Ansoft HFSS.

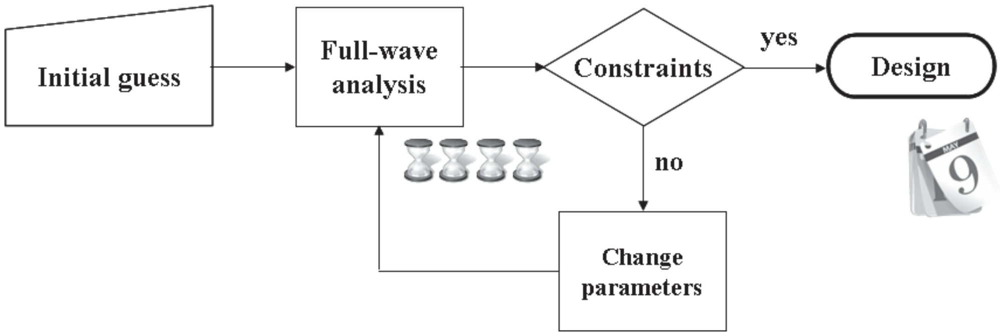


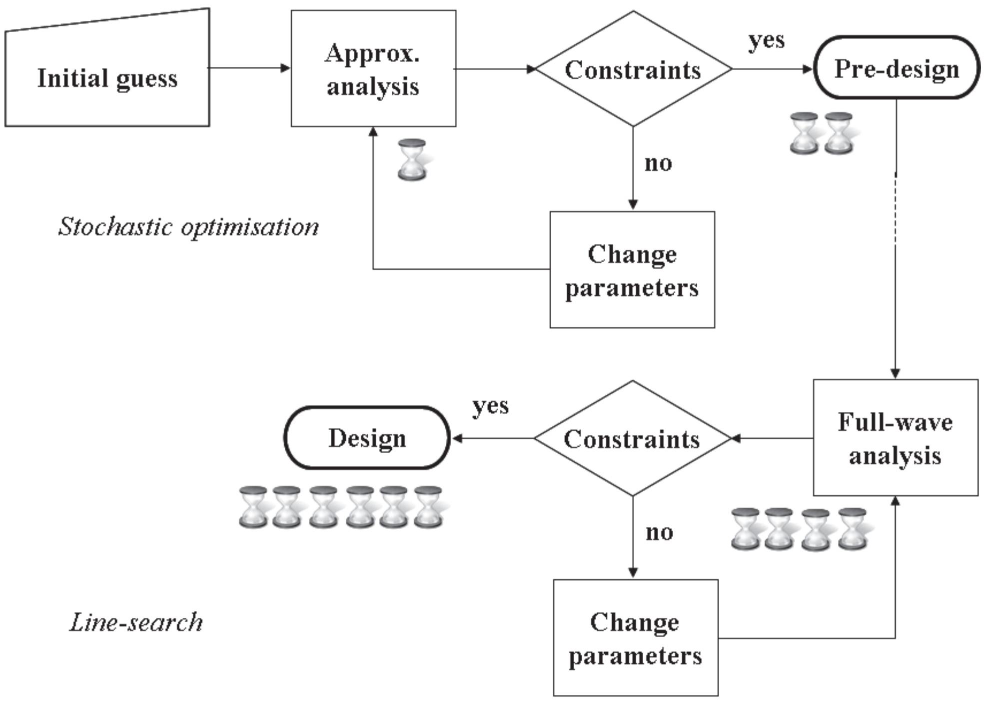
Fig. 4: Stochastic optimization based on full-wave analysis iterations is a (too) timeconsuming process.

Therefore, we propose a two-stage approach [56], wherein, first a stochastic optimization is used in combination with an approximate analysis and, second line-search techniques are combined with full-wave modeling, see Figure 5. Since one of the key features of the approximate analysis model needs to be that its implementation in software is fast while still sufficiently accurate, we may employ many approximate analysis iterations and therefore use a stochastic optimization to get a pre-design.

This pre-design may then be fine-tuned using a limited number of iterations using line-search techniques. Due to the limited number of iterations, we may now - in the final synthesis stage - employ a full-wave analysis model.

Using an approximate but still suffciently accurate model, the automated design - using stochastic optimisation - may be sped up considerably. The output at this stage of the synthesis process would be a preliminary design. Based on the accuracy of this design and the design constraints it is very well possible that the design process could end here, see for example [56]. If a higher accuracy is required or if the design requirements are not fully reached, this preliminary design could be used as an input for a line-search optimisation in combination with a full-wave model. For the complete synthesis process, using both approximate and full-wave models, see Figure 5, the time consumption will drop with respect to a synthesis process only involving a full-wave model. The reason is that the most time-consuming part of the process, i.e. when the solution space is randomly sampled, is conducted now with a fast, approximate, reduced-accuracy model. The question that remains is what may be considered to be `suffciently accurate'.

Fig. 5: Antenna synthesis based on stochastic optimisation in combination with an approximate model and line-search with a full-wave model.



3 Approximate antenna modeling

From a synthesis point of view, approximate antenna models are a necessity. They need to be combined with a full-wave analysis program, but if - depending on the application - the accuracy of the approximation is sufficient, the approximate model alone will suffice. In [51] and [54] the use of (at least) two full-wave simulators is advised, but not many companies or universities can afford to purchase or lease multiple full-wave analysis programs. For many companies, not specialised in antenna design, even the purchase or lease of one full-wave analysis program may be a budgetary burden. Therefore the availability of approximate, sufficiently accurate, antenna models is not only required for the full synthesis process. It is also valuable for anyone needing an antenna not covered yet in the standard antenna textbooks, who does not have access to a full wave analysis program.

The purpose of the approximate and full-wave models is to replace the realisation and characterisation of prototypes, thus speeding up the design process. This does not mean however that prototypes should not be realised at all. At least one prototype should be realised to verify the (pre-)design. A range of slightly different prototypes could be produced as a replacement of the fine-tuning employing line search techniques in combination with full-wave modeling.

A question that still remains with respect to the approximate modeling is what may be considered `sufficiently accurate'.

This question cannot be answered unambiguously. It depends on the application; the requirements for civil and medical communication antennas, for example, are much less stringent than those for military radar antennas. If we look at a communication antenna, to be matched to a standard 50 Ω – transmission line, we will not look at the antenna input impedance but rather at the reflection level. In general, any reflection level below –10 dB over the frequency range of interest is considered to be satisfactory. This means that, if we assume the input impedance to be real-valued, we may tolerate a relative error in the input impedance up to 100 %. For low-power, integrated solutions, working with a 50 Ω –standard for interconnects may not be the best solution. A conjugate matching may be more efficient. In general, we may say that we consider an approximate antenna model sufficiently accurate if it predicts a parameter of interest within a few percent relative to the measured value or (verified) full-wave analysis result. Such an accuracy also prevents the answer to drift away during the stochastic optimisation.

Another question is when to develop an approximate model. The answer to this question is dictated both by the resources available and a companies' long-term strategy. If neither a full-wave analysis program for the problem at hand is available nor an existing approximate model, then one can resort to trial-and-error or develop an approximate model or a combination of both, where outputs of the experiments dictate the path of the model development. If a full-wave analysis program is available and the antenna to be designed is a one-of-a-kind antenna or time is really critical, one can resort to an educated software variant of design by trial-and-error, meaning that the task should be performed by an antenna expert. When the antenna to be designed can be considered to belong to a class of antennas, meaning that similar designs are foreseen for the future, but for different materials and other frequency bands or in other environments, it is beneficial to develop a dedicated approximate model. The additional effort put into the model development for the first design will be compensated for in the subsequent antenna designs. An antenna design may also be created by generating a database of substructure-analyses, employing a full-wave analysis model. Then a smart combining of these pre-analysed substructures results in the desired design. The generation of the database will be very time consuming but once this task has been accomplished, the remainder of the design process will be very time-efficient.

The last question is how to develop an approximate model. First of all, the approximate model will be tailored to the antenna class at hand. To achieve that, the antenna structure will be broken down into components for which analytical equations have been derived in the past, in the pre-computer era, or for which analytical equations may be derived. By distinguishing between main and secondary effects, approximations may be applied with different degrees of accuracy, thus speeding up computation times. It appears that much of the work performed in the 1950's, 1960's and 1970's that seems to have been forgotten is extremely useful for this task. In [57] we have followed this approach for a couple of classes of antennas. For each class of antennas we have taken a generic antenna structure and have decomposed it into substructures, like, e.g., sections of transmission line, dipoles and equivalent electrical circuits. For these substructures and for the combined substructures approximate analysis methods have been selected or developed. The main constraints in developing approximate antenna models have been desired accuracy in the antenna parameter to be evaluated (the amplitude of the input reflection coefficient or the value of the complex input impedance) and computation time for the software implementation of the model.

4 Summary

Notwithstanding the progress in numerical electromagnetic analysis, the automated design of integrated antennas based on full-wave analysis is not yet feasible. In a two-stage approach, wherein stochastic optimisation techniques are used in combination with approximate models to generate pre-designs and wherein these pre-designs are used as input for line-search optimisation in combination with full-wave modeling, an automated antenna design is feasible. Therefore, a need exists for approximate antenna models for different classes of antennas. For one-of-a-kind antenna designs an iterative, manual use of a full-wave analysis program is advised. So, today, not only full-wave models are needed but there still exists a need for approximate models. That both full-wave and approximate models are needed cannot be said more eloquently than Ronold W.P. King did in 2004 [58]:

> "At this age of powerful computers, there are those who believe that numerical methods have made analytical formulas obsolete. Actually, the two approaches are not mutually exclusive but rather complementary. Numerical methods can provide accurate results within the resolution determined by the size of the subdivisions. Analytical formulas provide unrestricted resolution. Numerical results are a set of numbers for a specific set of parameters and variables. Analytical formulas constitute general relations that exhibit functional relationships among all relevant parameters and variables. They provide the broad insight into the relevant physical phenomena that is the basis of new knowledge. They permit correct frequency and dimensional scaling. Computer technology and mathematical physics are a powerful team in the creation of new knowledge."

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Het slimme leven

Freek Bomhof, (TNO),
Jeroen Laarakkers, (TNO, NERG) en
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NERG, KIVI NIRIA, en TRANS-bijeenkomst op de TUD op vrijdag 12 maart 2010

Inleiding

Op vrijdag 12 maart heeft het congres "Het Slimme Leven" op de TUD plaatsgevonden. Het congres werd georganiseerd door NERG, KIVI NIRIA en TRANS (TUD, KPN, TNO). "Het slimme Leven" thema leeft binnen deze groepen, vooral gecombineerd met het transectoraal innoveren thema. Er waren maar liefst 150 aanwezigen.

De lezingen

Nico Baken wist bewonderenswaardig in 15 minuten zijn verhaal over transsectoraal innoveren neer te zetten. Hierna kwam Robbert Dijkgraaf die een inspirerend verhaal hield over hoe wetenschap in zijn algemeenheid onze welvaart weet te verhogen. Emile Roemer moest door zijn nieuwe drukke werkzaamheden helaas afzeggen maar Paulus Janssen, ook van de SP, verving hem uitstekend. In zijn lezing gaf hij aan welke oneigenlijke prikkels er soms zijn om domme beslissingen toch door te zetten, of verstandige ideeën juist niet uit te voeren. Bram Reinders van Liander gaf als laatste spreker aan hoe Liander met transsectorale innovatie bezig is.

De reacties

Het gegeven dat "Het Slimme Leven" door partijen als Eneco, KPN, IBM opgezet wordt, gaf een aantal kritische reacties. Waarom nu juist die grote partijen? Die zouden helemaal niet transsectoraal kunnen innoveren, die letten alleen maar op hun eigen business case.

Vervolgens kwamen er een aantal kritische opmerkingen over (grotere) bedrijven in zijn algemeenheid. Zij zouden vooral op hun EBITDA[1] letten en daardoor geen oog hebben voor de "echte value case". Daarbij wordt gedoeld op het micro-niveau - willen de mensen dit wel? - en het macro niveau - wordt de maatschappij er beter van?

Vanuit de zaal kwam een zeer relevante opmerking dat het allemaal te ingewikkeld wordt voor de eindgebuiker binnen Smart Living: Waarom zou een consument voor zijn energie, zijn energietransport, zijn slimme meter, zijn display, etc. willen kiezen? Al die keuzes maken het véél te ingewikkeld.

Belemmeringen voor transsectoraal innoveren werden, naast de hierboven genoemde EBITDA-discussie, goed verwoord door Wolfje van Dijk (KPN). Hij observeerde dat onwil om samen te werken ook uit angst voort kan komen. Bijvoorbeeld angst dat je het al die tijd niet goed gedaan hebt of angst voor nieuwe ideeën.

Opmerkelijk was, zeker voor een gezelschap met een hoog ingenieursgehalte, dat er veel aandacht uit de zaal kwam voor de "zachte kant" van innovaties - waar doen we het allemaal voor. Het woord "empathie" viel zelfs. Nico had natuurlijk al een voorzet gegeven door naast de drie bekende P's van duurzaamheid (people, planet, profit) ook de P van pneuma (adem, geest) te benoemen.

Wat observaties

Als je een bijeenkomst organiseert met een aansprekende titel, zoals ook bijvoorbeeld in een "Open Innovatie" themabijeenkomst, is dit dermate aansprekend dat iedereen er zijn eigen interpretatie bij heeft. Hierdoor wordt er een wat diffuse definitie van de term gehanteerd wat resulteert dat zo'n beetje alles er onder valt. Bij "Open Innovatie" wordt vaak de Senseo (samenwerking DE en Philips) opgevoerd als voorbeeld. Dit is in feite "gewone" samenwerking en niet een vergaande vorm van open innovatie. Ook bij dit congres werden daar fraaie staaltjes van neergezet. Bijvoorbeeld iemand die als consultant werkzaam was en "dus" al jarenlang transsectoraal innoveert. Immers als consultant kun je in elke sector innovaties bereiken. Het transsectorale innoveren zoals we dat bij Smart Living hebben uitgelegd, is echt wel een stapje minder plat. Die aanscherping is op het congres niet gemaakt.

Concrete nieuwe voorbeelden vanuit de zaal ("het is toch te dol voor woorden dat we X niet doen en Y nog niet voor elkaar hebben") werden er maar weinig gegeven.

Op het eind bij de paneldiscussie ontspon er zich nog een gedachtewisseling over top-down versus bottom-up. Als je transsectoraal innoveren wilt versnellen, moeten er dan initiatieven zoals Smart Living komen, of zelfs een "Davos van het transsectoraal denken", of heeft het alleen kans van slagen als het een "grassroots"[2] beweging is? (Maar hoe organiseer je dat dan?) De meningen bleven verdeeld op dit punt.

1 Earnings Before Interest, Taxes, Depreciation and Amortization. Dit is een maatstaf voor de winst die een onderneming haalt met haar operationele activiteiten zonder dat hier kosten en opbrengsten van de financiering in verwerkt zitten.

2 Grassroots ("graswortels") is een Engelse term voor politieke processen die aan de basis worden ontwikkeld. Vaak betekent dit dat burgers in plaats van beleidsmakers initiatieven ontwikkelen en beslissingen nemen.

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7 colleges van ieder 4 uur + 1 gepland inhaalcollege 1x per week in de periode november 2010 t/m januari 2011(exacte data en tijden volgen zodra het collegerooster bekend is); Eindhoven

Nieuw -masterclass -the design and application of industrial linear motors
8 colleges van afwisseiend 2 en 4 uur in de periode november 2010 t/m januari 2011 (exacte data en tijden volgen zodra het collegerooster bekend is); Eindhoven

Nieuwe machinerichtlijn in 2010! (vernieuwd!)
1-daagse cursus; 18 november 2010

Life cycle costing
1-daagse cursus; december 2010; Den Haag

Beveiliging van elektriciteitsnetten
2-daagse cursus; december 2010; Delft

Principes van digitale radio en draadloze netwerken
5-daagse cursus; februari 2011; nader te bepalen

Grondslagen van de gasinfrastructuur
2-daagse cursus; tweede helft van maart 2011; Apeldoorn

Masterclass -vermogenselektronica; advanced topics
8 colleges van afwisselend 4 en 2 uur; april t/m juni 2011 (exacte data en tijden volgen zodra het collegerooster bekend is); Eindhoven

Masterclass -hoogspanning III
7 colleges van 2 uur; april t/m juni 2011 (exacte data en tijden volgen zodra het collegerooster bekend is); Delft

Schakelen in elektriciteitsnetten
2-daagse cursus; 2 aansluitende dagen in juni 2011; Arnhem