Technical Theme Topics

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EMC: Looking Ahead

If you can look into the seeds of time and say which grain will grow and which will not; speak then to me. (Macbeth Act 1)

I have asked two experienced EMC practitioners to attempt a forward look into EMC developments in the years to come. Prediction as we all know is a risky business. All we can say with certainty is that change is central to our lives “there is nothing permanent except change” (Heraclitus, circa 500BC). But to quote Poincare “…it is far better to foresee even without certainty than not to foresee at all.” In this spirit I have secured the insights of two teams: one from Europe, paper by *Leferink*, and the other from the USA, paper by *Wilson et al*, which are contained in this Theme Papers column. Naturally, some readers may have different ideas, priorities or expectations. I hope however that the two papers will stimulate discussion and thought as to how EMC is likely to develop.

Future columns of the Theme Papers will cover topics such as EMC in power electronics and drive systems, the Internet of Things, and EMC.

Interfered Technology: A Radiant Future

A Look Forward to EMC in 2023, Five Years from Now

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Introduction

In 1973, a three-part full-page article was published in the local newspaper describing our society in the region of Twente, the Netherlands, in 1923, 1973, and 2023 [1]. The author of this article was only 11 years old at the time, but the predictions made were interesting enough to keep that article for 45 years. The article [1] predicted several innovations for 2023, 50 years ahead, such as a magnetic levitation monorail from Twente to Amsterdam reducing the travel time from 2 hours to less than 30 minutes, as shown in Figure 1. However, all we got after 45 years was a new motorway, with lots of traffic jams, and a train that still takes 2 hours. Despite over a century of research and development, maglev trains are currently operated in just three countries: Japan, South Korea, and China. Other innovations predicted in 1973 for 2023 were clothes made by printers (yes, nearly), no cars in city centres (yes), products made in Shanghai (yes), European regions instead of European countries (no, although Catalonia would like this), no manufacturing but only research and development (no), Holec and Signaal merged (no, Holec split up into several divisions now owned by Siemens, Eaton, and General Electric, and Signaal was sold by Philips to Thomson-CSF, now THALES). And the announcement that the University of Twente will be organizing a conference on communication technology, including electronics. This was a very good prediction: communication technology will be a key issue in 2023.

But many predictions were wrong. As Niels Bohr once said: ''It is very difficult to make an accurate prediction, especially about the future.'' So is it possible to say anything about ElectroMagnetic Compatibility (EMC) in 2023, only 5 years from now?

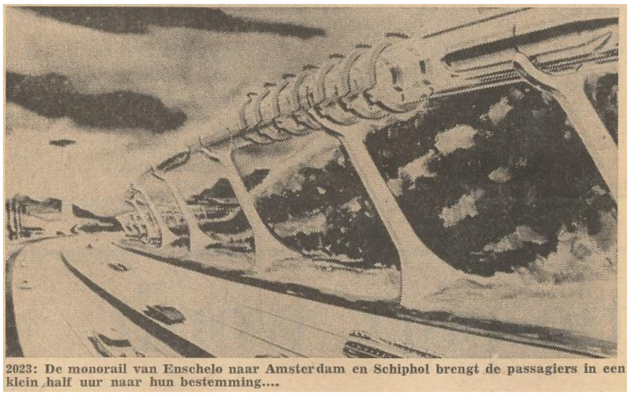

Figure 1. Picture from [1], published in 1973, predicting that in 2023 a magnetic levitation monorail would reduce the travel time between Twente and Amsterdam Airport from 2 hours to less than 30 minutes.

Evolutionary, Revolutionary, and Disruptive Technology

Several definitions for how to describe technological trends are given in [2]. These Emerging Technologies, which are not yet widely recognised, have the potential to become evolutionary, revolutionary, and disruptive:

- Evolutionary Technology is an incrementally developed technology that gradually improves its role in a component, a sub-system, or a system without a significant impact on a system role.
- Revolutionary Technology is a technology that dramatically improves a given role in a component, a sub-system, or a system. It increases the technology development cycle rapidly compared to related technologies and/or fills a role in a new market.

- Disruptive Technology represents a technological development which has the realistic potential for a qualitative or a very significant quantitative change in non-technical capabilities. It can cause a very significant change in the relationships between people and markets.

Analysis of historical data reveals that an emerging technology becomes a revolutionary technology when other evolutionary technologies are combined with it [2]. For example, the commercialization of mobile telephones in the mid-1990s was once considered to be an evolution of the landline telephone market. However, when combined with small, powerful computer chips, rechargeable batteries and a vast network, the mobile telephone dramatically changed user behaviour and disrupted the landline market.

The concept of evolutionary, revolutionary, and disruptive technology will be used to formulate a personal vision on EMC in 2023. The predictions are often based on historical data and predicting trends derived from such. As Confucius said: “study the past if you would divine the future."

EMC and Evolutionary Technology

We have seen an increasing number of new Electro-Magnetic Interference (EMI) problems in recent decades. Some of them could have been predicted because these problems resulted from technological evolutions. A typical evolutionary EMI problem is signal- and power-integrity interference: due to the shrinking size of components and the increased switching speed of the signals, electromagnetic fields in and between interconnections are becoming limiting factors in new products. Some people argue that signal- and power-integrity is not EMI because they consider this as an internal effect of a device. Considered at, for instance, on-chip gate level then interference from another gate is still EMI. The intra-EMI becomes inter-EMI when going deeper in a system. But it remains EMI.

The evolutionary effect of signal- and power-integrity interference can be recognised in the International Technology Roadmap for Semiconductors (ITRS) [3] which was published first in 1992 and has been updated since then on a regular basis. Figure 2 shows the node voltage trend as predicted in 2003, 2009, and 2013. The 2009 prediction did not come true, since we are now in 2018 and still in the 0.8 V region. The 2013 trend line has been corrected. As the noise margin depends linearly on the node voltage, the noise margin was reduced by a factor 5 in about 15 years. A reduced noise margin means there is an increased sensitivity to (external) interference.

Due to the smaller transistors in a chip, the rise and fall times are reduced due to the smaller capacitance of the gates, which also results in a higher sensitivity for higher frequencies. In 2003, it was predicted that the on-chip clock frequency would also increase and be higher than 40 GHz, as shown in Figure 3 . But now in 2018 we know better: the clock frequency is (still) in the lower GHz range, and is not expected to increase drastically, as can also be seen in the ITRS 2013 prediction shown in Figure 3 .

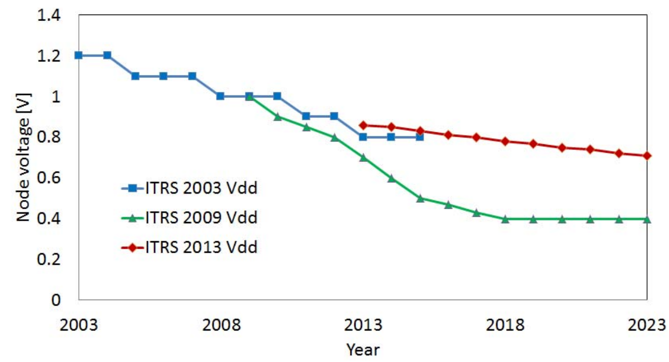

Figure 2. Node voltage as predicted in ITRS 2003, 2009, and 2013.

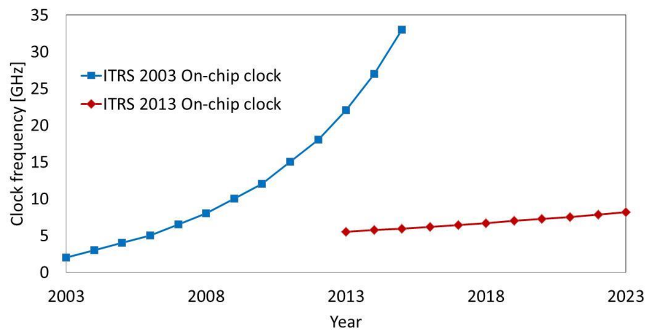

Figure 3. On-chip clock frequency as predicted in ITRS 2003 and 2013.

But what about Moore’s Law? This is still valid because the steady increase in the number of transistors in one integrated circuit has been achieved by increasing the number of logical cores. In Figure 4 the trend data for 40 years of microprocessors has been plotted, from [4], showing the flattening in clock frequency (green squares) while at the same time the number of cores increased, effectively resulting in the continuing growth in the number of transistors (orange triangle), confirming Moore’s Law.

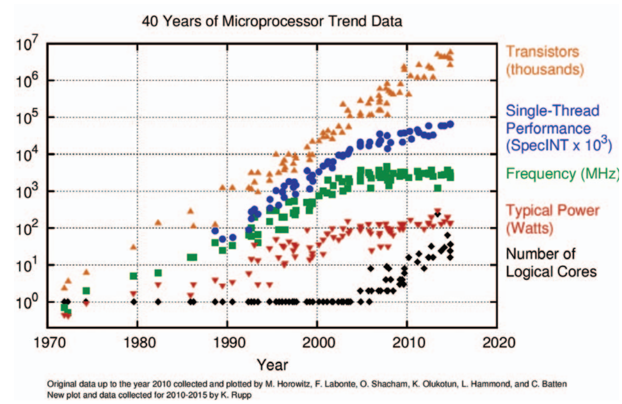

Figure 4. 40 years of microprocessor trend data, from [4].

Has the EMI risk, and specifically the on-chip signal and power integrity (SI and PI) risk due to the low increase in clock frequency, therefore been reduced? No: the SI and PI challenges have increased because now, due to the increased number and size of the interconnects, SI and PI also have to be analysed and solved. This trend is also confirmed in the number of publications on SI and PI. In Figure 5 the publications in IEEE Xplore with Signal Integrity and Power Integrity **in the title** have been listed based on the year of publication. It should be noted that although many more papers were actually published, they did not include SI or PI in the title. In addition, the papers published in the IEEE EMC Society publications "Transactions on EMC" and "EMC Magazine" have also been counted and shown in Figure 5 showing the interest in SI and PI. The EMC Society (EMCS) took its responsibility by renaming the flagship IEEE Symposium from EMC to EMC, SI & PI in 2016. Furthermore, the IEEE EMC Society has proposed the publication of a Transactions on SI & PI. Table 1 below shows the EMCS was right to take responsibility for SI&PI, and the large number of societies involved also shows how widespread the interest in the subject really is.

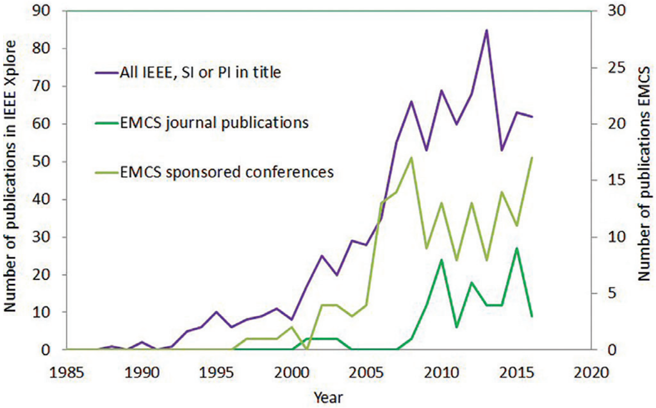

Figure 5. Publications in IEEE Xplore with Signal Integrity or Power Integrity in the title, and also for the IEEE EMC Society's Transaction and Magazine, and for the conferences sponsored by the EMC Society, for example the Workshop on Signal and Power Integrity (SPI).

Table 1: Ranking of Publications with SI or PI in Title, in Journals

Journal	Publications
IEEE Transactions on Electromagnetic Compatibility	33
IEEE EMC Society Magazine	22
IEEE Transactions on Components, Packaging and Manufacturing Technology	19
IEEE Transactions on Advanced Packaging	11
IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems	6
IEEE Transactions on Industrial Electronics	3
IEEE Transactions on Industry Applications	3
IEEE Journal on Selected Areas in Communications, IEEE Microwave and Wireless Components Letters, IEEE Transactions on Consumer Electronics, IEEE Transactions on Instrumentation and Measurement, IEEE Transactions on Magnetics, IEEE Transactions on Microwave Theory and Techniques, IEEE Transactions on Smart Grid	2
IEEE Internet of Things Journal, IEEE Journal of Solid-State Circuits, IEEE Latin America Transactions, IEEE Microwave Magazine, IEEE Potentials, IEEE Power Engineering Review, IEEE Spectrum, IEEE Transactions on Aerospace and Electronic Systems, IEEE Transactions on Circuits and Systems, IEEE Transactions on Dependable and Secure Computing, IEEE Transactions on Device and Materials Reliability, IEEE Transactions on Electron Devices, IEEE Transactions on Electronics Packaging Manufacturing, IEEE Transactions on Mobile Computing, IEEE Transactions on Nuclear Science, IEEE Transactions on Power Delivery, IEEE Transactions on Power Systems, IEEE Transactions on Very Large Scale Integration (VLSI) Systems, IET Circuits, Devices & Systems	1

What can we expect for EMC, including SI&PI, in the coming years? From the trends and predictions of the ITRS, we can expect the noise margin will continue to decrease, but not at such a fast rate. The clock frequency will not experience any significant changes. The logic half-pitch length and gate size will continue to get smaller, increasing the sensitivity for high frequency interference. Simply evolutionary steps, driven by the semi-conductor industry which is continuously increasing the number of transistors on a wafer. The ITRS stated in its final report that the modelling of effects that have a more global influence, such as cross talk, substrate return path, substrate coupling, EM radiation, and heating, will become increasingly important. Only the latter effect (heating) is not covered by EMC and SI&PI engineers.

This discussion about SI and PI is just one example of how evolutionary technologies will continue to create a radiant future for EMC engineers.

EMC and Revolutionary Technology

Revolutionary EMI issues are often more dramatic because they occasionally result in catastrophic failures, such as loss of life or delays in product introductions. One of the best known examples is the USS Forrestal disaster, where a missile was misfired due to EMI, resulting in many casualties. This actually resulted in the first standard on reverberation chambers, way back in 1971 [5]. Another example is the use of mobile telephones in cars causing airbags to explode, and the ban on the use of these phones in aeroplanes. A lessor known example is the delay in introduction of the road toll system in Germany, because when the transmission of GPS data was blocked, there was no built-in data backup for the wheel rotation, for example [6],[7].

What we can learn from these catastrophic failures is that the introduction of new (revolutionary) technology is accompanied by EMC risks. Knowing this, can we predict the future? We could give it a try. Take the revolutionary steps in power semiconductors, for example. When the Insulated Gate Bipolar Transistor (IGBT) was introduced, the EMI potential increased by roughly 40 dB. This was due to the increase in voltage handling capabilities by a factor 5, and the turn-off time which dropped 20 times, to around 100ns. As most interference is caused by the common mode current caused by the dV/dt, the combined interference potential is 5 x 20 = 100 = 40 dB. The power electronics engineers have to take EMI and EMC into account, and we can see this interest in Figure 6 which shows the number of publications listed in IEEE Xplore with EMI or EMC in the title, excluding publications in the IEEE Transactions on EMC and the EMC Magazine. The journal with the most publications was IEEE Transactions on Power Electronics.

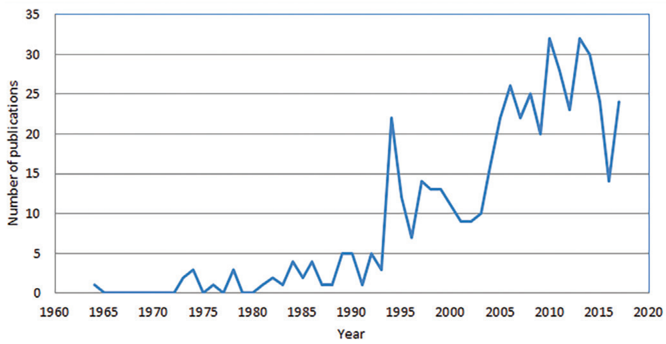

Figure 6. Number of publications with Electromagnetic Compatibility, Electromagnetic Interference, EMC or EMI in the title, in IEEE Xplore journals, except Transactions on EMC and IEEE EMC Magazine.

And we can expect more to come: new technologies have and will be introduced with much faster switching power electronics, for example using gallium nitride components, as shown in Figure 7 . These wide-bandgap power devices will enable an order-of-magnitude reduction in switching losses relative to the IGBT, but this comes at the cost of a 20–30 dB increase in the high-frequency spectral content of the power converter switching waveforms [8], and are thus causing interference at much higher frequencies and resulting in new and unexpected failures in other systems. Many EMI cases have been reported in for instance [9][10][11].

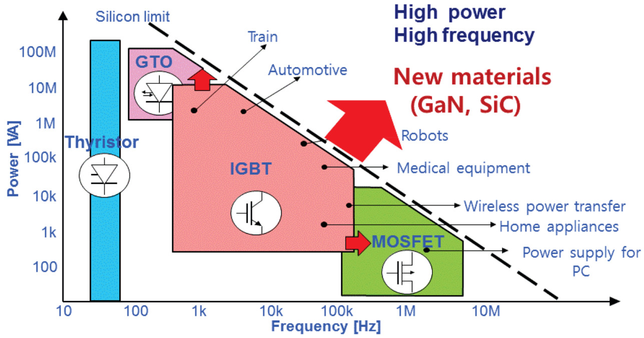

Figure 7. Trends in power semiconductors.

While EMI issues associated with evolutionary trends can be (easily) predicted, this becomes more difficult for EMI caused by revolutionary technology, because we, as EMC engineers, do not always know what "new" technology will be introduced. Except, of course, if this new technology is being developed by your own company, institute etc. But does the EMC engineer have enough influence to implement the filters, the shielding, the screened cables and connectors, and other EMC measures? In many cases he/she is bypassed by management and EMC is considered as just a "compliance (with legislative requirements)" issue, instead of a "compatibility (with the EM environment)" issue. One example is the smart energy meters being rolled out at a high pace around the world. It is well known that the static metering part is sensitive to EMI [9], [10], but they comply with legislative requirements [13] because EMI is more or less excluded in the pre-amble of this Directive. Compliance: yes. Compatibility: no [14].

A.H. Sullivan, Guest Editorial "Energy and EMC-Where Do We Go From Here?", IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-21, No. 2, May 1979, pp. 73-74

New aspects:

1) Possibilities of biological effects from ELF fields of extremely high-voltage ac power transmission lines,

2) EMC effects of the proposed solar-power satellite system,

3) EMC problems in the expanded use of electronic control and sensor devices in motor vehicles.

"Now for those of you who have not kept up with the automotive world, you should know that the manufacturers plan major new electronic systems in future automobiles. There will be new families of sensors and data processors to detect status and control the functions of automotive systems and subsystems. Unfortunately, it turns out that these electronic devices are extremely susceptible to the electromagnetic environment - an environment which is not at all technically well-defined at any given time and place. The full solution to this problem is not completely evident at present and, therefore, it gives EMC engineers a new bone to chew."

However, we can predict the future for some revolutionary technologies. For instance, a huge number of 5G wireless devices will soon be populating our living environment, creating higher demands for wireless coexistence and higher resilience to interference, which will often require a risk-based approach instead of the conventional rule-based approach. The reason why a risk-based approach is needed is because not all the electronics currently in use have been designed to cope with 5G EM fields. For example, the installed base of equipment in a hospital was designed in a time when WLAN, Bluetooth, and mobile phones were quite common, and the equipment is therefore resistant to these devices. But do they have immunity against the fields caused by these new 5G devices, operating at much higher frequencies than was anticipated? And what about RFID, or in-door tracking?

Another example of EMI due to revolutionary technologies is the conducted emission in the low frequency range, where especially the 2-150 kHz debate is intensifying. More and more devices have been shown to be susceptible, while the number and level of conducted interference sources is increasing rapidly [9]. Many suppliers can avoid taking responsibility for EM Compatibility as long as they are EM Compliant. On the other hand, the development and production of products with EM Compatibly might be very costly for suppliers, and could put them out of business.

A third example of revolutionary technology, but now in preventing EMI, can be cognitive power line communication. Power Line Telecommunication (PLT) is the default choice for smart meters, but often the PLT signal is interfered by power electronics. Adding a filter in the interfering product is not effective, as it also decreases the PLT amplitude. One option could be to apply cognitive communication. The interference on power lines appears to be cyclo-stationary, and linked to either the 50 Hz mains supply, or to the clock frequency of the power electronics. Instead of looking at the maximum level of interference as a function of the frequency, we could take a look at the spectrogram, and we might find a large space in time and/or in frequency domain which could be used for communication [15]. This concept requires the setting of dynamic levels for conducted electromagnetic interference requirements in order to enable PLT.

Once again, as pointed out earlier, all these many challenges are creating a radiant future for EMC engineers.

EMC and Disruptive Technology

What is disruptive technology? One example was given in the introduction: the emergence of mobile telephones has seen an enormous decline in the use of landline telephones, and has thus severely disrupted the business model for landline telephone networks. Other examples of disruptive technologies with an EMC impact, in the opinion of the author, include:

The generation of electrical energy using the sun (photo-voltaic) or wind, instead of polluting carbon-based fuels. This is resulting in a huge increase in power electronics, and a huge increase in EMC issues (see for example [10][11]) because the technical specifications for active infeed converters are not an EMC standard but a license to generate EMI [16]. A radiant future for EMC engineers.

Similar to the disruptive energy technology, the use of electric cars can be considered to be a disruptive technology, because it is eliminating the use of internal combustion engines, disrupting the conventional business model. The diesel scandals have proven this already as for instance Volkswagen announced a reduction of 30.000 jobs. Volkswagen also, in the same press release, announced to create 9,000 new jobs as it shifts to electric drive technology. The dense integration of power and control electronics combined with in-vehicle and external vehicle communication requires direct involvement of EMC engineers from the conceptual and design phase, and novel test techniques [17][18].

Autonomous systems, like robots and 'driverless' or self-driving cars, are also disruptive, because they eliminate the need for human intervention. Although this has been predicted by futurists for many years now, the author is sceptical about the autonomous car: driver-assistance, yes, but driver-replacement, no thank you. Nonetheless, autonomous systems, or even semi-autonomous systems, definitely will have a huge impact on the number and use of electronic devices. We need EM compatible sensors, lots of different interfaces, and extremely reliable operating controls which are immune to interference from any EM source, whether natural, like lightning, man-made, like ESD, or intentional EMI.

The Radio Equipment Directive (RED) [19] is also a disruptive driver (in Europe), as it now requires equipment to be constructed for efficient use of the radio spectrum, to avoid interference with other wireless communication systems. Furthermore, non-radio communication systems are excluded from RED, and therefore have to comply with the essential requirements of the EMC Directive. Conversely, equipment with a radio function, such as a laptop computer with wireless LAN and Bluetooth, is no longer included in the scope of the EMC Directive, but rather in the scope of RED. The same applies for a washing machine with RFID, or other equipment forming part of our Internet of Things. Because the impact is so huge, the discussions on the exact implications are still ongoing, as stated in [20]: "Non-radio products which function with radio equipment: to be finalised." It will also have an impact on standardization, as the RED standards are developed by ETSI, which provides standards for free, while the EMC Directive standards are developed by CENELEC, and these standards have to be paid for.

Time-domain EMI meters were developed more than 10 years ago [21], [22] but are now the state of the art and provided by many suppliers of test equipment. Time-domain EMI meters can be considered to be a disruptive technology, because these receivers are so fast compared to conventional super-heterodyne receivers, the latter will eventually (already now) be forced out of the market.

Andrew Farrar, IEEE EMC Society-The Decades Ahead, IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-25, No. 3, August 1983, pp. 57-158

"To understand the trend of EMC technology, one may consider the rate of growth in the ingredients that form this technology. EMC technology is basically a combination of all the disciplines employed in the fields of communications and electronics, taken in the broad sense of those terms..... EMC technology is the result of crises which surfaced more and more frequently as electronics and communication systems reached greater heights of sophistication.....The demand on spectrum may become one of the challenging issues in EMC technology in the decades ahead, and cannot be ignored.....EMC education has generally been limited to its practitioners. Many special courses set up by educational institutions involved in offering courses for continuing education have taught the rudiments of EMC discipline to many who have entered this career. In the next decade, this discipline will be installed as an optional course in the curriculum at a number of colleges and universities in the United States and Europe. The need for teaching EMC fundamentals to a large number of engineers is both technologically and economically expedient. There is a definite need for more competent engineers in this discipline.....The EMC technology a few decades hence will be a great deal more complex and diversified than it is now..... Whatever your choice may be, a great challenging future lies ahead."

What to Expect in 2023?

In summary: a radiant future for EMC Engineers!

(And also for EMC researchers, as several of these subjects need further research.)

In 2023 we will (sadly enough) have even more EMC standards than the many hundreds of standards we already have in 2018. We will have issues between ETSI and CENELEC on "what is radio" and who is responsible for the standards. But we will also have harmonized standards, for better or worse, for the 2-150 kHz range, as well as standards for the >6 GHz range. Instead of the plethora of standards in the civil world, there will be only one worldwide accepted standard for military equipment and systems, the AECTP 500 series, applicable from DC to above 40 GHz, replacing national military standards [23]. One might complain about technical quality, but if a standard results in EM Compatibility then the main objective will have been achieved.

In 2023 we will only use time-domain EMI analysers, either heterodyne or direct conversion (oscilloscope) [24], [25]. The direct conversion (or full time domain [24]) facilitate also multi-channel measurements allowing novel evaluation techniques. Furthermore EMI

From: Quasies and Peaks, July-August 1957, reprint in IEEE EMC Society Magazine, Vol. 4, Quarter 3, p. 29

Notice of a Symposium on Electromagnetic Interference to be held 19-21 November 1957 has gone out from the U.S. Army Signal Engineering Laboratories, Fort Monmouth, New Jersey.

The notice states, in part:

"The large density of electronics equipment which will appear in our Field Armies, and in the Continental U.S. for both civilian and National Defense, may breed intolerable electromagnetic interference. The intent of the symposium, which is to be held in the Fort Monmouth area, 19-21 November 1957, is to smoke out those technical factors, theoretical or practical, which limit the efficient use of the Electromagnetic Spectrum and invite technical discussion on far-reaching means for a much more efficient usage of the spectrum to satisfy the electronic density needs of the future."

measurements will not be evaluated only in the frequency domain, but also in the time domain using time-frequency spectrograms.

In 2023, the reverberation chamber will be the preferred measuring environment [26], [27]. EMI measurements on open area test sites and anechoic chambers show a very low repeatability, and thus a large variation in measurement results, caused by the complex radiation pattern of modern products at high frequencies. But more research is needed to allow traceable emission measurements in reverberation chamber for conformity assessment purposes, and to determine the emission limits that apply to the reverberation chamber on the basis of those that presently apply to the open area test site, as stated by CENELEC [28].

In 2023, we will still see many fire-fighting consultants solving a multitude of EMI problems, simply because managers deny the possibility and probability of EMI in a new product. EMC support in the system life cycle, as described in many EMC handbooks and including the key elements Awareness-Network-Rules-Support [29], is in the management system and quality books of most companies, but still not used.

In 2023, the number of SI & PI engineers in the semiconductor industry will have increased. The IEEE EMC Society Transactions on Signal Integrity and Power Integrity will be a great success, attracting many publications.

In 2023, the IEEE EMC Society Letters on Electromagnetic Compatibility Practice and Applications (L-EMCPA) will also be a great success. Following the rapid increase in the number of practical papers at major conferences, in 2019 the L-EMCPA was created to stimulate engineers from industry to promote their work in this new publication.

In 2023, the use of macro- and behavioural models (merging EM and circuit) and statistical techniques and models in simulation tools will be the state of the art. The conventional deterministic techniques will not be capable of handling the vast number of variations of a product and to estimate the risk of interference.

In 2023, tooling vendors will continue to provide fully-integrated tools, while many large industrial consortia will continue to develop open EM tool platforms. In these platforms, the best-of-class solvers can be plugged-in for simulation (or modelling) of a specific problem, while the geometric and electric databases and user interface remains the same, reducing the learning curve of engineers dramatically.

In 2023, university groups will collaborate much more with industry. In the past, research groups at universities were driven by the technology and its possible applications. While industry is driven by applications based on societal or economic relevance, fundamental solutions, which can be provided by universities, will be needed.

In 2023, the ITU levels on man-made noise have been updated with the levels observed in the 21st century, and are showing a dramatic increase of the noise levels in built environments. The levels found in semi-enclosed environments, like inside buildings, trains and cars, will have also been included and serve as the basis for link budget calculations of communication engineers. The urgent need to use the man-made noise levels for EMI requirements, however, will take another decade of negotiations….

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Biography

Frank Leferink *(M'91–SM'08) received his B.Sc. in 1984, M.Sc. in 1992, and his Ph.D. in 2001, all in electrical engineering, at the University of Twente, Enschede, the Netherlands. He has been with THALES in Hengelo, the Netherlands, since 1984 and is now the Technical Authority EMC. He is also manager of the Network of Excellence on EMC of the THALES Group. In 2003 he was appointed as (part-time, full research) professor, Chair for EMC at the University of Twente. Prof. Leferink is the former president of the Dutch EMC-ESD Association, Chair of the IEEE EMC Benelux Chapter, member of ISC EMC Europe, Chair of EMC Europe 2018, Member of the Board of Directors of the IEEE EMC Society, and Associate Editor of the IEEE Transactions on EMC.*