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The Physical Basis of EMC
By Keith Armstrong
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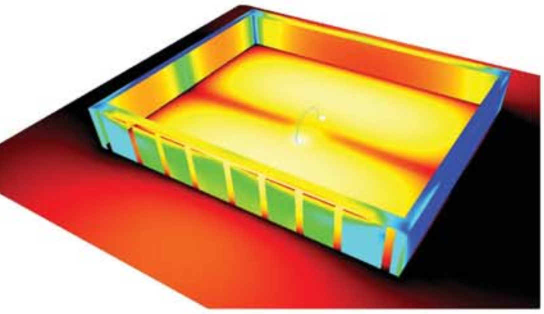

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CHANGING THE STANDARDS

What's In This Issue

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www.theemcjournal.com

www.emcia.org

www.emcuk.co.uk

www.emcacademy.org

The EMCUK Ladies. From the left: Charlotte, Anne, Lynne, Jane, Sophie and Vanessa

Another successful EMCUK Event at The Racecourse Newbury.

Our ladies look forward to seeing you all for the 7th year at EMCUK 12th and 13th October 2010.

The event where the EMC Industry comes to network and do real business. **www.emcuk.co.uk**

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Secretariat for EMCIA

The Trade Association for the EMC Industry.
Web: www.emcia.org

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Editorial & Publishing Director:
Alan E Hutley
alan@nutwooduk.co.uk

Technical Consultant:
Dave Fynn
alan@nutwooduk.co.uk

Advertisement Sales Director:
Lynne S Rowland
lynne@theemcjournal.co.uk

Production & Circulation Director:
Pam A Hutley
pam@nutwooduk.co.uk

Nutwood UK Ltd
Eddystone Court, De Lank Lane,
St. Breward, Bodmin, Cornwall PL30 4NQ
Tel: +44 (0)1208 851530
Fax: +44 (0)1208 851630
Web: www.theemcjournal.com

New Company for Simon

After many years working in the EMC Industry, Simon Young has started a new company called Frequensys Limited. Frequensys provide specialist knowledge and consultancy in the EMC and RF & Microwave industry. With the backing of EM Test (Commercial, Automotive Transient and Conducted Immunity test equipment) and Siepel (Shielded and Anechoic Chambers and Material, RAM) Frequensys is providing EMC solutions from individual test generators to fully integrated EMC test systems.

In these difficult times it is even more important to provide cost effective solutions and the innovations from EM Test are proving to be very useful to customers as they must cut costs but at the same time continue to invest and develop their products. For example, their ISO7637 solution is always progressing and looking to include new and updated standards from car manufacturers. The AutoWave Generator makes this system very flexible. The new NetWave also looks to provide DC and AC test capabilities to meet new EN61000 standards that have previously been overlooked with regard to updating and automating the testing.

Siepel are a fully integrated shielding and absorber manufacturer based in Europe meaning that they can provide very cost effective solutions. Together with their unique plastic paint absorber finish it allows them to give excellent extended warranties and full turnkey guaranteed solutions meeting CISPR, EN61000-4-3 etc.

Frequensys does not intend to sit still either and has have recently signed up new suppliers providing RF Power Amplifiers, Current and BCI probes, LISN's, Field Probes and antenna measurement systems.
www.frequensys.co.uk

Winners on the Racecourse

Hursley EMC Services Ltd have exhibited at every EMC UK show since it started in 2004 and are enthusiastic supporters of the annual industry get-together. This year's event, at Newbury Race Course on October 13th and 14th was no exception.

Commercial Director Julian Jones was pleasantly surprised by the numbers of visitors to the stand. "EMC UK is about more than just the exhibition for us. It is the chance to meet up with other EMC partners to discuss various technical issues and review how the industry is doing in general. Although the Tuesday was quieter than expected, we had a lot of genuine interest on the Wednesday and made some very important contacts," he says. "Due to the volume of existing business back at the lab, we were only able to spare two people to man the exhibition and there were times when a third pair of hands would have been appreciated. Having said that, we have already had two projects booked in as a result of show contacts and have met over 30 new prospects - well worth tearing ourselves away from the lab for two days!"

In order to attract a wider audience, Hursley EMC Services shared a stand with their Safety testing partner, Nemko UK. Nemko's Managing Director, Melvyn Harries, was also pleased with the response. "It was very interesting to meet so many potential customers in a concentrated period of time," he reports. "Sharing the stand between ourselves and Hursley was definitely beneficial for both parties with our own prospective clients being able to visit and discuss EMC and Safety issues. I'm certain we shall more than cover our expenses, with some promising long-term prospects."

Julian Jones, Commercial Director of Hursley EMC Services (left) with Peter Cross, Nemko UK's Lab Manager at EMCUK 2009

Hursley and Nemko expect to repeat their double act at forthcoming shows.
www.hursley-emc.co.uk
www.nemko.co.uk

Cranage Launch New Test lab for Surge Protection

A new test laboratory with the facility for generating combination waves at 24kV 12kA has been launched by Cranage for evaluating the performance and safety of Surge Protection Devices in low-voltage power systems and telecommunication networks.

Products such as trailing sockets, plugs, TV and telephone extension leads which incorporate surge protection components can now be fully evaluated to the requirements of EN61643-11 +A11 and EN61643-21. These standards are published in the Official Journal of the European Union as a requirement for implementing the Low Voltage Directive 2006/95/EC.

The SPD test lab at Cranage is believed to be the only facility in the UK that is fully equipped to test to the new A11:2007 requirements for Type 3 SPD's. This amendment, effective from July 2009, also specifies phase synchronous short circuit withstand testing up to 1500A. In the 12 months leading up to July, Cranage designed and developed suitable test equipment and constructed a safe working environment, isolated from other work in progress, as products would either explode or catch fire as a result of the test.

Tests undertaken at Cranage on many electrical accessories which provide a surge protection function have shown that use of certified or approved components will not necessarily lead to a safe product. "Manufacturers that choose to verify conformity with the essential requirements of the Low Voltage Directive on the basis of having type approval documentation are probably not even aware of the risk they are taking," warned Keith Richens, Managing & Technical Director of Cranage EMC & Safety, a UKAS accredited test house and approved product testing laboratory for TUV Rheinland, based in Shropshire.

He also explained that declared protection ratings based on MOV component specs serve no purpose whatsoever. "In this market, we seem to be dealing with customers who are simply not aware of the design or manufacturing quality issues that can affect safety or performance," he added, "both of which strongly influence the outcome of SPD compliance tests."

For further information go to **www.cranage.co.uk/spd.htm** or email info@cranage.co.uk

QinetiQ's Dragon Runner robots are sent to Afghanistan to support British troops

Responding to an urgent operational requirement QinetiQ, a leading international supplier of military robots, has announced that it has been awarded contracts by the UK Ministry of Defence (MOD) to supply approaching 100 Dragon Runner robots, associated spares and technical services to support of current military operations in Afghanistan.

Dragon Runner is a small, rugged robot that weighs between 10-20kg depending on the chosen configuration. It can be easily carried by a soldier in a backpack and is robust enough to operate in rough terrain to help protect troops. The variant selected by the UK MOD is equipped with a manipulator arm to assist with the disarming of improvised explosive devices but the versatility of the Dragon Runner platform means that it can also be configured for a variety of other reconnaissance and surveillance operations. The Dragon Runner robot is also able to operate in sewers, drainpipes, caves and courtyards to detect danger.

Already being deployed, the all-seeing, all-listening Dragon Runner has the ability to send back video footage back to the operator at a safe distance thereby enabling troops to assess a situation prior to moving forward or entering a structure, potentially safeguarding lives.

The backpack-able Dragon Runner is particularly suited to operational environments similar to those experienced in Afghanistan where the road system has been ravaged by almost continuous fighting since the late 1970s and where many troop movements are conducted either on foot or by helicopter. The use of robots also has significant benefits in Afghanistan where the United Nations estimates that 200,000 people have been disabled by landmines and the explosive remnants of war.

QinetiQ's initial contract with the UK MOD is valued at over £12m. This includes the supply of replacement parts and the provision of support throughout the operational life of the systems. This is an essential part of a UK based maintenance and support plan that has been carefully designed to enable the UK MOD to return battle-damaged robots to active duty as quickly as possible.

Dragon Runner was originally developed by Automatika, a US company acquired by QinetiQ North America. The robot has since has been further developed as a result of UK and US military user input and it can travel at speeds of around 5mph, travel over rough terrain, as well as climb stairs and open doors. The basic chassis is 20cm wide, 7.5cm tall and 23cm in length and can be easily adapted in the field with various accessories and a manipulator arm to be mission specific. In addition to IED identification and defeat, other functions include perimeter security, checkpoint security and the inspection of suspect vehicles.

"With this very important contract and our work with the UK and US military, Dragon Runner is set to become a vital tool in military campaigns throughout the world," said Mary Carver, MD of QinetiQ's Technology Solutions business. "The majority of the 3,000+ military robots that we have delivered to our customers so far are being used to disable roadside bombs however we're now seeing increased demand for military surveillance and reconnaissance as well as for homeland security and specialist intelligence operations."

www.qinetiq.com

News and Information

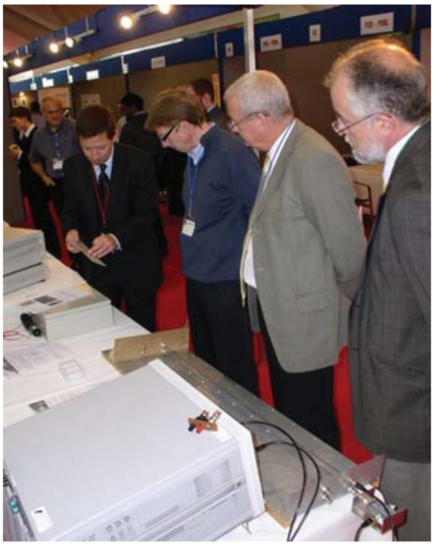
IEEE EMC Society UK&RI Chapter

During EMCUK, the UKRI Chapter of the IEEE EMC Society ran a series of practical and computer based demonstration sessions. These informal table-top demonstrations showed a range of EMC concepts and principles, phenomena, effects, measurement methods, modelling approaches and simulation methods. As with previous years, there was a wide range of demonstrations including the time and frequency analysis of voltage and current on a high speed clock line as a function of the pulse rise time and termination impedance, shielding effectiveness analysis of an enclosure and the impact of different source/monitor types, the coupling and screening between wires and, the comparison of longitudinal and transverse voltages on wires.

The next meeting for the UKRI Chapter takes place at the University of Westminster on Wednesday 16th December. More details are available from either Paul Duxbury (paul.duxbury@ieee.org) or Roy Ediss (roy.ediss@ieee.org).

We hope to see you there.
www.ieee.org.uk

Stuart Charles gave a fascinating demonstration examining the effect of the pulse rise time and termination impedance on the voltage and current on a high speed clock line.



David Welsh demonstrated how the shielding afforded by an enclosure is highly dependent on the design of the enclosure, especially with regard to any discontinuities which may exist such as seams and ventilation panels.

Tim Williams showed how the coupling between a pair of wires is affected by the addition of a screen between the wires and the quality of the screen ground connection.

The University of Oxford offers a series of high quality short courses for professionals in the technology industry

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- Practical RF/Microwave Design (18-22 January 2010)
- Digital Signal Processing - Theory and Application (25-27 January 2010)
- Digital Signal Processing Implementation - Algorithms to Optimisation (28 January 2010)
- Successful RF PCB Design (11 February 2010)

Systems Engineering

- Systems Engineering Fast-Track (Four-day course held over 2 weekends - 6-7 March and 20-21 March 2010

Business skills for engineers and scientists

- Applying Knowledge Management: Principles and Practices (1 December 2009)
- Successful Change Management for Engineers, Scientists & Staff in Hi-Tech Companies (2 December 2009)
- Essentials of Project Management for Engineers, Scientists & Staff in Hi-Tech Companies (3 December 2009)
- Advanced Project Management for Engineers, Scientists & Staff in Hi-Tech Companies (4 December 2009)

http://cpd.conted.ox.ac.uk/courses.asp

Nationally important' Defence Technical College given green light for development by Vale of Glamorgan Council

The Vale of Glamorgan Council has resolved to approve the planning application for the Defence Technical College (DTC) at MOD St. Athan and over the coming weeks both the Welsh Assembly Government and Ministry of Defence will complete the statutory processes required to formalise this consent.

The DTC is a nationally important project involving the redevelopment of a large part of the 1000 acre MOD St Athan site, which is home to the RAF 4 School of Technical Training.

The DTC will bring together in one location the technical training for all three Services creating the largest vocational training operation in the country. With up to 3000 students present at any one time, the DTC will create a development similar in size to a small town. As a result, it will have all the facilities that would be expected of a small town, including excellent recreational and sporting amenities which will be a particular feature of the development.

An artist's impression of a classroom at the future Defence Technical College

Metrix, the consortium that is behind the DTC is led by technology services company QinetiQ and facilities management specialists Sodexo.

Metrix chairman, Charles Barrington, said: "This is exciting news for the MOD, for Metrix and for the people of South Wales. It is truly a win-win situation for all the stakeholders involved in this nationally important project. This decision is a huge step forward in our plans to reach contract agreement with the MOD in 2010."
www.metrixuk.com

The Ofcom Saga

Why Ofcom is not fit for purpose — the PLT issue

Text in blue are quotations from the OFCOM document 2.9.2009.

Ofcom's PLT statement of 2nd September this year (www.ofcom.org.uk/radiocomms/ifi/enforcement/plt/) is a prime example of why it is not fit for purpose as a spectrum regulator and protector. Almost every line contains things that are economical with the truth, irrelevant, or spin – that is, when they are not blatant misdirection, or just plain insulting. Let's look at a few quotes from it....

> "Ofcom has exercised its enforcement functions under the EMC Regulations. Ofcom has investigated alleged breaches of the EMC regulations resulting from the supply of Comtrend PLT apparatus by BT...... On the evidence, Ofcom has not so far found that there is a breach of the EMC essential requirements. Ofcom has therefore decided against taking further enforcement action at this time"

But what "evidence" are they talking about? Of the technical evidence submitted in formal complaints by the UKQRM group (www.ukqrm.org) and by the RSGB, Ofcom has refused to respond to any of it.

By all accounts Ofcom has undertaken no technical tests or examined the Comtrend PLT devices (the ones that are the subject of all Ofcom's complaints of interference from PLT devices) against the points made in these complaints.

The RSGB's complaint (published on their website, www.rsgb.org) was made on 31 July, just four weeks before Ofcom's PLT statement. That's hardly sufficient time for them to consider the evidence in detail and then write their response, if they could actually have been bothered to do so. Which they weren't.

Indeed, their response does not even mention the two central points of RSGB's complaint:

a) Comtrend's PLT products emit conducted noise at levels *way* above the limits in EN55022, the most relevant EMC product standard

b) They rely for their EMC Declaration of Conformity on a discredited CISPR committee draft (CISPR/I/89) – simply a committee paper – never a published standard – which anyway was withdrawn several years ago.

Either of these plain and obvious facts should be enough to have their products immediately withdrawn from the entire EU market. That Ofcom have not done so brings the whole process of Single Market Compliance and CE marking into disrepute.

> "Over the past 12 months Ofcom has received 143 individual PLT interference complaints; all from radio enthusiasts... There are many other users of the HF Band including long range aeronautical and oceanic communications, the Ministry of Defence and international broadcasters. Ofcom has not received complaints of interference to these services."

Ofcom are apparently suggesting that complaints from radio enthusiasts are not as important as those from professional radio users. Would Ofcom have acted differently if there had been complaints from the professionals? The EMC Directive and the UK's corresponding 2006 EMC Regulations do not discriminate in this way, and in fact the EMC Directive's Recitals make it clear that Member States must actually protect amateur radio from "electromagnetic disturbance".

Although professional radio users may not have complained of interference from PLT yet, you can be sure that they have been telling Ofcom how worried they are that it may happen!

As for being economical with the truth, Ofcom's statement just happens <u>not</u> to mention that the total number of complaints they have received about PLT interference, in just over a year, is already their 4th highest after complaints about lighting equipment; thermostats and aerial pre-amps which have been accumulating for several years.

Their statement also just happens <u>not</u> to mention that the *rate* at which they are receiving complaints of interference from PLT is far higher, per million units sold, *than from any other technology*.

> "Evaluating the complaints received and the evidence so far obtained, Ofcom has concluded that there does not at present appear to be significant public harm arising from this situation."

Perhaps Ofcom could point to the place in the 2006 EMC Regulations where it says that the number of interference complaints are a factor in determining whether something meets the Essential Requirements or not? And perhaps they could also point to the place where it says that professional radio users are more important than mere enthusiasts?

And where does the test of "significant public harm" arise in the EMC Regulations? None of these issues exist anywhere other than in the fevered brains of Ofcom's spin-doctors, who hope to convey the impression that they have some meaning – some relevance to the issue of interference from PLT, which of course they do not.

Ofcom has managed to get BT to sort out many of the 143 reported problems with Comtrend PLT products. (BT sell the Comtrend devices bundled with their "BT Vision" product, so that customers don't have to trail Ethernet cables from room to room, causing unsightly lumps in the carpets).

But the point is that the interference complaints are caused by the fact that these PLT products have a non-EMC-compliant design. If the PLT devices were compliant in the first place, they would most likely not have caused any interference.

> "It is recognised that EMC compliant equipment may still, in certain circumstances, have the capacity to cause interference to other radio communications equipment. This may happen due to the manner in which it is installed or operated."

Well, yes, but this is irrelevant. This is not a situation where a compliant device happens to cause interference to a radio receiver. Comtrend PLT devices are designed in such a way that they are almost certain to cause interference when operated in the vicinity of an HF (short-wave) receiver.

And as to "the manner in which they are installed" – how is this even possible? All you do is plug them in – how wrong can you get that?

> **"Is there an EU harmonised standard for PLT?**
> No. The EU has not yet published a suitable harmonised standard for this type of apparatus."

There is no standard specifically for PLT, but PLT is quite clearly already covered by EN 55022 – whose conducted emissions limits the Comtrend devices exceed by about 30dB. And as for creating "a suitable harmonised standard for this type of apparatus" – it seems that this may prove to be impossible (see later).

> **"Are existing EU harmonised standards for other products helpful?**
> Existing harmonised standards are helpful only to a limited extent because they are not specifically intended for this type of equipment."

Well, the information technology (IT) EMC standard, EN55022, *does* cover PLT (as mentioned above), because PLT devices are simply another kind of IT device. But what the PLT industry lobby wants is a standard that says that *simply because a product is PLT*, it is permitted to emit 1,000 times more radio-frequency noise into the mains network than anything else is legally allowed to emit.

If such a standard was created, you can be sure that other powerful industry lobbies would very quickly insist on having their own EMC standards that allowed *them* to emit 30dB more noise into the mains distribution too.

After all, if PLT products can emit noise at this high level and yet enjoy a presumption of conformity to the EMC Directive, why not their products? Then they could remove all their mains filters and save a very great deal of money.

> "Ofcom believes the electromagnetic disturbance produced by this technology is an inevitable by-product of its operation and not attributed to poor design or manufacturing."

This is a perfectly correct statement! Only not in the way that Ofcom wants it to appear to the reader.

The Comtrend PLT design is not at all "poor" and neither is their manufacturing. Both are perfectly competently done. It is just that the design of Comtrend's PLT products is <u>*intended*</u> to put signals onto the mains distribution network at 1,000 times the maximum level required to protect the radio spectrum from interference. So *of course* "the electromagnetic disturbance produced by this technology is an inevitable by-product of its operation"!

Aren't Ofcom's spinmeisters clever? One has to be impressed!

But since Ofcom are employing such clever people, why doesn't it employ them to do something a little more useful, perhaps something that contributes to Ofcom's legal duty of protecting the radio spectrum?

For example, they might apply their huge and powerful brains to noticing that Comtrend's EMC Declarations of Conformity are complete eyewash.

> **"Would the development of an EU standard for PLT help?**
> Yes. At present, testing and assessment takes place against a backdrop of wider technical uncertainty than is normally the case and there is an increase in the take-up of this apparatus across Europe.
> The development of such a standard would be an important step. The standard could be used by manufacturers and Notified Bodies to assess performance against recognised benchmarked values.
> If the apparatus complied with the harmonised standard under the Regulations, there would be a legal presumption that the apparatus met the essential requirements."

There is work ongoing in CISPR/I to try to create a product-specific standard for PLT devices, but it suffers from huge difficulties because the opposing factions (PLT manufacturers versus almost everyone else) are each determined to get their own way, and there is no middle ground.

Either PLT emits at 1000 times the emissions limits, or it complies with those limits and doesn't work.

(At least, this is the entrenched position taken by the PLT industry, although recent work has shown they can emit at the limits given in EN 55022 (the "CISPR limits") and still achieve data rates that would satisfy the vast majority of their market. But the PLT Industry appears to believe that because it spends so much on lobbying, it should be able to get just exactly what it wants. Unfortunately, because the way the European Commission operates, this is quite a reasonable belief.)

Anyway, an "EU standard for PLT" is a complete *non sequitur*. There is no need for any product to declare compliance to *any* standard. A technical assessment for EMC compliance purposes can use Harmonised Standards, or not, as the manufacturer sees fit. So why all this fuss about standards?

Ofcom states that it believes that the electromagnetic disturbance is an inevitable by-product of the operation of PLT devices – which is actually an admission of non-compliance! Since they don't appear to understand this basic point, we suggest Ofcom bothers to actually read the Essential Requirements in the UK's EMC Regulations – where they will see that apparatus is simply not permitted to be designed/ constructed in a way that interferes with other equipment, and especially not with radio reception.

The fact is – as many have said – broadband PLT ("Greedy PLT" as it is coming to be known) such the Comtrend products, uses an inappropriate technology. It deliberately produces a lot of electromagnetic energy, then tries to couple it into an unknown impedance of unbalanced, unscreened cables (i.e. the mains distribution network in a house). Any radio engineer would call that a recipe for disaster. And it is.

This is why there is all this fuss about creating an "EU standard for PLT". Such a standard would effectively authorise the Greedy PLT industry to claim presumption of conformity and legally affix the CE marking to their horribly noisy (by design) products, even though they could not possibly comply with the Essential Requirements.

A final piece of nonsense and obfuscation:

> "The EU Commission is aware of concerns resulting from the proliferation of PLT in the EU and in response, issued a mandate (M/313) to the European Committee for Electrotechnical Standardisation (CENELEC) to produce a PLT harmonised standard"

M313 is *totally irrelevant* to the compliance of PLT devices. In fact, it specifically excludes them. Instead, M313 concerns the compliance of complete data *networks*.

Spin, once again. Or is it obfuscation? Whatever, it is intentionally misleading. It is also offensive and/or insulting, because it assumes that readers are so ignorant that they can't tell the difference between a network and a device that connects to it.

M313 has been worked on for 10 years with no signs of success. There has been some further work on it recently, but agreement looks as far off as ever, and even then many commentators suggest that it could never be applied to PLT networks, simply because – by their very nature – most mains networks pre-date the EMC Directive and were never installed for the purpose of carrying data in the first place.

Should we be surprised by all the spin, smokescreening, whitewash, eyewash, hogwash and (no doubt) many other kinds of wash, in Ofcom's PLT statement of the 2nd September 2009? Well, probably not, because Ofcom is manifestly unfit for purpose. We should probably expect that – given its contradictory roles – something had to give, and the PLT statement is just a result of that failure to reconcile opposites.

Ofcom was conceived and created to fill the role of a single regulator to oversee the apparently converging fields of broadcasting, telecomms and spectrum protection. As far as spectrum protection is concerned, Ofcom is required to be both poacher and gamekeeper. What has happened is that the needs of telecoms and broadband (the spectrum poaching role) have prevailed over proper management of the spectrum (the gamekeeper role).

Someone who has long worked in Government in the UK, and who shall remain nameless (for obvious reasons), wrote the following in a private email recently:

> "Having worked in Ofcom I know how that works too. Created by the present Government, it is rather like an out-of-control child that sometimes attacks its own parents and ignores anything it doesn't like. It is dominated by media luvvies and telecoms economists, with spectrum management coming a poor last (just one fact, out of many: they have reduced EMC enforcement/ interference staff by 60% since taking that duty over from the Radiocommunications Authority). And it has its own effective spin machine that – like the whole organisation – is not accountable to anyone, which is not surprising when you realise that both of its Chief Executives have been No.10 spin-doctors themselves!"

The only real, sustainable, sensible answer is to remove all EMC regulatory duties from Ofcom and give them to a separate, independent Regulator, who is able to focus on managing the radio spectrum without being dominated by big business interests.

More reasons why Ofcom are not fit for purpose, they refuse to answer questions... Why?

As if the PLT fiasco was not enough, Ofcom have now got themselves into a quite bizarre position over something else.

You may have recently read in Daily Mail Online that Ofcom field staff tracing interference to air traffic control from an oscillating aerial amplifier detected it was integral with the indoor aerial of a lad's TV in his parents' house. The full story is at **http://www.dailymail.co.uk/news/article-1223307/Plane-madness-Schoolboy-TV-aerial-confiscated-Government-officials-interfering-aircraft-signals.html**

Having heard that antenna pre-amps were a major cause of interference to air traffic control it seemed obvious we should ask Ofcom to clarify the situation. And in particular under what powers were they operating.

Once purchased and in use, the EMC Regulations would not apply and we were not aware of any interference Regulations made under the Wireless Telegraphy Act which covered antenna pre-amps.

The email thread that follows gives an accurate account of the Ofcom response.

Sent to Sherington Gaskin OFCOM 29.10.2009

I was interested to see the interference case reported at Mail Online Thursday 29th October. Link below. I am looking to write this up in more detail in The EMC Journal. www.theemcjournal.com

In order that I can be certain of accuracy can you please advise **"under what powers and in which parts of the legislation available to OFCOM, were your staff operating in this case?"**

Thank you in anticipation of your assistance.

Sent to Sherington Gaskin 5.11.2009

I would appreciate a response to my email sent 29th October.

Received from Rhys Hurd 08.11.09

Alan, Your question regarding the faulty booster aerial story has been forwarded on to me. In response, this case of interference was conducted without invoking any of our legislative powers, and was concluded through the co-operation of the user of the faulty aerial.

Sent 08.11.09

Thank you Rhys for your response. I am certain you appreciate that this scenario has raised some interesting questions.

Whilst I fully I understand that it is preferable to resolve these matters without resort to legislative powers, I assume OFCOM staff must have been working with the backing of some legal power, especially for interference to a safety service.

What would happen in a similar case if for example, the householder was not co-operative or was away. **Please advise... under what powers and in which parts of the legislation available to OFCOM, your staff would operate?**

Look forward to your response. Just for the record what is your position within OFCOM.

Received 09.11.09

Alan, Apologies, I'm a communications manager at Ofcom.

I really don't want to get drawn into a hypothetical discussion on this – and would rather deal in facts only.

Let me know if I can help with anything else.

Sent 09.1109

Rhys, why do think you are being drawn into something (you are not)... you are being asked to answer a perfectly reasonable question. Something I would have thought well within the capabilities of an OFCOM Communications Manager. I would still like an answer to the question please... under what powers and in which parts of the legislation available to OFCOM, your staff would operate? I am struggling to understand your reluctance to answer

Received 09.11.09

Alan, As I said, I'm not willing to discuss hypothetical's.

If I can help with anything else, please let me know.

Sent 09.11.09

Rhys, This is not hypothetical it is a perfectly reasonable question, please explain why you do not consider it as such. I am surprised that OFCOM refuse to answer a question from the Press. Is your stance supported by the senior Management of OFCOM?

Received 09.11.09

Alan, I'm not comfortable answering hypothetical scenarios like the one you've presented.

Sent 09.11.09

This is not finished. You are wrong, you should be prepared to answer what is a perfectly reasonable question (assuming of course you know the answer) if you do not, then please forward my request to someone who does. I want this question answered.

This was unanswered.

Sent 18.11.09

Rhys, I am just about to put the Journal to bed. In order to ensure there is no misunderstanding. Will you please confirm you are not prepared to answer my question. Alternatively you could answer it.

Received 19.11.09

Alan, my position has not changed on this.

Your first question was based on a specific case. My answer to that question was very clear: "this case of interference was conducted without invoking any of our legislative powers, and was concluded through the co-operation of the user of the faulty aerial."

Your second question was hypothetical. And as I keep saying, I am not willing to discuss hypothetical's.

I trust this will be accurately represented.

Sent 19.11.09

Yes, it endorses the fact that OFCOM are not fit for purpose.

Watch this space.

Frankly we find it quite appalling that Ofcom would not answer a simple question of fact from the Press. Why?

It so happens we read in RSGB's magazine RadCom for December, an item about interference from plasma screen TVs and cited a non-interference condition in the TV licence. Co-incidentally, their story also touched on the same question of radiating pre-amps. Even though it looks clear to us both... that the Communications Act specifically allows them to act under this TV licence condition, Ofcom apparently denied they had any powers to act here.

.

Could these be the reasons why?

1. Ofcom don't know what powers they have, so they are covering up.

2. They have no powers and have as much legal authority as the man in the street to stop interference to safety services, but they don't like to admit it.

3. They've got themselves in a mess over the law, including the TV licence condition, and don't know what to say.

4. Something else, but they won't tell.

From our perspective it simply endorses our opinion that Ofcom... is not fit for purpose.

Banana Skins...

Editor's note: The volume of potential Banana Skins that I receive is much greater than can possibly be published in the Journal, and no doubt they are just the topmost tip of the EMI iceberg. Keep them coming! But please don't be disappointed if your contribution doesn't appear for a while, or at all. I'd need four pages in every EMC Journal just to keep up!

546 Singapore Grand Prix gearbox failure

And after their one-two in Monza a fortnight ago, this was a sobering session for Button and his Brawn team mate Rubens Barichello.

The Brazilian, who lies 14 points behind Button with four Grands Prix to go this year, had a golden opportunity to close the gap but a gearbox failure in practice, caused by electro-magnetic signals from the subway system beneath the Marina Bay Circuit, meant he entered qualifying knowing he would have a five-place grid penalty no matter what.

(Extracted from an article by Tom Cary in the Telegraph, 27 September 09, which was kindly sent in by Dave Imeson, Secretary of the EMC Test Labs Association, www.emctla.co.uk.)

547 "Smart" life raft beacons too dumb

Considerable progress has been made regarding the re-introduction of personal locator beacons (PLBs). Below is a summary of where we currently are in the process.

Background: Personal beacons, which were being carried by some passengers on offshore helicopter flights to oil and gas installations, were withdrawn from service in March, following the ditching of an offshore helicopter in the UK sector in February. It was found that interference from the personal beacon had caused the 'smart' long-range beacons on the life rafts to shut down.

The smart technology fitted to the life raft beacons is designed to shut the beacon down if it detects another beacon signal within a certain radius. This is to ensure that only one high-powered aircraft beacon is transmitting at a time, which helps search and rescue operations to home in more effectively and protects battery life. However, in the February ditching, the lower powered (non-smart) passenger PLBs were detected by the smart beacons, which caused life raft beacons to shut down. This could have had implications for search and rescue operations *(because the high-powered beacons shut down in favour of the lower-powered personal beacons, which would not be as easy to locate – Editor).*

(From an email entitled: "Helicopter Task Group update – Re-introduction of Personal Locator Beacons – 04 November 2009", by the United Kingdom Offshore Oil and Gas Industry Association Limited, trading as Oil & Gas UK, kindly sent in by Simon Brown, Principal Specialist Inspector, HSE Hazardous Installations Directorate – Offshore Division. To find out more about the work of the helicopter task group and other important areas of work, please go to: www.oilandgasuk.co.uk/issues/helitaskgroup.cfm.)

(This item is not, strictly speaking, an EMI incident like those we normally report here. It is more of an operational incompatibility, but nevertheless it is important because we are making equipment 'smarter' all the time by using digital processing to run more software – but of course it is still very dumb indeed when compared with a person, not clever enough to deal with unforeseen problems like this example of 'interference'.)

548 Bad connection in 50kV line interferes with TV, cellphones, even cable TV

A bad connection in an overhead HV cable was producing S9+10dB on my receiver. On a quiet afternoon you could hear the acoustic noise from the arc 100 feet away! The power utility was initially uninterested until I threatened to complain to the FCC that their AC mains line fault was producing enough RF interference to make HF communication impossible. The work crew asked me to show them the location, and they sort of freaked out at the intensity. It was a 50KV line and at twilight the arc was clearly visible. As they were working, people who lived nearby stopped by to see what was happening. After the mechanical fault was repaired, the locals were very happy because they could watch TV and use their cell phones. The RF noise was intense enough to penetrate the cable TV system.

Given your professional interest in EMC and RF noise sources, I thought you might find the handbook "The Mitigation of Radio Noise from External Sources at Radio Receiving Sites, 6th Edition", published by the US Naval Post Graduate School, interesting and useful. It has been a great help in locating "local" power line noise sources. In a personal Email with George Munsch, he told me the companion "internal noise" handbook is about 90% complete, but the School lacks the funds for completion. www.arrl.org/tis/info/HTML/power_line_handbook/ExternalNoiseHandbook.pdf.

(Kindly sent in by Terrence Fugate, WN4ISX, 13 October 2009.)

549 Access BPL can seriously interfere with safety of flight

Before the Federal Communications Commission, Washington, DC 20554, In the Matter of Carrier Current Systems, including Broadband over Power Line Systems, ET Docket No. 03-104

Amendment of Part 15 regarding new requirements and measurement guidelines for Access Broadband over Power Line Systems, ET Docket No. 04-37

Reply Comments of Aeronautical Radio, Inc.

Aeronautical Radio, Inc. ("ARINC") hereby submits its Reply Comments in these proceedings. The record makes clear that access broadband over power line service ("Access BPL") can seriously interfere with the nation's high frequency communications system that guards the safety of flight and thus should be authorized only under conditions that protect the HF Aeronautical Mobile (R) Service.

(From: http://gullfoss2.fcc.gov/prod/ecfs/retrieve.cgi?native_or_pdf=pdf&id_document=6516214698.
Also see: http://gullfoss2.fcc.gov/prod/ecfs/retrieve.cgi?native_or_pdf=pdf&id_document=6516214700, http://gullfoss2.fcc.gov/prod/ecfs/retrieve.cgi?native_or_pdf=pdf&id_document=6516214699, and http://gullfoss2.fcc.gov/prod/ecfs/retrieve.cgi?native_or_pdf=pdf&id_document=6516214701.

Kindly sent in by Peter Kerry, EMC Consultant, 19 October 2009, who saw them on the UKQRM website www.ukqrm.org)

550 Boy's TV interfered with aircraft

A signal booster on the television set of a Bedfordshire boy has been found to be interfering with aircraft. The aerial on 12-year-old Nicky Chamberlain's bedroom TV was disrupting communications between pilots and air traffic control at Luton airport.

Communications regulator Ofcom traced the problem to the home in Knaves Hill, Linslade, 18 miles from the airport.

Nicky's dad, Dave Chamberlain said: "I came home to find an Ofcom engineer parked outside the house. It was bizarre. I had never heard of anything like this before. Nicky had the booster for a couple of years and there had been no problem. Recently they changed the flight-path and that must have caused the problem with pilots talking to the airport."

He added: "We are decorating Nicky's bedroom now and when that's finished we will get him a new aerial that does not interfere with passing planes."

A spokesperson for communications regulator Ofcom said: "It is not common for something like this to happen. We have field engineers who go around the country investigating for radio interference. In this case the faulty aerial booster was found to be interfering with the pilot's radio."
(Taken from BBC News: http://news.bbc.co.uk/go/pr/fr/-/1/hi/england/beds/bucks/herts/8327549.stm, 2009/10/27, kindly sent in by Peter Day, System/Development Engineer, Hitech Instruments Ltd, and by John Davies, Managing Director, Blackwood Compliance Laboratories, on 30 October 2009. Visit http://news.bbc.co.uk/1/hi/england/beds/bucks/herts/8327549.stm, which has a video.)

551 Detecting PC keyboard strokes by sniffing the ground

My mate John sent me this BBC news link just now, it's fun in case you hadn't seen it: http://news.bbc.co.uk/1/hi/technology/8147534.stm

A couple of lads have discovered they can pick up keystroke signals from PS/2 connections on the mains earth at a distance. The presentation to which it refers is here: http://dev.inversepath.com/download/tempest/tempest_2009.pdf

I'd thought the BBC report was a bit flaky on the description of the connection, and assumed it was a typical journalistic misquote, but actually the report quotes the presentation quite accurately. The authors themselves aren't really clued-up on EMC. It turns out that they are monitoring the noise voltage between the ring main earth and building metalwork, which has enough of the coupled PS/2 signal to give useable data when filtered.

Of course, TEMPEST as a subject has been around for years, but it's fun to see a couple of hackers (for this is what they are) getting into the public domain with it. I particularly like one of the points in the "Why bother?" slide of the presentation: "As always....more important: girls will melt when you show this..." And the Tempest acronym is decoded as "The Emissions Might Produce Extremely Sweet Talks"
(Kindly sent in by Tim Williams, EMC Consultant, Elmac Services Ltd, www.elmac.co.uk, in July 2009.)

552 Wireless headphones tune-in to Elvis

I bought a pair of wireless headphones a few years ago, I put them on in the shop and was surprised to find music come out of them. Not knowing what frequency they worked on, didn't think to much of it. Anyway it turns out that they run in the 863 to 870 MHz area and they are the auto tuning type so they regularly tune in to probably this broad cast. Someone who is probably at home all day, has it connected to their home stereo, and has a particular liking for amongst others Seasick Steve, Thin Lizzy and Elvis. Currently broadcasting Elvis.
(Kindly sent in 20th October 2009, the author wishes to remain anonymous.)

553 Tyre pressure warning triggered by Fort Meade

Click and Clack (Tom and Ray on NPR's [National Public Radio] Car Talk) had a caller this morning saying that her Vesta tire-pressure warning system goes off whenever she drove on a particular stretch of highway. After a little grilling, it turns out she was passing the NSA complex at Fort Meade. C&C concluded it had to be Radio Frequency Interference, and wondered whether it affects only Vestas, or perhaps other late-model cars with the newly mandated wireless sensors that might operate on the same frequency.

(Kindly sent in on 24th April 2009 by Matthew Wilson, Product Design & Production Manager, GB Electronics (UK) Ltd, who saw the above extract (Sun, 19 Apr 2009 11:06:45 PDT, From: "Peter G. Neumann" neumann@csl.sri.com, Subject: Vesta tire-pressure warnings) on the 'comp.risk' newsletter moderated by the 'ACM Committee on Computers and Public Policy', http://catless.ncl.ac.uk/Risks, and thought of the Banana Skin column.)

554 Scientists Map Earth's EM Emissions

An international team of scientists have issued a report on whistler-mode chorus waves, a type of electromagnetic emission generated by electrons in Earth's radiation belt, that have the potential to cause massive interference with satellite electronics as well as ground based communications.

The researchers used data from NASA's THEMIS (Time History of Events and Macroscale Interactions during Substorms) satellites to map the distribution of these waves.

They found that on Earth's nightside, chorus occurs only near the equator, but that daytime chorus extends to higher latitudes. Also, it appears that the amplitude of chorus waves depends strongly on geomagnetic activity.

At a distance greater than seven Earth radii (approximately 45,000 kilometres) moderate chorus is present more than 10 percent of the time and persists even during periods of low geomagnetic activity.
(Extracted from a report in Interference Technology magazine: http://www.interferencetechnology.com/lead-news/article/scientists-map-earths-em-emissions.html, 3rd June 2009. An abstract of the scientists report is at: www.agu.org/pubs/crossref/2009/2009GL037595.shtml.)

Banana Skins

Banana Skins are kindly compiled for us by Keith Armstrong.

If you have any interesting contributions that you would like included please send them, together with the source of the information to: keith.armstrong@cherryclough.com

Although we use a rather light hearted approach to draw attention to the column this in no way is intended to trivialise the subject. Malfunctions due to incorrect EMC procedures could be life threatening.

John Woodgate's Column

A varied menu this time; there is never a dull moment in EMC and compliance!

Automotive aftermarket product EMC

The car industry and the European Commission made a complete hash of the first automotive EMC Directive by not dealing with aftermarket products properly, if at all. Of course, that couldn't be admitted and it's taken a long time for things to fall into some sort of order. To what extent was the disregarding of aftermarket products motivated by a desire to suppress them, one might wonder. 'Our cars already have everything … well, only the campers actually have a kitchen sink, but …'. This simply did not take into account the new communication and multimedia products that people would want to fit to cars that didn't have them, not ancient cars but quite recent models.

Anyway, now we have the final draft of EN 50498, which has been produced by EMC experts in CENELEC, so it should be realistic. To satisfy the requirements of the current Automotive Directive 2004/108/EC, **it is not possible to avoid testing for certain requirements**. This is **different** from the position under the EMC Directive 2004/108/EC, which does not make testing mandatory, just compliance with the Essential Requirements.

The standard covers only radiated and conducted transient emissions and immunity to conducted disturbances. It is quite short - only nine pages. It remains to be seen how readily products can be made to conform.

Watts cooking?

After a very long process of moving the requirements from CISPR11/EN 55011, CISPR14-1/EN55014-1 is being amended to include induction cooking appliances. The draft is at the first voting stage, and includes the special tests required by these products. The frequency range for radiated emission limits is 30 MHz to 1 GHz, which is an extension compared with the present requirements. The latter can be applied until EN 55011 is amended to remove induction cookers from its scope.

The document contains some strange sentence constructions and really needs editing by a native English speaker.

Pea-Ell-Tea

What will we do to pass the time when this is finally resolved? In USA, the IEEE has received over 3000 comments on one draft standard, and CISPR isn't far behind in the Comment Stakes.

In CISPR, the crucial text is being processed as an amendment to CISPR22/EN55022. The current comment document has received many fundamental criticisms. It proposes two types of PLT modem, one of which, it seems, might be acceptable if the maximum sending power were reduced considerably, but not so much as to make the maximum data rate unacceptably low for reasonable purposes. Anyone who wants to pipe HDTV around the house can surely make an effort to install appropriate cables. The other type of modem proposed is widely considered to be wholly unacceptable.

Another criticism of the document is that it proposes to measure the *common-mode* emission from the modem into a balanced load. A very badly-designed modem might have a problem in this configuration, but since the output has to be transformer-coupled for safety reasons, it is likely to be quite well balanced even in a low-cost product. So very little emission would be measured! However, the mains wiring in a house is nowhere near a balanced network and is bound to include sections where only a single conductor of a twin (and earth) cable is connected, the other being interrupted by a switch. These discontinuities partly convert differential-mode signals to common-mode. Differential-mode signals do not radiate, but common-mode signals do.

However, in the absence of discontinuities, the usual 3-conductor house wiring cable can act as a transmission line for common-mode signals, the two mains conductors in parallel form one leg and the earth conductor forms the other. In this case, the common-mode signal behaves as a differential-mode signal in the 'new' transmission line, and does not radiate. But in a house, the amelioration that this effect might bring is probably very small. In a point-to-point wiring application, it might well result in a substantial reduction of emission compared to those predicted from the normal mode-conversion estimates.

'Referee' test methods

This long saga has resulted in a Solomonic decision by the IEC Standards Management Board - that each committee can choose whether to designate one of several methods as the 'referee' method (thus completely devaluing all the others) or to state that they are all equally valid and in case of dispute, the original method used to demonstrate compliance shall be used in case of dispute.

This is likely to make matters worse, because TC77 will, according to current policy, require its sub-committees to designate referee methods, while CISPR, according to current policy, will allow its sub-committees to choose. This cannot possibly be a satisfactory situation.

Digital dividend hitch

Releasing the upper part of the UHF TV band for telecommunication raises a serious problem for CATV networks, which will continue to use that band for sending TV programmes. The problem is that TV sets connected to the cable network may very well not have sufficient immunity to the telecoms signals, and will feed them back into the cable network. A new Mandate has thus been issued by the European Commission, for the European standards bodies to study this urgently and take any necessary action.

CISPR18 - a very semi-known standard

CISPR 18 is a three-part series of Technical Reports about the

EM influence of overhead power lines and high-voltage equipment on other services. It hasn't been revised for many years, and there were doubts about its future. However, and enquiry indicates that the publication is used in several countries and ought to be revised.

CISPR 16-3 CISPR Technical Reports

While these are hardly holiday reading, they are accumulated wisdom of EMC experts over many years, and do explain some of the apparently arbitrary requirements in some EMC standards. So don't disregard Part 3.

PLT again

In its infinite wisdom, the European Commission extended the life of EN55022:1998 in the belief that it would allow the continued sale of non-compliant PLT modems, whereas the 2006 edition would not. The opinion of many EMC experts is that there is *no difference* in this respect between the two standards; neither render the modems in question compliant. CISPR/I has been asked to advise.

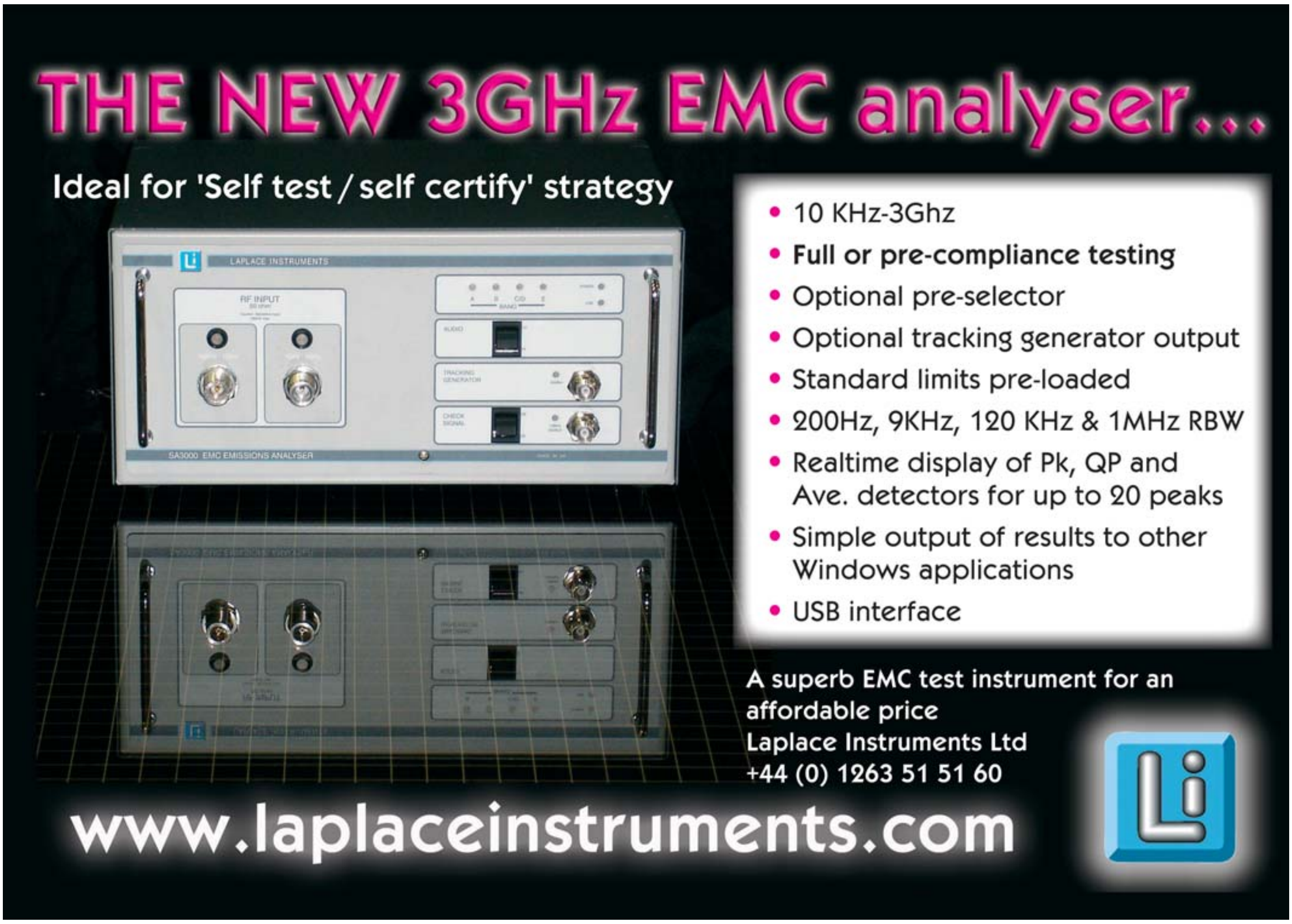
PLT has also raised the matter of actual radiated emission measurements below 30 MHz. These are very difficult, because the near field extends so far from the source, and the spectrum is full of wanted transmissions and clutter already. The matter is also raised by questions of emissions from plasma display screens. A new questionnaire has been circulated on the subject; an earlier questionnaire seems to be well off the mark in respect of one possible solution - suggesting limits but with no provision for standard methods of measurement!

The Australian National Committee has submitted a 22-page document on a test plan for PLT modems, results of a world-wide survey of DM to CM conversion, and the invalidity of measuring the CM emissions of a modem into a balanced load.

This is all very valuable, even though I don't like the terminology used in one case. 'DM emissions' are mentioned. DM signals DO NOT emit; what is mean is 'emission from CM signals derived from DM signals by mode conversion'.

Happy Christmas (or whatever winter solstice celebration you favour)!

J. M. Woodgate B.Sc.(Eng.), C.Eng. MIET MIEEE FAES FInstSCE
Email:desk@nutwooduk.co.uk
Web: www.jmwa.demon.co.uk



PRODUCT GALLERY

The Design Guide "Trilogy of Magnetic" in its 4th edition

Würth Elektronik has now launched the 4th edition of the design guide "Trilogy of Magnetics" in English. The design guide for EMI Filter Design and SMPS & RF Design Circuit is completely revised, newly structured, and covers a multitude of new components and applications.

The design guide is divided into the following chapters: Basic Principles, Components, and Applications. A keyword index, as well as a formulary, complete the book.

The objective of the design guide, "Trilogy of Magentics", is to practically familiarize customers and users with the characteristics and applications of inductive components. The design guide was published 8 years ago for the first time and is now a standard work for lots of development departments and universities. Over 15,000 copies of the book have been sold in the last 8 years.

In the 4th edition, the explanation of old techniques and components has been set aside to have more room for new components and applications. Notably, a multitude of external authors from our customer base and our well-known manufacturers passed on their experiences and solutions in the Basic Principles and Applications section.

The following articles are exemplary highlights:

- Calculation, dimensioning and construction of customer-specific transformers (Do-it-yourself transformer design)

- A transformer's effect on return loss
- Class-D amplifier
- An introduction to frequency compensation
- Basic principles of Ethernet & Power-over-Ethernet

Furthermore, the Trilogy includes over 200 practical examples to the following topics:

- Filter circuits
- Audio circuits
- Video circuits
- Interfaces
- HF circuits
- Motor control units
- SMP
- Line filter
- Power supply

The guide is available to order now for £45.00. To order your copy, please contact Wurth Electronics UK on 0161 872 0431 or your local sales representative.

Tel: +44 (0)161 872 0431
sales-uk@we-online.com
www.we-online.com

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Rohde & Schwarz system solution generates phase-coherent multichannel signals for testing radar receivers

At productronica 2009, **Rohde & Schwarz** presented a flexibly configurable system solution for testing receivers in radar systems. Manufacturers and operators can use this application in development, production and service to simulate phase-coherent multichannel signals. The radar test system generates simple modulated or unmodulated pulse sequences and can also be expanded to a maximum of ten channels to create realistic scenarios.

The radar test system from Rohde & Schwarz makes it easy to integrate even complex signal generation functionality into the development and production of radar systems. It provides high level and phase accuracy over a wide dynamic range (up to 118 dB) as well as extremely high setting speed throughout the entire range (< 1 µs/step at 50 dB). As a result, very fast, highly automated tests with complex sequences can be performed.

The application utilizes three R&S SMBV100A signal generators. It allows testing of three-channel monopulse radars such as those used in air traffic control systems. By deploying the appropriate number of signal generators, users can generate up to ten phase-coherent RF signals.

The radar test system features an integrated R&S FSV signal and spectrum analyzer that performs internal system calibration and provides accurate test results over a wide temperature range by recalibrating during startup or after temperature changes. In addition, the R&S FSV analyzes important parameters such as power or spurious of the transmitted radar pulses.

An R&S OSP switch and control platform as well as an R&S CompactTSVP serve as the interface to the radar receiver. The R&S CompactTSVP PXI platform allows testing of the digital and analog signals of the DUT so that users can determine if the received and transmitted signals correspond. Furthermore, the graphical user interface on the PC makes it easy to set the signal parameters.

The radar test system is on display at the Rohde & Schwarz booth (booth 375) in hall A1.

Tel: +44 (0)1252 818888
contact.uk@rohde-schwarz.com
www.rohde-schwarz.com

Innovative shielded window material takes a new approach and sets high standards for optical, electrical and mechanical performance

Chomerics Europe, a division of Parker Hannifin, has introduced a new shielded window display material that offers a range of important benefits compared to existing solutions. Winshield C is a cast monomer material that combines excellent physical properties with outstanding electromagnetic shielding performance and optical clarity. Applications include display filtering in test equipment, medical instrumentation, public information displays and military radios and computers.

Unlike most shielded window materials that comprise an electrically conductive medium such as a mesh laminated to a substrate, Winshield C is a single component material. The monomer material combines excellent light transmission performance of 90% that is close to that of crown glass, whilst being less than half the weight. The material can be cast in thicknesses of between 1.5mm and 6.0mm and can be easily machined to provide features such as mounting holes and grooves for gaskets and seals.

The -60°C to +100°C operating temperature range of Winshield C is wider than that of most other materials on the market and allows

it to be used in challenging indoor and outdoor environments. Excellent chemical, impact and scratch resistance further enhances the suitability of the new material in such applications.

Termination is via silver busbar and all Winshield C shielded windows are suitable for the application of silk screen graphics using 'two-pack' inks. Chomerics provides comprehensive design and technical support for Winshield C and all other materials in its comprehensive range of shielded optical products. A comprehensive online selection guide is also available to help designers choose the most appropriate material for their specific applications.

Tel: +44 (0) 1494 455400
chomerics_europe@parker.com
www.parker.com/chomerics

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Teseq Fully CISPR-Compliant Digital EMC/EMI Receivers

TESEQ, the leading developer and provider of instrumentation and test systems for EMC emission and immunity testing announces the introduction of the Narda PMM 9010, a fully digital receiver covering the frequency range 10 Hz to 6 GHz. The PMM 9010 is the cornerstone of a system which grows together with the users' needs. All EMC conducted measurements are be possible by simply upgrading the PMM 9010 with specific options, e.g. Click Meter, and accessories such as LISNs and probes This will allow the PMM 9010 to provide full compliance testing to any known international standard or proprietary specifications.

Practically maintenance free and exceptionally stable, the PMM 9010 EMI Receiver is the ideal solution for reliable measurements over a long working life. In the event of service being required simple to replace plug-in pre-

calibrated subassemblies are available providing fast, cost effective repair in the event of damage to the RF front-end or similar events. This ensures the user minimum down time and ensures the calibration of the receiver.

Paul Dixon, Managing Director of TESEQ comments, "The PMM 9010 is a simple to use, flexible and portable EMC receiver offering a cost-effective, modular solution that will grow with user's needs. The PMM 9010 is easy to use for any kind of measurement as a stand-alone instrument, integrated in systems or driven by PC and features a proprietary "Smart Detector" productivity booster feature designed to dramatically improve test speed."

At the heart of the receiver is a state of art 30 MHz EMI Digital Receiver based on direct Analogue to Digital conversion with sophisticated computation. It offers calibration-free operation of almost all of its key components, i.e. RBW filters, detectors, demodulation, while the RF front-end is self-calibrated by the internal, precision RF signal generator.

Major features include, uniquely compact and lightweight at just 3.5 Kg. Hardware and firmware designed around the current EMC standards and simple to upgrade to future changes. Powerful digital Click Analyser with full compliance to latest CISPR 14-1 specifications. 1 (internal option) or 4 (external option) channels, frequency ranges from 10 Hz to 30 MHz; 3 GHz to 6 GHz. Full compliance with the latest edition of CISPR 16-1-1 standard, including RMS-AVG detector and APD function. All CISPR and MIL-STD-461E RBW filters are available. Integrated preamplifier and pulse limiter, built-in tracking signal generator up to 30 MHz Multimode functions, sweep, spectrum analyzer, scalar network analyzer, manual receiver, optical link between main and high frequency units, no aging of critical parts in the receiver that may cause degradation of measurement accuracy. Manual, semi-automatic and fully automatic test modes, AC and battery powered for maximum flexibility

Teseq provides a traceable calibration certificate with each tester and accredited calibration services are also available from TESEQ calibration labs upon request.

Tel: +44 (0)845 074 0660
michael.hill@teseq.com
www.teseq.com

emcia Member

Murata launches low capacitance electrostatic discharge protection devices

Murata introduces the LXES series of ceramic and silicon based ESD protection devices. Both types feature high suppression levels, high repetition durability and ultra-low capacitance for use in high speed data transmission environments. ESD protection devices are critical components in protecting sensitive circuits in electronic equipment such as mobile phones, notebook PCs and netbooks, digital cameras and other consumer devices from electrostatic discharge (ESD).

With increased demand for more features in mobile devices, and reduced feature size in today's ICs, preventing damage from electrostatic discharge has become even more of a challenge, as many solutions suffer from insufficient or degraded suppression characteristics after repeated electrostatic discharges. Murata solved these problems by enhancing the aforementioned characteristics and repetition durability through the original product design.

Silicon based parts in the LXES series feature a low capacitance design (down to 0.25pF typical), which also minimises signal loss on high speed data and transmission

lines. Additional features include high suppression levels (less than 100V output when input voltage is 15kV) and high repetition durability (1000 cycles at 8kV contact voltage). The product series includes two, four and six line array designs, along with single line devices.

Ceramic parts in the LXES series also feature ultra-low capacitance (down to 0.05pF typical) and small case size, down to 1.0 x 0.5 x 0.33mm. Crucially, the ceramic devices produce very little distortion (under -100dBm at 800MHz) making them suitable for use in antenna circuitry. They also feature high repetition durability (1000 cycles at 8kV contact voltage).

Tel: +44 (0) 1252 8111666
ayatonooka@murata.co.uk
www.murata.co.uk

AR's Impulse Generator, Leak Detector and Noise Meter represent the next wave in EMC Testing

AR RF/Microwave Instrumentation offers several products with a level of accuracy, dependability and versatility not found in competing products for use in EMC testing.

Variable Rate Impulse Generator Provides Exceptional Versatility

AR's Model 533X-11M (10 kHz – 1 GHz) variable repetition rate impulse generator is a calibrated broadband signal source that is used primarily as a calibrator when performing substitution type interference measurements. It has a variable pulse repetition rate from 50 Hz-5 MHz or it may be triggered by the power line frequency, an external trigger source or manually. The availability of these various operating modes is what makes Model 533X- 11M so much more versatile than other impulse generators. The unit is used as a calibrated broadband signal source; a calibrator for substitution type broadband interface measurements; receiver bandwidth measurement; and for rapid gain checking of tuners.

Leak Detector System Effectively Tests Shielded Enclosures

Leak Detector Model CL-105/CL-106 tests shielded enclosures at their most likely points of degradation – the seams, doors, and filter connections. The System consists of a transmitter, receiver, antenna probe, a flex antenna extension, headphones, and a durable carrying case. The high sensitivity of the receiver enables it to meet the most rigid MIL standards for shielded room acceptance. The system is built to withstand even the most adverse conditions. It is designed to allow replacement of the antenna probe shield when worn, a feature that can save money for users down the line.

Radio Noise Meter Measures Broadcase Band EMI Pollution For The Power Industry

Model NM-21FFT Radio Noise Meter is extremely sensitive and simple to operate. The unit operates at one fixed frequency, either 834 kHz or 1000 kHz. It can be special ordered with a fixed frequency anywhere in the 600 – 1500 kHz range. The absence of broad frequency coverage eliminates all tuning and calibration requirements. It also enables the circuitry to be designed for high image rejection, high IF rejection, low spurious response, and high overall accuracy. The unit is hand-portable, withstands rough field use, and has low (5 watt) power consumption.

The 533X-11M, CL-105/CL-106, and NM-21FFT are manufactured by AR Receiver Systems and sold through AR RF/Microwave Instrumentation.

Tel: +44 (0)1908 282766
sales@uk-ar.co.uk
www.uk-ar.co.uk

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EMC solutions efficient and economic

SCHURTER presents its new 3-phase line filters, series FMAC ECO and FMBC ECO. These compact and cost optimized filters are in ECO designed and especially suited for use in drive systems, engineering installations and places where frequency inverters cause electromagnetic disturbances.

The EMC filters are arranged for use with 480 VAC installations and are available in single or two stage versions. The FMAC ECO single stage filter is available from 10A, while the two stage FMBC ECO filter from 8A. The FMBC ECO series has a leakage current of just 5 mA, making it ideal for use in installations equipped with residual current circuit breakers. The filters can be mounted lengthwise or upright which provides maximum flexibility in design.

With these new 3-phase line filters, SCHURTER focuses on costs savings while efficiently solving EMC problems.

The series has ENEC approvals. Approvals to cURus have been applied for.

Technical features:

- 3-phase line filter for 480 VAC
- Rated current range FMAC ECO (single stage): 10 – 150 A
- Rated current range FMBC ECO (two stage): 8 – 115 A
- 2 mounting options
- ENEC approval, UL pending

Tel: +44 (0)1243 810810
sales@schurter.co.uk
www.schurter.co.uk

EMC Filter Directory 2010

This will be published in January 2010. To get your free copy email: pam@nutwooduk.co.uk with your full contact details and we'll pop it in the post.

Rittal's new Toptec CR Outdoor Enclosure System

Rittal's Toptec CR is a twin-walled outdoor enclosure system that offers all-round protection for highly sensitive electronics systems such as those needed for mobile telephony, data transmission or instrumentation.

The fully pre-configured outdoor enclosure is based around Rittal's market leading TS 8 system frame in stainless steel with fully integrated base/plinth and roof. The completely welded enclosure body ensures top EMC values and Rittal's TS 8 system technology also guarantees the highest level of stability and adaptability thanks to the extensive accessory range, which includes 19" mounting angles and mounting plates, lighting, heaters and a variety of gland plates for cable entry at the bottom.

Front and rear doors and side panels are made of galvanised and zinc phosphated sheet steel and, together with an outer aluminium roof, comprise a very tough and stable outdoor enclosure. As a result of using the same door cut-outs for the cooling unit and air/air heat exchanger, various climate control modules can be chosen. In addition, the twin-walled doors, reduce the influence of solar radiation (the "chimney effect"), ensure ideal conditions inside the enclosure and

prevent condensation forming.

The vented rain canopy which can be unfastened from inside also helps reduce the effects of solar radiation and is designed to prevent water building up over the doors. Multiple units may easily be bayed together for larger systems as the roof / rain canopy does not extend beyond the side walls.

Front and rear doors are each equipped with a swivel handle and semi-cylinder lock with security locking mechanism, offering the highest degree of protection against unauthorised entry. Tiny gaps between the doors and side panels make it difficult to use crowbars or jemmies giving good protection against vandalism.

The Rittal Toptec CR is available in widths of 600 and 800 mm, heights of 1200 and 1600 mm, and with a depth of 600 mm.

Tel: 01709 704000
information@rittal.co.uk
www.rittal.co.uk

PRODUCT GALLERY

Compact and modular solution from Rohde & Schwarz simplifies complex measurements in network analysis

The new R&S ZVAX24 hardware extension unit converts the vector network analyzers of the R&S ZVA family into space saving solutions to make intermodulation or pulse profile measurements easier. Even applications up to +43 dBm can be performed with no problem. Thanks to its modularity, the R&S ZVAX24 can be tailored to the individual application: It can be equipped with combiners, harmonic filters, pulse modulators and high power couplers. Therefore, users only invest in what they truly need. The new T&M solution from Rohde & Schwarz enables manufacturers from the wireless communications, automotive, or aerospace and defense industry to develop active components and then test them in production.

The R&S ZVAX24 is custom-tailored to the R&S ZVA24, but can be used with all vector network analyzers of the R&S ZVA and R&S ZVT family. Connecting the extension unit to the vector network analyzer is quite handy: The

R&S ZVAX24 is placed under the vector network analyzer and the RF ports are connected via semi-rigid coaxial cables. Control is performed via USB directly from the vector network analyzer, which displays a dialog box containing a block diagram of the extension unit. Depending on the test task, the required RF components can be connected.

Users who, for example, want to perform tests under pulsed conditions implement the modulators for pulse generation. The built-in pulse generators of the R&S ZVA vector network analyzer can then generate single pulses, periodic pulses or variable pulse sequences. The resolution of 12.5 ns is higher by a factor of ten compared with equipment previously available on the market. As a result, short pulses can be characterized more precisely. Since the pulse generators support user-configurable pulse trains, the user can generate arbitrary sequences of pulses of any width, duration and power which can help to characterize components under real-world conditions.

The combination of the R&S ZVA and R&S ZVAX24 is also particularly good for measuring intermodulation. To generate the required two-tone signal, the test setup using conventional vector network analyzers with only one internal generator must be expanded by an external generator and a combiner. In the case of the Rohde & Schwarz solution, the internal combiner of the extension unit uses the two sources of the four-port R&S ZVA and outputs the two-tone signal directly at the port. There is no need to perform any highly complex wiring and calibrations of any additional components. Together with the intermodulation wizard, intermodulation measurements can be configured and performed quickly and conveniently.

To test harmonics, the R&S ZVAX24 enables users to activate filters in the generator path and in the receive path. The filters improve signal purity and achieve very good suppression (60 dBc for the second, 70 dBc for the third harmonic) at maximum power. Furthermore, two high-power couplers can be integrated to permit an input level up to 43 dBm – a feature that permits tests on high-power amplifiers, for example.

The R&S ZVAX24 hardware option for the R&S ZVA and R&S ZVT vector network analyzers is now available from Rohde & Schwarz.

Tel: +44 (0)1252 818888
contact.uk@rohde-schwarz.com
www.rohde-schwarz.com

New hand-held safety instrument measures static magnetic fields up to 20 Tesla

Now available from **Link Microtek** is an ultra-portable PDA-style safety instrument that is designed to provide accurate measurements of the static magnetic fields found in the vicinity of medical imaging systems or in industrial applications such as metal production.

Despite its extremely compact case size of just 127 x 75 x 21mm, the THM1176-PDA magnetometer is capable of measuring field strengths as high as 20 Tesla, and it also incorporates full PDA computer functionality.

Equipped with a USB-powered isotropic 3-axis Hall probe, the instrument measures all three axes simultaneously to provide the total field, regardless of the orientation of the probe.

Four measurement ranges are available – 100mT, 500mT, 3T and 20T – with a choice of automatic or manual range setting. Results can be shown either numerically or graphically on the colour display, and the instrument can also be

connected directly to a PC.

Featuring a bandwidth of DC to 1kHz and a minimum battery life of 6 hours, the THM1176-PDA is supplied with a variety of accessories, including spare battery, charger, cables, PC software and carrying case.

Tel: +44 (0)1256 355771
sales@linkmicrotek.com
www.linkmicrotek.com

PRODUCT GALLERY

Agilent Technologies introduces versatile, compact Network Analyser with Wide Frequency Range

Agilent Technologies Inc. (NYSE: A) have introduced a compact network analyser, the Agilent E5061B, that analyses a frequency range as low as 5 Hz up to the RF (radio frequency) range of 3 GHz. This network analyser's broad range and versatility eliminates the need for additional low-frequency-dedicated instruments.

Applications for the Agilent E5061B, part of the ENA series of network analysers, include general RF-network measurements, such as filters or amplifier tests, and LF (low frequency) measurements necessary for loop-gain evaluation of DC-DC converters. The E5061B's frequency coverage is suitable for power distribution networks (PDN) measurements, which evaluate the quality of a DC power supply circuit. This type of evaluation is increasingly important, especially in high-speed digital communication equipment.

Features of the Agilent E5061B include:

- S-parameter test port, 5 Hz to 3 GHz, with a wide dynamic range of 120 dB at > 1MHz, 90 dB at < 100 Hz;
- gain-phase test port, 5 Hz to 30 MHz, switchable 1 MO/50 O input;
- DC bias source from 0 to ±40 Vdc, which can be added to AC test signal (for both S-parameter and gain-phase test port) or can be used as a sweepable DC source; and
- compact form factor with a 254-mm depth, requiring less desktop space.

"The new E5061B represents an extension of a recognised industry standard in RF network analysis capabilities from Agilent," said Akira Nukiyama, vice president and general manager of Agilent's Component Test Division, Kobe. "Delivering the excellent RF performance that is common to the ENA series, the E5061B also offers accurate LF measurement capability. It's the ideal, general-purpose LF-to-RF network analyser that meets a variety of network measurements."

Agilent's ENA Series addresses a broad array of component and circuit tests, including EMC-related applications and automotive, wireless communications, aerospace and defense, education and medical applications. The series includes the Agilent E5071C (9 kHz to 8.5 GHz /300 kHz to 20 GHz), the Agilent E5061A/62A (300 kHz to 1.5/3.0 GHz) and now the Agilent E5061B, expanding coverage to LF measurement requirements down to 5 Hz.

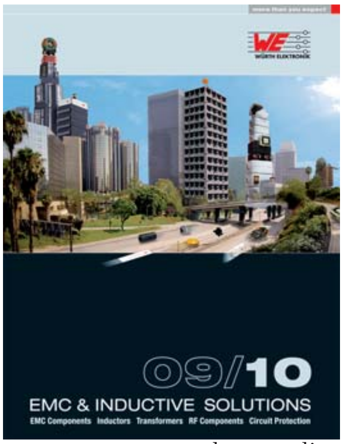
Complete information on the Agilent ENA network analyser series is available at http://www.agilent.com/find/ena.

Tel: +44 (0)118 927 6201
contactcenter_uk@agilent.com
www.agilent.co.uk

New Catalogue

Wurth Elektronik, one of the world's leading EMC & Inductive specialists, have just released the 2009-2010 catalogue. The catalogue, now available to order, demonstrates a range of new products including:

- WE-LFS clip on ferrite using a MnZn core for applications in the low frequency range of 300kHz - 30MHz.
- WE-PDF - Flat wire power inductor for lower losses at high frequencies.
- WE-HCC - High current shielded power inductors.
- WE-FB for LT3573 - Flyback transformer for use with Linear Technology's IC. Input voltage of 24V and isolation voltage of 1.5kV ideally suited for output power of approximately 5W.
- WE-LF SMD - 230V SMD current compensated power line choke in frequencies up to 30MHz.



All catalogue items are available ex-stock and samples are delivered free of charge within 24-48hrs.

Tel: +44 (0)161 872 0431
sales-uk@we-online.com
www.we-online.com

New FCT filter 'D' type connectors from Aerco

Aerco now stocks new filter versions of the popular FCT 'D' type connectors that are available in the same dimensions as the standard FCT non-filtered 'D' types. These new connectors use chip-on-board technology rather than the more traditional tubular capacitors and provide a space saving, cost-effective solution to the growing need for filter connectors for use in today's increasingly complex electronic systems.

Selective filtering is possible with different values being provided on each contact and they are built with tin-plated, dimpled shells for handling high frequencies. Available in 9, 15 and 25 way they are compatible with all standard 'D' type connectors and allow cost-effective development of EMI/EMC approved designs providing protection against surges, conducted disturbances, induced or electrostatic disturbances and conducted emissions.

Also available are shielded plastic caps for dust and RF protection and either metal or shielded plastic hoods. A special crimping flange is available to complete shielding at the cable outlet of the connector shell.

Tel: +44 (0)1403 260206
www.aerco.co.uk

AR's New "A" Series Amplifiers are Smaller, More Powerful and More Economical

New innovations at **AR RF/Microwave Instrumentation** are enabling the company to produce smaller, more compact amplifiers with just as much power as the older, larger models.

The new "A" Series amplifiers, for example, are 25% — 50% smaller than previous models, yet the new size does not mean a reduction in power. These newer, smaller models fit easily into a control room; and because of the new design, they are more efficient, using less energy than other amplifiers. The smaller, more efficient design also results in an increased performance to price ratio. In other words you get more for your money.

The new "A" Series includes the following models:

- Model 2500A225 (10 kHz – 225 MHz / 2500 watts)
- Model 1000A225 (10 kHz – 225 MHz / 1000 watts)
- Model 500A250A (10 kHz – 250 MHz / 500 watts)

With the wide frequency range, it's now possible to test to virtually any standard with the "A" Series amplifiers.

Each model features the latest FET technology, and can be controlled remotely with IEEE, RS-232, USB and Ethernet interfaces.

Tel: +44 (0)1908 282766
sales@uk-ar.co.uk
www.uk-ar.co.uk

emcia Member

The Physical Basis of EMC

Eur Ing Keith Armstrong CEng MIET MIEEE ACGI, Cherry Clough Consultants

Contents - *in this issue:*

1 Introduction

1.1 The aim of this article

My aim in writing this, is to try to impart an understanding of electromagnetic phenomena in a way that can be easily understood by practising engineers.

Armed with these few basic principles, electromagnetic compatibility (EMC) issues are easily *visualised*, and problems more easily solved, using only very simple mathematics and plain English.

Usually, articles like this start off by expounding Maxwell's famous equations, sometimes even deriving them from first principles. These are then used to solve a few simple constructions, such as an infinitely thin infinitely long perfectly-conducting wire suspended over an infinite plain of perfectly conducting material. Having to this far, they then usually abandon the reader, as if everything that could be said, had been said.

Unfortunately, no products are made using infinitely long wires or infinite planes. One reason is that they would be impossible to ship to customers – there would not be enough cardboard in the world to package them!

Another difficulty is that most modern products contain a great deal more than one conductor – typically they will have several million semiconductors (maybe hundreds of millions) and other linear and non-linear components interconnected by an equal number of wires (many of which will be metallised silicon).

So what use are Maxwell's equations to the product designer? It turns out that they are of no *direct* use at all! (Do I hear thousands of academics howling in anguish? Sorry!)

However, they *are* used to create computer simulations that *are* of practical use; plus they underpin the basic physical principles that this article aims to communicate.

These principles are of great practical utility – I have been successfully using them for over 20 years in a huge range of applications, from μW to MW, and many other EMC specialists have been using them for even longer. But you won't often find them clearly described in textbooks!

I learnt Maxwell's equations from renowned electromagnetic experts in my final year at University in London, UK, and passed the exam well enough. But when I met my first interference problem as a designer, I eagerly pulled out my lecture notes only to find that there was not even one word in them that appeared to bear any kind of relationship at all to the practical problem I had to solve.

I never opened those notes again, and after the mid-1970s I couldn't even if I wanted to – because they had been lost in Beirut, Lebanon, during the civil war it was experiencing at that time.

Low-frequency EMC issues (say, below 100kHz) are relatively easy to understand using normal circuit design techniques, so this article will focus mostly on the physical basics of EMC at radio frequencies (RF), which most electronic circuit designers find difficult because of the apparently weird, and sometimes counter-intuitive things that can happen at frequencies above a few MHz.

1.2 Who will benefit from understanding these principles?

This article is not about the good EMC design techniques I normally write about, but instead about *the reasons why these techniques work so well*.

These same reasons underpin <u>all</u> EM phenomena – which means all signals and power too – so they are important for achieving signal integrity, power integrity, and for determining good EMC engineering techniques when designing, constructing and installing electrical and electronic devices, products, equipment, systems and installations of all types, and of any size from vanishingly small to continent-spanning.

1.3 A brief description of some basic EM principles

I make no apologies for mangling the academic approach to EMC in what follows. I am trying to use common English terms familiar to practising engineers who – if they ever learnt Maxwell's equations – have forgotten everything about them.

Understanding the following eight basic principals make it easy to *visualise* EM phenomena, without using any maths, in any situation. There are many other principles that will be described later on, but these are the ones that really help visualise EMC problems and their solutions.

i) Everything that we think of as being an AC voltage or current is really EM energy (Watts, Joules) propagating as a wave.

It makes no matter how small or large are the voltages, currents or powers, or what the application is.

If we have 1mW of power in a signal, or 10kW of power in a mains-powered load, then there is 1mW and 10kW of EM energy, respectively, in the EM fields associated with their send and return conductors.

Waves propagate in the three dimensions of space, and the one of time, and have different amplitudes at different places and different times.

The distribution of EM wave energy in space is called an EM field. It is rather like dropping a stone into calm pool of water causes waves to spread out over the water, leaving behind a 'field pattern' of ripples.

The way most of us were taught about electric current, as if it was caused by electrons rushing backwards and forwards along a wire, is no help at all at RF frequencies, and leads to mistakes in design – such as imagining that single-point earthing/grounding could possibly control where return currents flow at RF.

Of course, electrical currents do involve movement of electrons, but their velocity is about walking speed, about 3 miles per hour – rather less than the velocity of electromagnetic wave propagation at the speed of light!

ii) EM waves and fields consist of both Electric (E) and Magnetic (H) waves and fields.

This is exactly why they are called "electro-magnetic"!

E waves and fields are measured in Volts per metre, H measured in Amps per metre.

iii) When a conductor is exposed to an EM wave, its free electrons move around in response to the wave – generating what we call a current.

When a circuit's voltages and currents move the electrons in its conductor around, they cause the same EM waves to arise as would have made the electrons move in that same way.

This is called the ***Principle of Reciprocity***, and it means that a conductive structure (e.g. a cable, printed circuit board (PCB) trace, etc.) that has a certain antenna behaviour when it 'picks up' an EM wave and gives rise to currents and voltages in a circuit, has exactly the same antenna behaviour as an emitter of EM waves – when currents and voltages are made to occur in it by some circuit.

This understanding also shows that "conducted" and "radiated" EM phenomena are just 'two sides of the same coin' – they are not, in fact, different types of phenomena.

We classify EM phenomena as either conducted or radiated purely on the basis of whether we use conducted or radiated tests to measure them. All that a propagating EM wave knows is the impedance and velocity of the medium it is travelling through, both of which are affected by the presence of conductors.

Note that it is impossible to have electrons moving without there being an associated wave propagating in the nearby space. This wave is not confined to the locality of the conductors carrying the electrons, and how it spreads through space is defined by the relationship between its send and return current paths – which brings us to point iv).

iv) **EM wave propagation, and its associated fields, are shaped by the "accidental antenna" structures that we think of as send and return current paths and the dielectric materials (insulators) that surround them.**

And, as we learned in iii) above, by the principle of reciprocity, the voltages and currents that are picked-up by conductors from their ambient fields depend upon the shape of the accidental antenna created by that circuit's send and return current paths and their insulators.

To reduce emissions and increase immunity, we design using conductive structures that behave as poor accidental antennas.

Many low-cost (often free) EMC and signal integrity design techniques are based on this approach.

v) **Induced and radiated coupling**

If we consider the EM wave associated with voltages and currents in a given arrangement of send/return conductors, for example an individual part of an electronic circuit, we see that any other conductors that this wave meets as it spreads through space will also experience currents and voltages as a result.

This fact of wave (field) coupling is used to design intentional EM couplers, for example transformers, and radio systems (i.e. transmitters and receivers).

It also explains some of the ways in which crosstalk, differential-mode and common-mode interference arise. A proportion of the EM energy associated with the currents and voltages in one circuit (i.e. arrangement of conductors) has coupled through the air (or other insulators) into a quite separate set of conductors.

The energy lost by the original circuit, the "source", has an effect on its voltages and currents. The energy picked-up by the other circuit, the "victim", is a noise – an unwanted signal.

We are all familiar with the idea that electrical energy (Watts, Joules) is carried by conductors. But in fact conductors only guide electrical (EM wave) energy, which can also flow equally well through insulators like vacuum, air, plastic, etc.

vi) **Electrons are naturally forced to flow near the surface of a conductor.**

The higher the frequency, the smaller is the thickness below the surface of the conductor, in which they flow.

This is called the ***Skin Effect***, so these currents are called ***Surface Currents***.

Skin effect reduces the proportion of an AC current that can flow *directly through* a conductive material (i.e. from one side to the other).

So, for example, metal sheets are poor conductors in their *thickness* dimension. The higher the frequency – the poorer they are. Skin effect shows us how to assemble shielding and filtering so that they work best, see 2.6.2, 3.3.2 and 4.4.3 of [1].

vii) **Return currents automatically take the path (or paths) that minimise the overall amount of EM energy.**

This is rather like the way that a falling drop of water automatically assumes a spherical shape to minimise the energy in its surface tension.

It means that all we have to do to make a poor accidental antenna (see iv) above), is to provide a path for the return current that is very close physically to the send current's path – much closer than the wavelength at the frequency concerned.

To make the antenna effect poorer (to further reduce emissions and improve immunity) we make the return path closer to the send path.

Note that we don't have to *make* the return current flow in the nearby path we have created for it – all we do is create the path and the current *naturally prefers to take it*, even when parallel paths exist that it could take instead.

The resulting EM field patterns become much more compact, have less energy in them, and couple less with other conductors. The accidental antenna behaviour of the conductive structure is therefore less efficient – reducing emissions and improving immunity.

This is a lovely example of how the laws of nature (or laws of physics, if you prefer) actually try to help designers control EM interference (EMI) and achieve EMC.

This understanding makes it possible to visualise where a return current flows, and see how its path can be altered to improve EMC.

viii) **Everything presents an impedance to a wave**

Every conductor has impedance, so wherever and whenever there is a current in it, there is always a corresponding voltage. And vice-versa.

This applies equally to superconductors, as they only have a zero resistance (just one of the three constituents of impedance: resistance, inductance and capacitance). They still have inductance and capacitance.

Every insulator or dielectric (vacuum, air, plastic, fibreglass, ceramic, etc.) has a "wave impedance", so that whenever and whenever an H field exists in it, it always experiences a corresponding E field. And vice-versa.

These eight basic EM principles arise as a direct result of quantum mechanics and quantum electro-dynamics – the laws of nature that give rise to Maxwell's equations.

I learnt this when I bumped into my old electromagnetic lecturer at a conference about 20 years after graduating, and asked him why Maxwell's equations were like they were. (I felt like a 3-year old asking "But *why*, Daddy, *why*?")

He simply pointed me to textbooks on quantum electrodynamics written by Richard Feynman, who discovered how to use quantum mechanics to calculate exactly how EM fields interact with the free electrons in metals and other conductors.

So forget kindergarten ideas of electrical currents and voltages, e.g. that electrical current consists of electrons bobbling along, and that waves and fields are side-effects, and use the above principles instead. They make it possible to easily visualise any/all linear EM phenomena. (I'll deal with the non-linear EM phenomena, which occur in semiconductors and corroded metal joints, later on.)

The remaining few thousand words and all of the graphics in this article go into more detail on the above principles, and also discuss useful associated issues.

2. Wave and Field theory

Design for EMC at RF is mostly about controlling the shapes of E and H fields so that they are at their most intense where we want power or signals to occur in conductors, and are weak elsewhere so that emissions are low and – because of reciprocity – the conductors do not pick up much noise from other EM fields.

This sounds very difficult, and might be assumed to use a great deal of mathematics, but in fact all we need to help us design are the basic principles mentioned in 1.3, a few other principles, and some simple sums.

2.1 E and H fields

Fluctuating voltages, whose magnitudes are measured in Volts (V), are associated with correspondingly fluctuating Electric fields (E), whose magnitudes are measured in Volts/metre (V/m).

Fluctuating currents, whose magnitudes are measured in Amps (A), are associated with correspondingly fluctuating Magnetic fields (H), whose magnitudes are measured in Amps/metre (A/m).

2.2 Wavelength, velocity and frequency

A wave has – of course – different amplitudes at different points along its path, which fluctuate as time progresses. Figure 1 shows a way of visualising an EM wave that is propagating along a particular vector, such as along a long thin wire. However, a wave travelling through the air will propagate over a solid angle, not along a single vector like that shown in Figure 1.

P (the EM energy), E and H are all orthogonal to each other – indicated in Figure 1 by drawing them along the mutually perpendicular x, y and z axes.

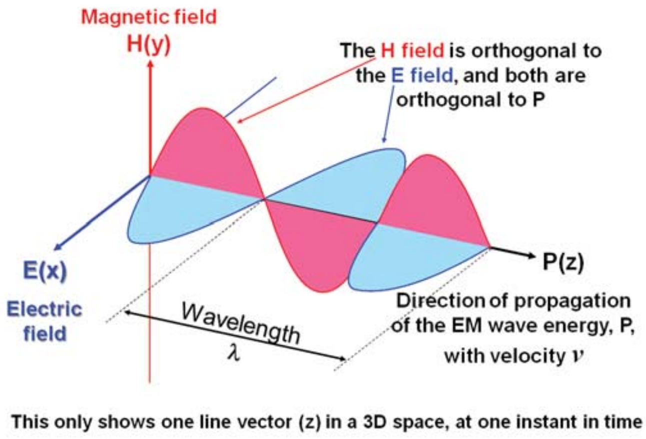


Figure 1 The traditional way of representing an EM wave

Figure 2 shows how a common EM simulator for PCBs represents the EM fields associated with a differential pair of traces on a PCB.

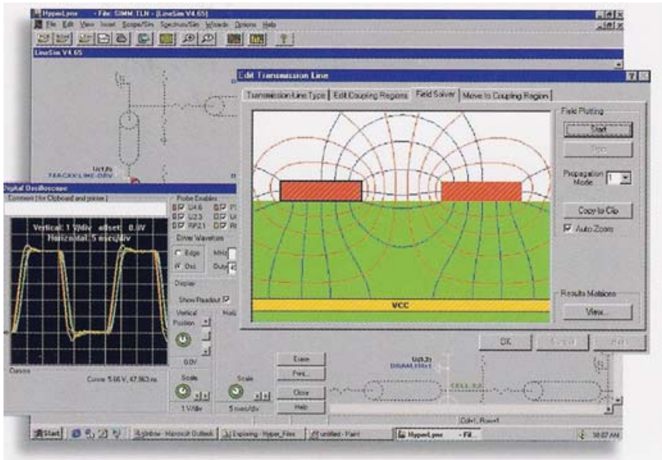


Figure 2 Example of an EM PCB simulator (Hyperlynx) showing plots of E and H fields

Because EM energy (signals, power, etc.) travel as waves, when a conductor is long enough it cannot experience the same voltage or current, at any instant in time, along its whole length. This "wave effect" is what causes the apparently weird effects that can occur at radio frequencies, or with fast digital signal edges, and makes matched transmission line techniques necessary for good signal integrity and low-cost EMC, see 2.7 and 5.6 of [1].

The ratio between the wavelength (λ) of the frequency (*f*) we are concerned with, and the dimensions of our conductors, is therefore very important indeed. For the EMC requirements of ordinary commercial or industrial designs we can usually ignore weird "wave effects" when conductor dimensions are < 1/100th of the λ (equivalent to approximately 3/*f* metres when *f* is given in MHz. GHz gives the result in millimetres).

For example, at 1GHz this means < 3mm for EM waves on conductors surrounded by vacuum or air; or < 1.5mm for waves propagating on traces embedded inside PCBs made of the common FR4 dielectric. Few if any conductors outside of the silicon metallisation within Integrated Circuits (ICs) are as short as this, and able to have their 'wave effects' ignored during design.

This crude guide will probably not be adequate where EMC requirements are higher, or the EM environment is harsher.

We easily convert between λ into f by using the relationship: $v = f \cdot \lambda$ – where v is the velocity of the wave's propagation in metres/sec, f is in Hz and λ is in metres.

But to understand v, we must first understand permeability, μ, and permittivity, ε.

2.3 Permeability (μ) and permittivity(ε)

All media or materials have the characteristics of conductivity (resistivity), permeability and permittivity. The characteristics of the vacuum (and air) are given the suffix 0, and so:

$\mu_0 = 4\pi \cdot 10^{-7}$ Henries/metre

$\varepsilon_0 = 1/(36\pi) \cdot 10^{-9}$ Farads/metre

Other media and materials are characterised by their *relative* permeability and permittivity, which is simply a numerical multiplier given the suffix R (for relative), and so their absolute permeability is: $\mu_0 \cdot \mu_R$, and their absolute permittivity is: $\varepsilon_0 \cdot \varepsilon_R$.

Conductivity (resistivity) is not associated with any fields, and is simply a characteristic that converts EM energy into heat. Resistance turns Watts and Joules of electrical power and energy into Watts and Watt-seconds of heat.

2.3.1 Impedance (Z)

In conductors: μ and ε cause inductance (L) and capacitance (C) to arise, respectively. L creates an impedance of $2\pi f$ L, and C creates an impedance of $1/2\pi f$ C, and the overall impedance of the conductor, Z, is $\sqrt{(L/C)}$, in Ω.

Since this means that L and C are always present, creating impedance in any conductor no matter how small, it means that *whenever* there is a fluctuating voltage in a conductor there is *always* an associated fluctuating current. And vice-versa.

Some digital designers have been known to believe that because the gates of CMOS integrated circuits have an almost infinite resistance, therefore digital signals have no send or return currents. But of course the fluctuating voltages that are the signal have to charge up the capacitance of the PCB trace and of the gate of the CMOS device, so need a correspondingly fluctuating current.

Since current always flows in loops (another law of nature, known as Kirchoff's Law), and since there is a send current in the trace and CMOS gate, there has to be an equal and opposite return current.

The practical meaning of this for signal integrity is that if the return current is impeded, for instance by having to flow around a slot or gap in a 0V plane, or having to flow in a path that encloses a large area (with respect to the send path), the inductance that is thereby added develops a voltage that distorts the signal's voltage.

And, of course, not having a return path that is close to the send path at all times, means that the circuit behaves as a more efficient accidental antenna, so the digital signal has excessive emissions and is more likely to suffer interference.

So a lack of appreciation of μ and ε and the inevitable impedances that they give rise to, causes some digital designers' PCB layouts to suffer from signal integrity and EMC problems.

In insulators (dielectrics): μ and ε cause effects similar to inductance and capacitance, meaning that *whenever* there is a fluctuating E field there is *always* an associated fluctuating H field. And vice-versa. As mentioned earlier, this is why we call the subject electromagnetism.

The impedance of a wave in the "far field" (see later) is given by the ratio of its E and H fields:

$$Z_{WAVE} = E/H = V/m \div A/m = \sqrt{(\mu_0 \cdot \mu_R / \varepsilon_0 \cdot \varepsilon_R)}\ \Omega$$

In air or vacuum, when μ_R and ε_R are both 1:

$$Z_{WAVE} = 120\pi\ \Omega\text{, say } 377\Omega$$

But in a medium other than air or vacuum, so μ_R and/or ε_R are greater than 1:

$$Z_{WAVE} = 120\pi\sqrt{(\mu_R/\varepsilon_R)}\ \Omega$$

Notice that the units of wave impedance are simply ohms, Ω, and in fact the Z_{WAVE} = E/H formula is sometimes called "Ohms Law for Fields".

2.3.2 Velocity of EM wave propagation

μ and ε also govern the velocity of propagation, v:

$$v = 1/\sqrt{(\mu_0 \cdot \mu_R \cdot \varepsilon_0 \cdot \varepsilon_R)} \quad \text{metres/second}$$

In air or vacuum, when μ_R and ε_R are both 1:

$$v = 3 \cdot 10^8 \text{ m/s}$$

It is actually a little less than the above figure of 300 million metres/second, and we assume it is equivalent to 3ns/metre, or 3ps/millimetre.

But in a medium other than air or vacuum, so μ_R and/or ε_R are greater than 1:

$$v = 3.10^8/\sqrt{(\mu_R \cdot \varepsilon_R)} \text{ m/s}$$

So when μ_R and/or ε_R are greater than 1, v is slower so the wavelength (λ) at a given f is shorter. For example, for a PCB's FR4 dielectric, μ_R is 1 but ε_R is 4.2, so for a wave propagating along a trace on an inner layer, its v is approximately half of what it would be in air, so its λ is about half too.

For example, a 1GHz wave in the air has a λ of about 300mm, but if travelling instead on a trace on an inner layer of a PCB, λ is about 150mm.

2.3.3 The effect of changing the impedance along the path of a wave

EM waves propagating through space, or along conductors, are reflected when they experience a change in impedance.

Examples include a wave propagating through the air and passing into a block wood, plastic, ceramic, etc.; or a trace on a PCB that increases its width (hence has higher C and lower L, therefore a lower impedance).

To have a significant effect on a wave, the change in impedance has to persist for longer than one-tenth of a wavelength, $\lambda/10$, so to analyse the path of a signal on in a trace in a PCB to make sure it is experiencing the same Z, called its "characteristic impedance", Z_0, all along its path to maintain good signal integrity, we have to divide the trace's length into segments that are no longer than $\lambda/10$, and make sure that each segment has the same value of Z_0.

This is known as transmission line design, and when the impedances of the circuit's source and load equal the Z_0 of the trace, it is called a "matched transmission line". Such lines are very poor accidental antennas and so have very low emissions and pick-up very little noise from ambient EM fields.

This phenomenon of wave reflections where there are changes in impedance, also tells us how to maximise reflections to design shields and filters for greatest attenuation, see 3.2.1 and 4.3.2 in [1].

2.4 Near-field and Far-field

Near to a circuit that has fluctuating voltages or currents, a "source", the corresponding E and H fields have complex patterns in space: their field strengths vary as a function of $1/r^3$, $1/r^2$ and $1/r$, where r is the radial distance from the source. They are called "near fields", because they have not yet travelled far enough to settle down into the E/H ratio that matches the wave impedance of their medium (usually air).

This is sometimes called the "induction region", because the effects of the fields can be described in terms of stray capacitance and stray mutual inductance effects (i.e. coupling that is dominated by E and H fields).

Figure 3 shows an example of the near-fields around a heatsink (which experiences fluctuating voltages and currents as the result of having significant levels of stray capacitance to the conductors in the device it is cooling). These were simulated using Microstripes – a computer EM field simulator that used to be called Flo-EMC, and is now owned by Computer Simulation Technology (www.cst.com).

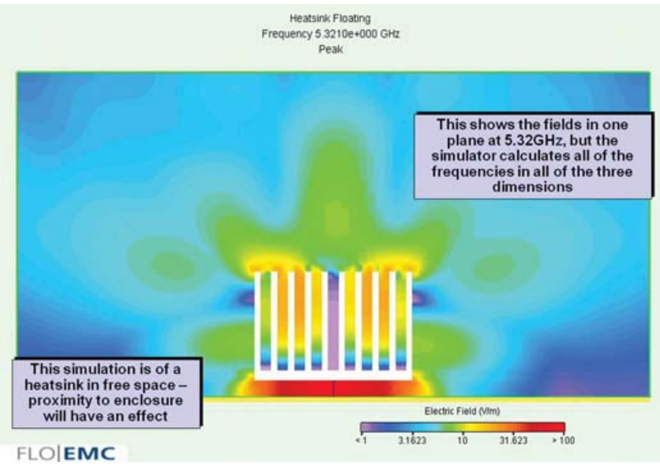


Figure 3 Near fields around a heatsink

When we get far enough away from a source, its propagating E and H waves turn into EM waves, which means that they have E and H fields in the ratio of the wave impedance of the medium: Z_{WAVE}.

This is now the "far field" region, and the distribution of the fields in space follows a simple "plane wave" with the wave energy spreading in space as a simple expanding sphere. Now, its field strengths vary as a function of only 1/r.

For sources with longest dimensions <<λ, the boundary between the near and far field regions occurs when r (the distance from the source) is $\lambda/2\pi$.

But for sources with dimensions >λ, the near/far field boundary is calculated as $r = 2D^2/\lambda$, where D is the largest dimension of the source.

(There is a third expression for when the source's longest dimension is inbetween these two size ranges, but it only gives an value for r that is a little larger than the largest value calculated using both of the above.)

Figure 4 graphs the near-field / far-field boundary for a product that has a longest dimension shorter than one-sixth of a wavelength over the range of frequencies of interest.

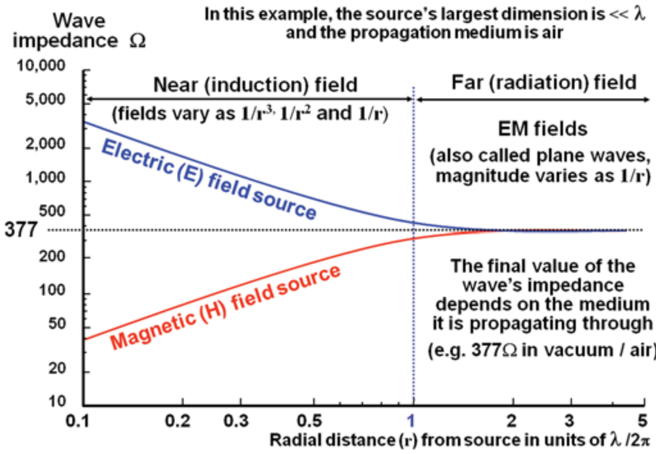


Figure 4 Near fields become Far fields with distance

Fluctuating voltages within Figure 4's circuits are initially associated with E-fields only, which have very high impedance. As the waves propagate further and further away from their E-field source, the impedance of the medium has more and more effect, causing an increasing proportion of the wave's energy to be converted into H field. So the ratio of E field to H field decreases, the further away from the source, and the wave impedance therefore decreases.

Eventually, when the wave has travelled more than $\lambda/2\pi$ from its source, its E/H ratio matches the wave impedance of the medium and does not change any more – it has reached the 'far field' region.

A similar effect occurs to the magnetic fields emitted by the fluctuating currents in the circuit. Initially they have a very low impedance, because their E/H ratio has such a small numerator, but as the wave propagates further from the source the impedance of the medium it is travelling in has more effect, causing E fields to be generated until the E/H ratio matches that of the medium itself – when the wave can be said to be in its 'far field' region.

3 EMC uses three types of analysis

Because of the effects of wave propagation, discussed in 2 above, we have to use three different kinds of analysis when analysing the EMC characteristics of electrical/electronic circuits and the rest of the structures that go to make a product or item of equipment. These are:

a) "Lumped Element" analysis when dimensions are much less than $\lambda/2\pi$.

b) "Transmission Line" analysis when one dimension is longer than $\lambda/2\pi$ (e.g. a long thin wire).

c) "Full Wave" analysis in 2 or 3 dimensions, when two or three dimensions are longer than $\lambda/2\pi$.

All circuits have RF resonant modes, sometimes called "eigentones", where their currents or voltages experience a resonant gain, called their 'Q factor'. Qs of 10 or more are common (i.e. gains of 20dB or more) in ordinary electrical and electronic circuits, with gains of 100 (40dB) not being unusual and up to 1,000 (60dB) being seen on occasion.

Higher Qs are associated with circuits that have low resistance. High values of resistance cause so much loss that only low Q values are possible.

Accidental antenna structures (that is: all conductors) are most efficient at their resonant frequencies, causing high levels of emissions and poor immunity. So it is very important to control resonances when designing to achieve EMC.

3.1 Lumped Element analysis

For conductor dimensions << $\lambda/2\pi$ we can use 'lumped element' analysis methods, which are based upon resistance (R), inductance (L) and capacitance (C). It is, in fact, the normal circuit analysis we all use in circuit design, but to be useful for EMC design purposes we have to take into account all the stray Ls and Cs that exist in our product. Stray L and C are sometimes called "parasitic" L and C.

Everything has R, L and C characteristics, including all components, wires, cables, PCB traces, connectors, silicon metallisation, bond wires, chassis, shields, mounting pillars, metal brackets, etc.

And everything also has stray (parasitic) R, L, and C, which can be *intrinsic* (e.g. the self-inductance of a wire lead) or *extrinsic* (e.g. stray C or L coupling due to proximity to other objects).

Let's look at these lumped element characteristics one at a time, from an EMC engineering perspective.

3.1.1 Resistance

Resistance increases with increasing frequency, f, due to the Skin Effect.

DC currents travel through the whole cross-sectional area of a conductor, but AC currents are forced to flow close to the surface, which is why it is called the skin effect.

This means that RF currents only penetrate weakly into the depth (thickness) of a conductor, decreasing the cross-sectional area of the copper they flow through and therefore increasing the resistance in their path, as shown by Figure 5.

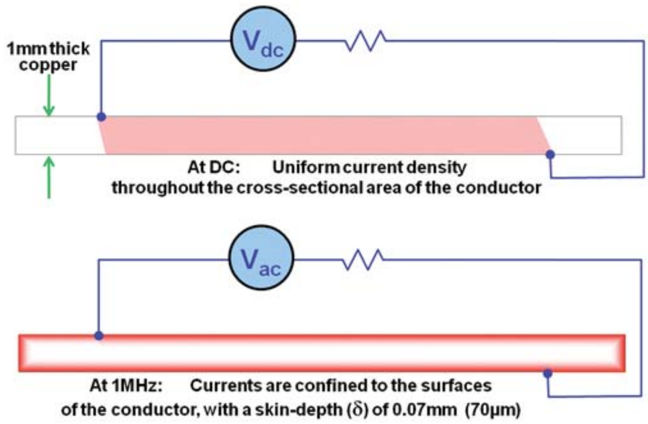


Figure 5 Comparison of current densities for currents at DC and 1MHz

Figure 5 shows quite clearly that at DC the current can take the shortest path *inside* the conductor, but at 1MHz it is forced to travel near the surface – which means that to get from one side of the conductor to the other it must flow around the edges. In a wide conductor, or sheet of metal, this can hugely increase the length of the current path.

One skin depth (δ) is the depth into the thickness of a conductor by which the current density has reduced to $1/e$, and is calculated as $\delta = (\sqrt{\pi \cdot f \cdot \mu_0 \cdot \mu_R \cdot \sigma})^{-1}$ metres, where σ is the conductivity of the conductor material. Each skin depth further below the surface, the current density reduces by a further $1/e$.

For copper conductors: $\delta = 66/\sqrt{f}$ (f in Hz gives δ in millimetres), for example at 160MHz $\delta = 0.005$mm, so at 0.05mm below the surface (10 skin depths) the current density is $(1/e)^{10}$ – which means it is negligible. At this frequency, the resistance of a 1mm diameter wire is increased to about 50 times its DC resistance, due to the approximately 50 times smaller cross-sectional area that is carrying the current.

Volume II of [2] gives the characteristics for a wide variety of metals, enabling their skin depths to be calculated; [3] lists the skin depths of many metals, and Figure 6 graphs δ against frequency for copper, aluminium and a typical grade of mild steel.

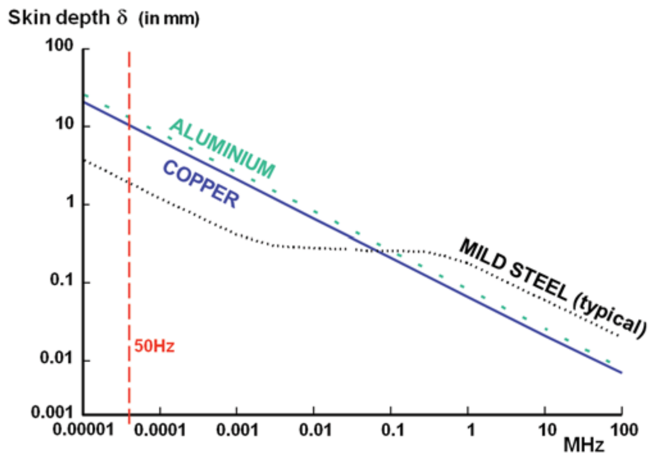


Figure 6 Graph of skin depth (d) for copper, aluminium, and a mild steel

As Figure 6 shows, mild steel has a skin depth that is a complex function of frequency, because of its μ_R of about 300, caused by its ferromagnetism. At lower frequencies its skin depth is reduced by its high value of μ_R, but between 1kHz and 1MHz it loses this characteristic and its μ_R decreases to 0. Since its conductivity is significantly less than aluminium or copper, its skin depth above 1MHz is larger.

There are many hundreds of grades of mild steel, and of course many other kinds of steels, including stainless types, and they all have different values of μ_R with different frequency variations. It can be quite difficult to find the μ_R for a particular type of steel, but it is usually impossible to discover its frequency characteristics. If you need to know this data, you will almost certainly have to measure it for yourself.

Nickel is also ferromagnetic and behaves like the mild steel in Figure 6, and there are also special high-permeability metals available with values of μ_R from about 10,000 to 50,000. These "hi-perm" metals may lose their permeability at lower frequencies than mild steel.

Skin depth has a very important part to play in shielding (see 4.3.3 in [1]), since any current that makes it to the other side of a shield radiates fields and therefore represents worse shielding. This is why Figure 6 has a line indicating 50Hz – to show how large the skin depths are at mains frequency.

Since one skin depth represents about 9dB of absorption, we can see that copper and aluminium sheets of about 10mm thick, and mild steel about 2.5mm thick, only provide a very small amount of shielding against magnetic fields at 50Hz. However, mild steel that is 10mm thick should give about 36dB attenuation at that frequency. This indicates that the best way to deal with magnetic fields at powerline frequency is to make sure that their source is so far away that the field levels are negligible and don't need shielding!

As mentioned earlier, resistance turns Watts and Joules of electrical power and energy into Watts and Watt-seconds of heat. It does not transfer (couple) or store electrical power or energy, like inductance and capacitance do.

3.1.2. Stray Inductance

A component purchased as an inductor will of course have a certain value of inductance, which will probably vary with frequency and temperature, and will have certain tolerances. But what we are concerned with here, is stray inductance. For a review of how stray inductances affect components themselves, see 1.8.1 of [1].

A thin wire has in *intrinsic* self-inductance of about 1μH per metre (1nH per mm), assuming the return path for its current is very far away.

If the return current path is a nearby conductor, it will have an *extrinsic* stray mutual inductance with its send path, which will cancel-out a proportion of the self-inductance and so reduce the overall inductance experienced by a current flowing around the send/return conductor path.

This is why, for good signal integrity, we need to keep the send and return current paths in intimate proximity all along their length, ideally twisting them together (see 2.2 of [1]). And for good EMC, we notice that such conductor structures have very compact, small, field patterns and so are poor accidental antennas.

Close proximity to ferromagnetic materials (e.g. steel, nickel, ferrite) with a $\mu_R > 1$ will increase both self-inductance and mutual inductance, but close proximity to conductive materials (e.g. cables, metalwork, etc.) will decrease them both.

As mentioned in 1 earlier, the true nature of electrical power and electronic signals is propagating EM waves, which carry the power or energy by means of electrical and magnetic fields. Inductance is associated with magnetic fields, and hence with transferring (coupling) and/or storing H-field power and energy.

The energy present in the H-field of an inductor, whether a component or a stray, is $\frac{1}{2}LI^2$ Joules (where I is the current in Amps and L is in Henries).

3.1.3 Stray Capacitance

A component purchased as a capacitor will of course have a certain value of capacitance, which will probably vary with frequency and temperature, and maybe with time, and will have certain tolerances. But what we are concerned with here, is stray capacitance. For a review of how stray capacitances affect components themselves, see 1.8.1 of [1].

A thin conductor on its own in free space has about 40pF of *intrinsic* stray "space charge" capacitance per metre of length (approximately 0.04pF per mm). The greater the surface area of the conductor, the greater will be its space-charge capacitance.

Close proximity to dielectrics with $\varepsilon_R > 1$, will increase all stray capacitances, both *intrinsic* and *extrinsic*. Whereas close proximity to other conductors will increase only *extrinsic* stray capacitances.

As mentioned in 1 earlier, the true nature of electrical power and electronic signals is propagating EM waves, which carry the power or energy by means of electrical and magnetic fields. Capacitance is associated with electric fields, and hence with transferring (coupling) and/or storing E-field power and energy.

The energy present in the E-field of a capacitor, whether a component or a stray, is $\frac{1}{2}CV^2$ Joules (where V is the voltage and C is in Farads).

3.1.4 Lumped Analysis of Resonances

3.1.3 and 3.1.4 mentioned the electrical energy associated with the H and E fields in capacitors and inductors – whether they are capacitor or inductor components, or stray (parasitic) capacitances and inductances.

Normally, the electrical energy present in a given circuit (or stray circuit) is a ratio of E and H fields, but at the resonant frequency the energy oscillates between being all H-field and all E-field, causing amplification of the circuit voltage and currents.

All types of circuits have L and C (even if they are only strays) and these cause resonant frequencies to occur at :
$f_{RES} = 1/(2\pi\sqrt{LC})$ Farads and Henries give the frequency in Hz.

These resonances are 'damped' by the resistance in the circuit, which is governed by skin effect as discussed in 3.1.1. More resistance means more power loss means a lower Q value. The above resonance formula is simplified and does not include the resistance term, but a more complete formula shows that resistance has a small effect on the resonance frequency, causing it to be a little lower than predicted by the simple formula above.

3.2 Transmission Line analysis

3.2.1 Analysing impedance section by section

3.1 showed that all conductors have R, L and C, and the L and C are involved with the storage and transfer of electrical power and energy (the EM wave).

2.4 discussed the near and far field regions of a propagating wave, and mentioned that in the far field the ratio of E and H fields in the wave is the same as the wave impedance (Z_{WAVE}) of the medium it is propagating through.

The same effect is present in EM waves propagating along conductors, but with the wave impedance replaced by the "characteristic impedance", Z_0, of the send/return conductor structure, which is given by $\sqrt{(L/C)}$ (L in Henries and C in Farads gives Z in Ohms).

When an EM wave (what we think of as our power or signal) is "launched" into a conductor by an active electrical/electronic device, it has the impedance of its driver. And when it is "received" in an electrical/electronic load, it has the impedance of that load. But beyond a certain distance from either the driver or the load, the impedance of the EM wave is governed by the medium it is propagating in, the Z_0 of the send/return conductor structure.

It was mentioned in the initial review of basic principles that changes in the impedance reflect a proportion of the propagating EM wave, with larger changes over longer distances reflecting more. Reflected wave energy, is energy that does not travel from driver to load, which has the effect of distorting the waveform received by the load – a signal integrity or signal quality problem.

In the case of electrical power, reflected waves mean that at certain frequencies the power distribution cannot deliver as much current, and so appears to have a higher impedance – a power integrity (sometimes called power quality) problem.

And reflected EM wave energy makes conductive structures behave as more effective accidental antennas – causing EMC problems by increasing emissions and decreasing immunity.

Changes in impedance that occur for a length of less than about $\lambda/6$ have little effect on reflection, so transmission-line analysis consists of analysing the entire length of conductor as $\lambda/10$ sections, including its driver and its load, and determining the impedance of each. This then makes it possible to determine how a wave will travel from the driver to the load, and what will be the effect on its waveshape, frequency response, and EMC characteristics.

The L and C associated with a $\lambda/10$ section governs the velocity (v) with which EM waves travel through that section:
$v = 1/\sqrt{(LC)}$, and the ratio of L to C governs the Z_0 of the section: $Z_0 = \sqrt{(L/C)}$.

The L and C values used in the above analyses are 'per unit length' (e.g. 1µH/metre, 100pF/metre) where the unit lengths used are equal to or shorter than $\lambda/10$. Remember that as the velocity decreases due to relative permeability and/or permittivity, the wavelength for a given frequency gets shorter, so the length of a $\lambda/10$ section depend upon the medium surrounding the conductors – their insulators (e.g. PVC insulation on wires) or dielectrics (e.g. FR4 fibreglass on PCB traces).

3.2.2 The effects of keeping Z_0 constant

If the same value is maintained for the Z_0s of each $\lambda/10$ section of the conductor from the source to the load, *and for the impedances of the driver and the load*, 100% of the EM wave (the electrical power or signal) is communicated from source to load (ignoring the loss associated with the resistance). This is called matched transmission line design.

Since very little energy is lost in such a design, the integrity of the waveform must be maintained, and the circuit must have very poor efficiency as an accidental antenna, and so must have low emissions and good immunity.

An example of matched transmission-line design is general purpose RF test equipment, connectors and cables, which has 50Ω impedances for all sources and loads, and uses connectors and cables with characteristic impedances of 50Ω over their entire lengths.

3.2.3 The effect of changing impedances over dimensions greater than $\lambda/6$

As mentioned earlier, such changes cause propagating EM waves to be reflected (whether they are signals or power), rather like the way that ripples spreading across a pool of water are reflecting from a floating object.

This is the technique that is used to achieve "EMC filtering" (see 3.2.1 of [1]) – we deliberately create changes in the characteristic impedance of a conducted EM wave, to reflect unwanted noise away from the circuit that our filter is intended to protect.

3.2.4 Transmission-line analysis of resonances

When a wave hits an impedance that is higher than the Z_0 it is propagating along, the reflection is in-phase with the wave at that point. The reflected wave thus adds to the original (impinging) wave and increases its amplitude at that point.

But when the change in impedance is lower than Z_0, the reflected wave is in antiphase, and subtracts from the impinging wave, decreasing its amplitude at that point.

So when a portion of a conductor with a constant value of Z_0 along its length experiences an impedance change (i.e. either higher or lower than Z_0) at <u>*both*</u> of its ends, the reflected wave "ricochets" backwards and forwards along that portion of the line.

A special situation occurs at the frequency at which the length of the portion of conductor is a whole number of half-wavelengths – a resonance occurs. Instead of the reflected waves decaying away quickly with successive ricochets, they maintain their original amplitudes.

This results in what is called a "standing wave" along that portion of the conductor. It is called that, because – if you probe at a particular location along the conductor (e.g. with a close-field probe and oscilloscope) – instead of seeing peaks and troughs in voltage and/or current occurring over time, you see a fixed amplitude all the time. Varying the position of the probe along the length of the conductor varies the amplitude and sign that is measured.

Of course, it is not really a fixed (standing) wave – it is a wave that is constantly being reflected back and forth between the changed impedances at each end of that portion of conductor. But the point is that its amplitude and polarity at a given point is a function of its position.

The creation of a standing wave causes the conductor to behave as a very efficient accidental antenna. In fact, when using conductors as *intentional* antennas, as radio transmitters do, a key factor is the "standing wave ratio" (SWR) and there are instruments specifically designed to measure it.

The length of the antenna is adjusted, to tune its resonant frequency to the frequency of the radio transmitter. When an SWR of 1 is achieved, it means that all of the signal is being reflected at both ends and the conductor has the maximum value of standing wave on it, optimising its efficiency as a radio transmitting antenna. The same approach is used to tune receiving antennas too.

(Actually, it is not normal to adjust the actual physical length of the conductor being used as an antenna. Usually, the conductor is made a little shorter than is necessary, and its "electrical length" is *increased t*o tune it to resonance, at the desired frequency, by varying a capacitive shunt.)

With same type of impedance change at both ends of a portion having a constant Z_0 along its length, the resonant frequencies of a conductor are $v \cdot l/2L$ where l is an integer (1, 2, 3, etc.) that describes the number of half-wavelengths in the standing wave and L is the length of the conductor between the changed impedances.

For a conductor in air (or vacuum), this expression converts to $150 \cdot l/L$ MHz when L is given in metres. So a 1m long conductor in air would resonate at 150, 300, 450MHz, etc.

When the conductor is not in air (or vacuum) its resonant frequencies are $150 \cdot l/L \cdot \sqrt{(\mu_R \cdot \varepsilon_R)}$ MHz, so for 100mm of trace on an inner layer of an FR4 PCB ($\varepsilon_R = 4.2$ above 1MHz, $\mu_R = 1$), the resonant frequencies would be 750, 1500, 2150MHz, etc.

The upper half of Figure 7 shows the concept graphically, for the situation in which the entire length of the conductor has the same Z_0 and the changed impedances at the ends are caused by the driver (source) and the load both being lower than Z_0.

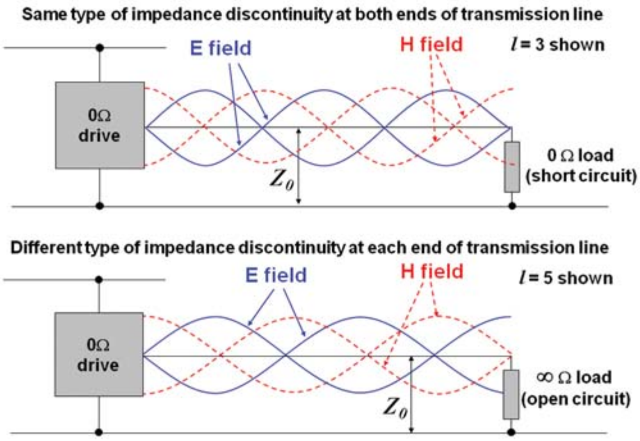


Figure 7

The astute reader will have recognised that I am simplifying things a little. For instance, the velocity of propagation in air or vacuum is not really $3 \cdot 10^8$ m/s, it is a little less, and the root of 4.2 is not 2, but my "roundings-off" are good enough, especially since in real life there are always added complexities which add to inaccuracies (e.g. conductors are not straight, and are affected by other conductors nearby).

Any EMC formulae that can be written down are going to be inaccurate in all but quite simple situations, and so should be treated as guidelines only in real product design.

When a length conductor has different opposing types of Z_0 changes at each end, standing wave resonances occur at the frequencies at which the conductor length is an odd number of quarter-wavelengths, as shown in the lower half of Figure 7. The resonant frequencies are given by $v \cdot m/4L$ where m is an odd numbered integer (1, 3, 5, 7, etc.) that describes the number of quarter-wavelengths in the standing wave.

For a conductor in air (or vacuum), this expression converts to $75 \cdot m/L$ MHz when L is given in metres. So a 1m long conductor in air would resonate at 75, 215, 375MHz, etc.

When the conductor is not in air (or vacuum) its resonant frequencies are $75 \cdot m/L \cdot \sqrt{(\mu_R \cdot \varepsilon_R)}$ MHz, so for 100mm of trace on an inner layer of an FR4 PCB, the resonant frequencies would be 375, 1125, 1725MHz, etc.

There is a complete formula for calculating a transmission line, called the "Telegrapher's Equation" because it was developed by people trying to send telegrams using codes rather like morse, over very long wires in the days of the Pony Express, and well before telephones and radio.

I am not providing all the equations in this article, as it would make it much too long and boring. Instead, I am trying to provide a conceptual understanding, to help designers visualise EM phenomena, and see how to use the various formulae or simulators in their work. The formulas are all available from textbooks like [2] [4] [5] and [6] and/or from the Internet (e.g. rfcafe, see [3]), where some on-line calculators may be available, for example from [7].

3.3 Full Wave analysis

When a conductor is > λ/6 in two or three dimensions, simple formulae are only practical for very simple situations like the flat plate and empty metal box shown later.

For any reasonable accuracy for real-life products and equipment, we must use 'full-wave analysis' based on simplifications of Maxwell's Equations. This is only practical by using computers to do the analysis, a technique that is called computer-based EMC simulation, or simply EMC simulation.

Figure 8 shows a simple metal plate in air, a conductor which is larger than λ/6 in just two dimensions. This presents a consistent (very low) impedance to propagating EMC waves, but at its edges it meets the air with its wave impedance of 377Ω. So it has the same kind of impedance change along all edges and experiences standing wave resonances when a whole number of half-wavelengths are fitted into its area.

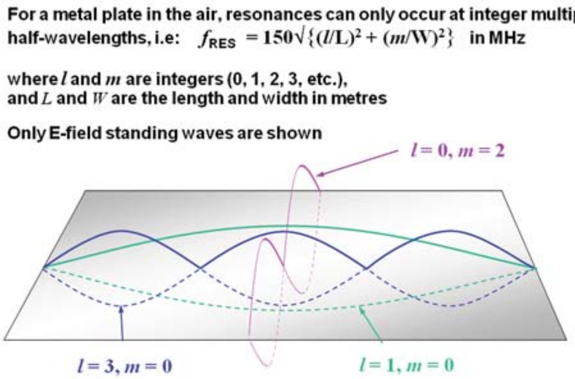


Figure 8 Standing waves caused by impedance discontinuities at edges of a metal plate

The simple expression for the resonant frequencies for this simple structure is $150\sqrt{\{(l/L)^2 + (m/W)^2\}}$ where: l and m are integers (0, 1, 2, 3, etc.) and L and W are the plate's length and width (if specified in metres, gives the resonant frequencies in MHz).

The first few, lowest-frequency resonances and the easiest to visualise can easily be found by setting l to 1, 2, and 3 whilst setting m to zero; repeating with m set to 1, 2, and 3 and l to zero. Figure 8 shows the $l = 3$, $m = 0$ mode.

If the metal plate was surrounded by a liquid or solid, its resonant frequencies would be given by $(v/2)\sqrt{\{(l/L)^2 + (m/W)^2\}}$, i.e. $(150/\sqrt{(\mu_R \cdot \varepsilon_R)})\sqrt{\{(l/L)^2 + (m/W)^2\}}$.

The three-dimensional situation is shown in Figure 9. This time it is the medium inside the empty box that is supporting the standing waves. The air has a wave impedance of 377Ω but the walls of the box have a very low characteristic impedance, so once again we have the same type of impedance change at both ends of a portion of the wave's propagation.

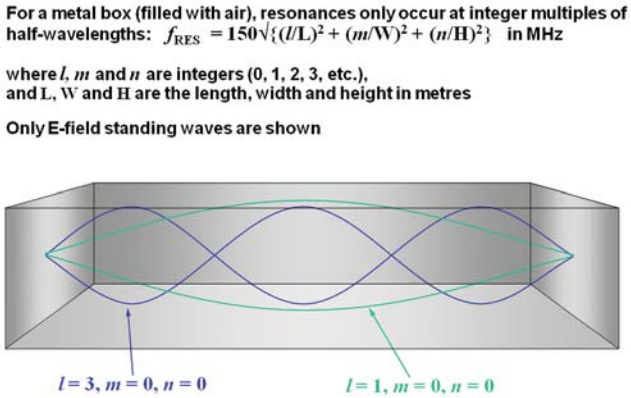


Figure 9 Standing waves caused by impedance discontinuities inside a metal box

Standing wave resonances can only occur at integer multiples of half-wavelengths, at $(v/2)\sqrt{\{(l/L)^2 + (m/W)^2 + (n/H)^2\}}$ MHz, i.e. $(150/\sqrt{(\mu_R \cdot \varepsilon_R)})\sqrt{\{(l/L)^2 + (m/W)^2 + (n/H)^2\}}$ MHz, where: l, m and n are integers (0, 1, 2, 3, etc.) and L, W, H are the box's length, width, height (in metres).

For a box filled with nothing but air, the expression simplifies to $150\sqrt{\{(l/L)^2 + (m/W)^2 + (n/H)^2\}}$ MHz. So an empty air-filled metal box 400 x 300 x 200 mm will have standing wave resonances at 375MHz (its 1,0,0 mode, when the standing wave exists along its length), 500MHz (its 0,1,0 mode, when the standing wave exists along its width) and 750MHz (its 0,0,1 mode, when the standing wave exists along its height).

Obviously, we could calculate the 5, 3, 7 mode (it is 5,773GHz) but we can't easily visualise it!

Figure 10 shows a computer simulation of the electric field distribution inside an empty shielded metal box, with some small apertures in its sides for ventilation. It was done using Microstripes, now part of Computer Simulation Technology Ltd's range of simulation products.

The simulator works its way through a range of frequencies, in three dimensions, and its result can be viewed as an animation. To see what is going on inside the box, it allows us to make a "slice" through the box, and Figure 10 is one frame from the animation, at one of the box's internal resonant frequencies – showing the standing waves in its 3,0,0 mode. Compare it with Figure 9's crude sketch of a box's 3,0,0 mode.

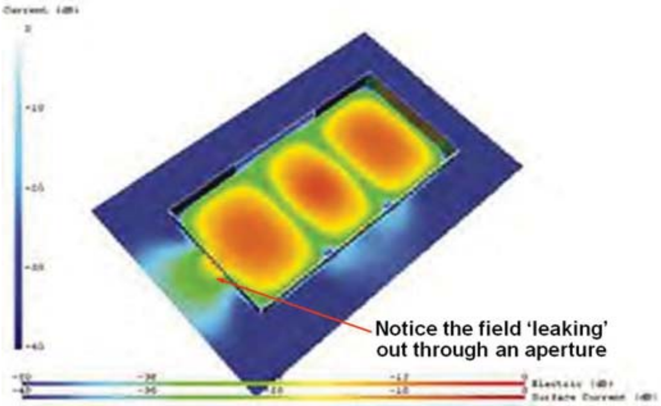


Figure 10 Simulation of the standing waves inside a metal box

11 References

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Part 2) Cables and connectors, May and July 2006
Part 3) Filtering and suppressing transients, Sept and Nov 2006, and Jan 2007
Part 4) Shielding (screening), March, May and July 2007
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Eur Ing Keith Armstrong CEng MIET MIEEE ACGI
phone/fax: +44 (0)1785 660 247
keith.armstrong@cherryclough.com
www.cherryclough.com

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