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ALEXANDRU TIMOTIN, A PROMINENT PERSONALITY IN SCIENCE

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This paper contains the presentation at the commemoration of the 100th Anniversary of the Birth of Acad. Alexandru Timotin at the Romanian Academy on April 29, 2025. Some of his outstanding scientific contributions are described. The appendix shows the relevance of his discoveries.

1. INTRODUCTION

Fig. 1 – Acad. Alexandru Timotin (1925-2007) [40].

I had the honor of meeting Alexandru Timotin (Fig. 1) in 1967, when he was teaching the course of Basic Electrotechnics and the optional course of Relativistic Electrodynamics. Later, I studied his wonderful textbook, Lessons on the Basics of Electrotechnics. After graduating with an Electrical Engineering degree in 1970, I was assigned to the renowned Department of Electrical Engineering, led by Remus Răduleț, where Alexandru Timotin examined me on several occasions for tenure and a PhD. He always wanted to understand the limits of my knowledge and made me readjust how to overcome them. As a reviewer of my doctoral thesis, he made me the most thorough report. He was a real mentor to me, a brilliant one.

In 1978, I was co-opted into the research team, a partner with the Studies and Research Directorate of Électricité de France EdF. I completed internships in Paris, where, under the guidance of Alexandru Timotin and Andrei Țugulea, I developed the IBM 360 computer program called DISTRIB, a general-purpose program for simulating electrical circuits containing elements with distributed parameters. It was successfully utilized by EdF to investigate the transmission of atmospheric overvoltage between the windings of high-power transformers.

Subsequently, another team I was part of, aiming at the development of the thesaurus of terms of the International Electrotechnical Commission CEI, whose first edition appeared in 1986 in Geneva, Switzerland, under the coordination of Remus Răduleț and Alexandru Timotin. For its realization, a dedicated telephone line was installed. It connected the server hosting the database, a Wang type minicomputer from ICPE, to a terminal located at the Polytechnic University of Bucharest. We have developed the program to populate the database of the Treasure, which is used daily by Alexandru Timotin and the team he coordinates directly.

I understood then that engineering, physical, mathematical, and algorithmic thinking are entirely different things, and they enhance each other equally in understanding reality. This is the vision of CSE – *Computational Science and Engineering*, which was not unanimously accepted at the time. Sensing from the beginning the massive potential of information technology IT, Alexandru Timotin encouraged and supported the development of the Numerical Modeling Laboratory (LMN) that I established in 1983 as well as the international projects of this laboratory, especially the seven major European educational and research projects, but also the Japanese partnership facilitating the publication of a special issue in 1998 dedicated to this partnership of the *Romanian Journal of Sciences Techniques*, whose editor-in-chief he was. I recall with pleasure how easily he established the algorithm for calculating the mechanical actions of the EM field in our finite element PC program, named FAP, which was developed in LMN.

Alexandru Timotin was a modern Enlightenment scholar with a vast amount of encyclopedic knowledge that he mastered in the smallest detail. He was inclined towards both the fundamental philosophical aspects of science and its applied aspects, such as scientific computing, algorithmic development, and computer programming. He had a brilliant mind, with great confidence in the power of reasoning. He viewed mathematics more as a tool than an end, being more interested in its physical meaning than in the formal and abstract aspects of science, yet very exact. He had a solid, multidisciplinary culture. He was an elegant, polite, and distinguished person. A luminous figure, but at the same time, a slightly mysterious air, difficult to understand where his extraordinary moral support came from.

To pay homage to my mentor's contribution to the foundation of electrical engineering, I have selected three of his most important scientific discoveries.

2. ABOUT MAXWELL-HERTZ THEORY

In his paper entitled "*On the interpretation of Maxwell-Hertz electrodynamics in the light of the theory of relativity*" [38], published together with Andrei Țugulea in 1964 in the Bulletin of the Polytechnic Institute of Bucharest, he showed that the Maxwell-Hertz theory is the best approximation at low speeds of movement (much lower than the speed of light) of relativistic electrodynamics. The essential difference between the two theories lies in their

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kinematic basis; Hertz's theory is based on the pre-relativistic kinematics described by the Galilean transformation, whereas the Einstein–Minkowski theory is based on the relativistic kinematics described by the Lorentz transformation. The question, therefore, arises as to whether this is the only physically essential difference between the two theories. The paper shows that the answer to this question is affirmative.

I quote the conclusion of this work:
"The Maxwell-Hertz theory is therefore the only pre-relativistic theory of electromagnetic phenomena compatible with the principle of relativity and Maxwell's equations for resting environments. The use of this theory in technology, insofar as relativistic effects are not important, is as justified as the use of Newtonian mechanics."

It is, without a doubt, a fundamental discovery in the context of scientific theories, essential for higher education.

3. THE BRIDGE BETWEEN CIRCUIT AND FIELD

A second fundamental scientific contribution consists of the elaboration, together with Remus Răduleț and Andrei Țugulea, of a general theory known as "transient parameters". In 1966 the three published in the Journal of the Romanian Academy Studies and Research in Energetics and Electrotechnics two monumental, reference articles, which laid the foundations of this theory and opened a new direction of research with a worldwide impact to nowadays The first paper [32] is dedicated to the characterization of long electric lines with losses in the presence of soil and the second refers to the non-wire elements of electrical circuit with additional losses due to the field effect (Fig. 2) [33]. Boundary conditions for the field problem have been established to ensure compatibility with external electrical circuits and the uniqueness of the internal electromagnetic field. In this way, Kirchhoff's equations, as well as the telegrapher's equations, were generalized.

Of the many works that followed the two and which contain applications and generalizations, one elaborated only by Alexandru Timotin is of special importance. It was published in 1971 and is titled *"The Passive Electromagnetic Circuit Element"* [39]. It generalizes the electrical circuit element by introducing the concept of "*magnetic terminal*" and additionally by considering spatial domains with multiple connected topologies (Fig. 3). These are the most general hypotheses about the circuit elements of that time. Another significant generalization of the theory of transient parameters occurred in 1972, when the Răduleț–Timotin–Țugulea team extended it to a broad class of energy-stored and dissipative multi-physics systems with a finite number of inputs but distributed parameters, described structurally rather than functionally. These systems are currently known as dissipative port-Hamiltonians [34].

From the series of generalizations, we also mention the circuit elements with the open-radiant border. Mihai Vasiliu studied these under the direction of Alexandru Timotin and later deepened by Irina Munteanu and Gabriela Ciuprina under the direction of Professor C.I. Mocanu and me. We have recently published a paper that presents the variational form of this concept and its software implementation, along with proof of the solution's existence and uniqueness [12], further emphasizing the importance and timeliness of the theme [13,14]. The Appendix contains more technical details about the concept of an Electric Circuit Element, demonstrating its relevance today.

In this way, a solid bridge was established, with a strong theoretical argumentation between the Theory of Circuits and the Theory of electromagnetic field. This is not only of theoretical importance but also of practical importance, as it forms the basis of modeling and simulation algorithms, and implicitly, the computer-aided design of high-speed and radio-frequency semiconductor integrated circuits, as well as antenna design. They are essential aspects of the most advanced technologies of the present, which is why their study is still relevant. Remarkably, Alexandru Timotin laid the foundations of this theory through his pioneering, creative, and innovative research. His vision and scientific intuition were outstanding.

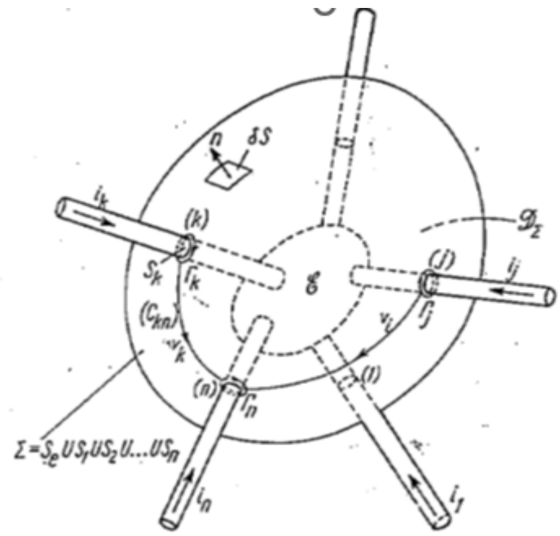

Fig. 2 – Multipolar circuit non-wire element [33].

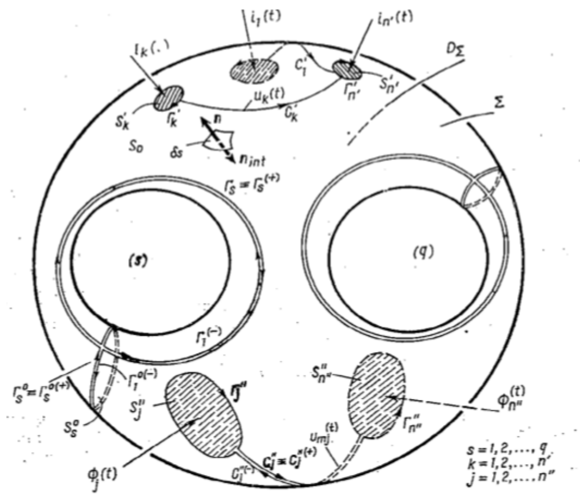

Fig. 3 – Multiple-related domains with the separation surface of an electromagnetic circuit element [39].

Each generation has contributed to the development and dissemination of this theory, contributing to the international recognition of its pioneers. The eminent scientist Ralf Hiptmair, head of the Department of Scientific Calculations at ETH Zurich, in a correspondence with us, a few years ago, named the members of the School of Electrical Engineering in Bucharest as titans of science. Without a doubt, Alexandru Timotin deserves this name.

4. **THE NEURON – AN OPTIMAL STRUCTURE**

A significant scientific contribution this time in the field of neuroscience is the paper published by Alexandru Timotin in the PROCEEDINGS OF THE ROMANIAN ACADEMY, in 2004, entitled *NERVE FIBER STRUCTURE: AN OPTIMAL PROJECT* [40]. This article contains mathematical proof that the myelinated neurons of vertebrates, therefore including those of humans, have the optimal structure, in the sense that the highest possible speed of transmission is of the neuronal signal along the axon (Fig. 4). I quote from the conclusions of the article:

"*The optimal proportions obtained, as well as the respective velocity values, correspond to the experimental values observed by biologists. It is a problem of geometric optimization of the structure of the fibers, which nature has solved through biological evolution, during the development of the spine, in order to have higher speeds with thinner fibers. Optimization is significant for the animal's response times.*"

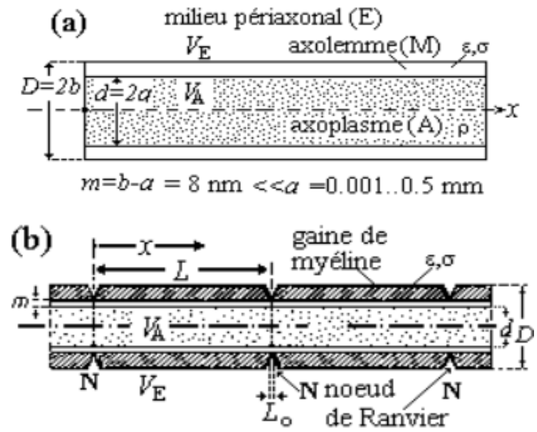

Fig. 4 – Structure lisse (a) de l'axone des invertébrés et structure myélinisée (b) de l'axone des animaux vertébrés [40].

5. **CONCLUSIONS**

Alexandru Timotin was a crucial link in the transmission of scientific knowledge development in our country. Fulfilling the sacred purpose of the university, it transmits between generations, especially the concerns for the deductive-axiomatic presentation of the theory of the electromagnetic field, the rigorous foundation of the theoretical basis of electrical engineering, as well as the care for the technical-scientific language. In a chain that spans almost a century, it begins with Remus Răduleț, who received his doctorate in 1931 from ETH Zurich, where he had the opportunity to meet Albert Einstein, W. Schrödinger, and Max Planck. He is included in the CEI *Hall of fame* for his outstanding contribution to scientific language. In Bucharest, he founded the Romanian School of Electrical Engineering, where, in the 1950s, the following generations took their doctorates, including Alexandru Timotin, Andrei Ţugulea, and C.I. Mocanu. The generation of the 70s was richer, including names like Cezar Fluerașu, Ion Ciric, F.M.G. Tomescu, Mihai Vasiliu, and Al. Nicolae, Fl. Hanțilă and I, among others. From scholars who received doctorates in the 90s, I mention Valentin Ioniță, Irina Munteanu, and Gabriela Ciuprina.

We note with regret that in the generation of the twenty-first century, the flame of science has begun to flicker. This proves serious deficiencies in the management of higher education and research, which have led to the collapse of the social prestige of teachers. My position as professor emeritus, therefore, as an honorable retiree, allows me to be critical. Reigniting the flame will be much more difficult and expensive, but hopefully, we may have miracles as we can see in Asian countries. It is a pity not to exploit a generous tradition that continued in much more inauspicious times as the middle of the previous century.

I think that Alexandru Timotin faced the darkest period of the communist regime, and he did it with stoicism and perseverance. Both he and Remus Răduleț did not belong to the Communist Party and did not have legionary nationalist sympathies, but were true models of morality. He was an authentic patriot because he cultivated the Romanian language with dedication and admired popular traditions, while being concerned about their fragility in the face of modernity. I think that if he could, he would have done the same as King Charles III to preserve traditional values.

In my capacity as co-founder of *the International Compumag Society* and former president of the IEEE Romania Section, I have had the opportunity to meet some of the most significant scientific personalities in the field of electrical engineering worldwide. Regarding them, Alexandru Timotin was a genuinely brilliant scientific personality, and I am proud to have collaborated with him. A truly genius of science, I carry an indelible memory.

I very much appreciate this commemoration of him, which takes place on the very day he turned 100 years old. However, I regret that his memory will remain especially alive in the minds of those who knew him personally, and who, in the future, will naturally be fewer and fewer. The way he lives in the virtual world is not commensurate with his personality. The evocations on the Internet are characterized mainly by complacency, in total contradiction to the seriousness and depth of the one evoked. The solution would be to create a platform hosted by the Academy and/or UPB that would post with open access (OA – Open Access) the complete work of Alexandru Timotin, or at least for a beginning, his list of published works. There is already, through the care of ICPE, a complete edition of the articles, which should only be scanned. Only in this way will we understand and keep alive its genius.

APPENDIX: ABOUT EM FIELD-CIRCUIT COUPLING

In memoriam of our professors Remus Raduleț, Alexandru Timotin, Andrei Țugulea, and C.I. Mocanu, founders of the Romanian School of Electrotechnics.

6. **MOTIVATION**

During the SCEE 2022, Amsterdam, 11-14 July [43], after the presentation of communications [24], [11], some attendees, competent and active members of the scientific community, expressed their concerns about the use of Electric Circuit Element (ECE) boundary conditions in the modeling of field-circuit coupling problems. This note aims to clarify certain aspects related to this problem, including the limitations of ECE boundary conditions and how they can be bypassed.

The general statement is that EM field problems, which are numerically resolved, yield a solution of the Maxwell equations with specified boundary conditions, where the EM field is only defined inside the computational domain, which is usually a bounded one. Like any model, it has a series of limitations, and it cannot be confused with reality. Therefore, it should be validated by comparing the simulation results to experimental results or to those obtained using other methods.

7. CLASSIC ECE BOUNDARY CONDITION

According to our best knowledge, the first article introducing the electric circuit element boundary conditions (ECE BC) for Maxwell's equations, aiming to model the coupling of EM field devices with distributed parameters to an external electrical circuit, is [33]. The concept has four conditions:

1. The computational domain is **simple connected,** having a finite number of disjoint surfaces on its boundary called terminals.
2. There is **no magnetic (inductive) coupling through at the boundary,** therefore the normal component of magnetic field density B_n is zero (or at least constant in time) in any point of the boundary: $\mathbf{n}\times\text{curl}\mathbf{E} = 0$.
3. There is **no electric coupling through boundary** (nether conductive current or displacement current capacitive coupling), **excepting terminals,** therefore the normal component of electric field E_n is zero in any point of the nonterminal boundary: $\mathbf{n}\times\text{curl}\mathbf{H}= 0$.
4. **Every terminal has the same potential**, therefore, the tangential component of the electric field $E_t = 0$ on terminals: $\mathbf{n}\times\mathbf{E}=0$.

In these conditions, a scalar potential V can be defined correctly at every point of the boundary (including the terminal voltages), as an integral of the electric field **E** along a line belonging to the boundary, if one terminal is the ground, with $V = 0$. The terminal currents (total, including conduction and displacement) are defined as integrals of the magnetic field **H** along closing lines belonging to the boundary, which can be just the boundaries of the terminal surfaces. The power transferred through the boundary, the integral of the Poynting vector on the boundary, is just the sum of powers transferred by all n floating terminals, which are the products of current i_k and voltage v_k of terminal $k = 1{:}n$. Moreover, consequently, the Kirchhoff relations are valid, since the sum of all $n+1$ currents is zero, and the total voltage along any loop included in the boundary is also zero. Therefore, ECE BC makes the device with distributed parameters **compatible with any external electric circuits,** as it couples its nodes to the terminals. If the constitutive relations are linear, with material constants positive $\varepsilon, \mu, \sigma>0$ in the entire computational domain, then the solution uniqueness, the passivity, reciprocity, and linearity of the device result, and the impedance, admittance, and in general, the hybrid matrix are properly defined, even for RF or microwave devices. These circuit functions are transcendental, characterized by an infinite number of poles and zeros.

By generalization, a whole class of linear dynamic accumulative–dissipative systems has been obtained, having an infinity of state variables and a finite number of inputs and outputs, to model coupled problems of several categories: electromagnetics, continuous media mechanics, heat diffusion, and mass transfer [32]. Numerical modeling of the devices from this class of port-Hamiltonian multi-physic systems is discussed in [24]. Nonlinear devices with ECE BC are considered in [25] and [13].

The classical ECE BC was used intensively for modeling passive components of RF Integrated Circuits and validated experimentally within the European and national research projects such as *Tempus, Codestar, Chameleon, Comson, MorNet* and *ToMEMS* [18,21,22,6,8]. These boundary conditions are implemented in both FIT – Finite Integration Method [4], and FEM – Finite Element Method [13,14,9,10].

The concept of ECE, introduced over 65 years ago, is a significant contribution of the Romanian School of Electromagnetism. A significant involvement has had C.I. Mocanu, with his early research in Model Order Reduction and introduction of Parallel-Series-Chain equivalent circuits of devices with field effects and ECE BC [29]. During this period, many authors expressed their understanding of the field-circuit coupling problems in the scientific literature, sometimes without proper citations. The classical ECE BC was reiterated in [26], along with recent developments, to acknowledge the original contributions of the Romanian school and to raise awareness among the international scientific community. The problem of EM field-circuit coupling has been the subject of numerous discussions in the literature, as evident in references [3, 1, 2], as well as the entire reference list of [35, 17]. The paper [26] contains a list of articles based on analytical methods to solve field problems with ECE BC. In the digital era, the ECE becomes increasingly essential for modeling and simulation of complex structures, such as VLSI circuits with field effects, RFIC, antennas, their CAD, and optimization, which are now a must.

8. OVERCOMING THE LIMITATIONS OF THE CLASSICAL APPROACH

8.1. MAGNETIC TERMINALS/HOOKS

In the classical approach, the boundary does not allow the inductive coupling between the internal and external parts of the computational domain. Therefore, it cannot be used to model coupled inductors, one of which is located within the computational domain and the other outside, nor the influence of the external parasitic magnetic field. To model the inductive parasitic effects, an extension of the classical ECE BC is necessary.

A critical generalization was proposed in [39], which introduces the concept of a passive electromagnetic circuit element with, a *"magnetic terminal",* allowing it to couple the distributed parameter device to both external electric and magnetic circuits. We refer to it as *MECE (magnetic and electric circuit elements*). Moreover, this paper also introduces elements that consist of multiply connected domains (which we call *MMECE – multiple connected magnetic and electric circuit elements).* Naturally, the boundary conditions have a more complicated form in this case. On the surface of magnetic terminals $\mathbf{n} \times \mathbf{H}(M,t) = 0$ and $\mathbf{n}\times\text{curl } \mathbf{H}(M,t) = 0$ hold. The power transferred by a magnetic terminal is the product of its magnetic voltage and the time derivative of its magnetic flux. These kinds of terminals could be intentional, for example, when only a part of the transformer's magnetic core is modeled. However, in the study of parasitic inductive coupling, the magnetic terminals are unintentional and do not have a clearly defined shape/contour. We refer to them as *"magnetic hooks"* [19, 4, 21, 22, 31]. A convincing application of this concept, with experimental validation, is presented in [7], where the model of an integrated circuit is finalized as a couple of reduced electric and magnetic circuits called *MEEC – magneto-electric equivalent circuit***,** capable of modeling both intentional and unintentional (parasitic) couplings with the noisy EM environment. For this reason, it is not enough to use the classical concept of electrical circuits, based on topology and constitutive relations of components; it was necessary to use a generalized idea of the *"geometric circuits",* in which the position of nodes and the shape of branches have relevance. This is necessary to compute the induced voltage in the loops of the circuit (in the co-tree branches) due to the magnetic fluxes that cross the fundamental loops [23]. Parasitic capacitive coupling can be modeled by using non-intentional terminals. They are virtual electric terminals, like magnetic hooks [23].

8.2. TERMINAL SPLITTING

Real terminals are never perfect conductors; therefore, they have a potential variation over their surface. It is negligible if the terminals are very good conductors and/or their size is small. This condition cannot be removed from the ECE BC entirely, as it is necessary to couple to external circuits, which all have only one voltage at each node. If the variation of the potential over the terminal is relevant, the only solution is to split that terminal into many disjoint parts. However, if the electric and magnetic terminals are iteratively slitted to obtain more accurate numerical solutions, they are eventually reduced to the nodes or faces of the mesh. Hence, we no longer have ECE BC, but classical $\mathbf{E}_t$ or $\mathbf{H}_t$ BC [20], [21], and the advantages of ECE are lost.

8.3. MULTIPLE CONNECTED DOMAINS

As mentioned earlier, the multiple connected domains with ECE BC were introduced in [39]. Each hole contributes to the transferred power with two terms, products of e.m.f. (time derivative of magnetic flux) and conjugate m.m.f. (total current) passed through the hole and the associated handle, as in [27]. In [37] and [36], the homology theory is used to approach this problem. In [23], this concept is reiterated, and its numerical aspects are discussed.

A detailed presentation of this concept, with a solid mathematical foundation and a discussion of its numerical modeling, which, according to our understanding, concludes the debate regarding field-circuit coupling, is presented in [17]. It also contains a series of important references to this subject. The topological aspects of field-circuit coupled problems are relevant, since both electrical and magnetic circuits are, by definition, abstract representations of multiple connected domains.

8.4. RADIATING BOUNDARY

The radiating boundary combined with ECE BC is introduced in [30]. In the general case, the boundary also contains patches with classic BC regarding $\mathbf{E}_t$ or $\mathbf{H}_t$. The numerical aspects of this problem are discussed in [11].

Perfect Matched Layer (PML) is compatible with ECE, since it can be terminated by a non-terminal surface or a perfect conductor. Other absorbing boundary conditions (ABC) can be expressed by

$(\mathbf{E} - \mathrm{Z}\,\mathbf{H} \times \mathbf{n}) \times \mathbf{n} = \mathbf{e} \times \mathbf{n}$ or $(\mathbf{H} + \mathrm{Y}\,\mathbf{E} \times \mathrm{n}) \times \mathbf{n} = \mathbf{h} \times \mathbf{n}$,

where **e** and **b** is outgoing waves (typically zero, excepting the problems of scattering field), They are known waves incident from the exterior of the element on its boundary, and $Z=Y^{-1}$ is the superficial impedance/admittance, defined ether as a local positive defined operator (e.g. in Silver-Muller BC), or a global operator (*e.g.*, EM integral equations in the boundary for the external domain).

According to [30], ABC surfaces must be surrounded by the ground terminal. In E-formulation, they can be incorporated in the nonterminal surface, since in this case, $\mathbf{h}_t=0$ is a natural BC, so from an external point of view, the total injected current is zero, which is the second ECE BC.

9. EFFECT OF THE INCIDENT FIELD ON CIRCUITS

As mentioned before, the classic definition of the electric circuits, by their topology and the constitutive relations of the components, is not appropriate to model the influence of the parasitic external field. The sources of these circuits are only voltage or current sources, connected to nodes, so power is injected only at nodes, then through the terminals. To model the field influence accurately, considering, for example, the induced voltages in circuit loops by the inductor magnetic field or the parasitic capacitive couplings, the real "circuit" should be regarded as a field structure, considering all geometrical details. This is done when the RLC effects are extracted in the integrated circuits, starting from their layout [41]. This approach can also be extended to consider the parasitic field.

Another example is the scattered field by the structure, which represents the circuit, considered as an object of receiving antenna type [28]. Of course, these approaches require an intensive computational effort, since the structure is no longer a "circuit". Therefore, the geometrical model of the real circuit should be simplified as much as possible. The simulation effort can be reduced considerably, using a higher level of abstraction, which is the "geometric circuit", as in [22,23,7].

Another question related to this subject is how the incident field can be computed, far from its source, outside the computational domain used to model the field source. The far-field of the antenna can be calculated from its near-field. It is the solution of the EM integral equation, outside the boundary of the computational domain, *i.e.*, $\mathbf{E}_t$ on a sphere inside the computational domain. In [25], the radiation pattern of a patch antenna was determined using Onelab, as described in [44].

10. EFFECT OF THE EXTERNAL PARASITIC FIELD

To consider the EM effect of the noisy environment (*e.g.*, the noise generated by the external electronic circuits) to a structure modeled as a field problem, the boundary tangential field should be nonzero. It can be a classical boundary condition $\mathbf{E}_t$ or $\mathbf{H}_t$ as well as the ABC BC of affine type, with nonzero $\mathbf{e}_t$ or $\mathbf{h}_t$.

11. CONCLUSIONS

The mathematical and numerical models of the electromagnetic field should not be confused with reality. This is why the models must be validated experimentally or by comparison of the simulation results obtained with other models of the same device. Fortunately, ECE BC has a decisive criterion for validation. It is the value of the transferred power, which in ECE is the dot product of vectors of terminal currents and voltages. At the same time, in any other field, computation is the integral over the boundary of the Poynting vector. The difference between these two quantities describes the accuracy of the model; it should be as low as possible in both the frequency domain and the time domain.

The approach to modeling field-circuit coupling, based on the ECE BC described here, is a compelling and flexible method for a large class of practical devices. This is our conclusion, based on decades of intensive research in this area. However, an essential part of the scientific community appears not to fully understand its relevance, its limitations, and how they can be overcome in the day-to-day modeling activity. This is why I felt the need to write this appendix.

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