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Fixing EMC problems
by applying good EMC design techniques

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It is always very much better to design EMC in from the start of any new project. Not only does it achieve EMC compliance in the quickest time and with the least cost, it also improves signal integrity (SI) and power integrity (PI), reduces warranty costs, and reduces the time it takes to get to market (even when compared with the time it would normally take if EMC compliance was not done).

In other words: good EMC design techniques help achieve financial success, even when EMC compliance is not required.

However, good EMC design is not generally taught in University Degree, Masters, or Doctorate courses, so each year sees a new intake of design engineers ready to make the same very costly and time-consuming mistakes as their predecessors.

(In fact, some of the electronic design techniques that are taught, and/or the way the teaching is done, encourage bad EMC design practices!)

So we often, unfortunately, find ourselves having to fix EMC test failures in a hurry, and preferably without adding more manufacturing cost than is necessary.

Not very much has been written about how to quickly and cost-effectively fix EMC problems in practice, and I have generally found it much easier to show someone how I go about it, rather than write it down.

But after 23 years of solving EMC problems for over 500 customers from almost all application areas (following on from 20 years of solving “internal EMC” problems in new equipment designs) I feel that I have learnt enough to be able to write some useful things about this important topic.

This brief article is one of those useful things.

1 Applying good EMC design techniques

When trying to fix an EMC emissions problem with a product, system or installation that was not designed using good EMC techniques throughout, there are generally several design issues that need modification *all at the same time* before the EMC problem is solved.

Examples of good EMC design practices used when modifying a PCB, product, system or installation to pass EMC tests include:

- Creating (or improving) the RF Reference Plane
- Segregating circuits, wires and cables
- DC power supply decoupling
- AC or DC power supply filtering
- Signal filtering
- Signal shielding
- Partial or full enclosure shielding
- Galvanic isolation
- Transmission-Line design and matching
- Etc., etc.

For anything that has been designed for functionality but not for EMC, I generally find there are as many as ten, sometimes a dozen design techniques that need to be applied *simultaneously* to fix its EMC emissions and/or immunity problems.

This means that fixing EMC problems is not like normal fault-finding, in which we apply a modification that we expect to fix the fault, and if it doesn't we remove it and try something else.

Instead, we must keep on applying good EMC design techniques until the EMC performance is good enough, and only then go back and remove some of them to find out which ones are really necessary.

The two examples below are based on designs that did not take good EMC engineering practices into account at all during design, or else used EMC engineering techniques that are no longer appropriate for typical modern electronic products (e.g. cable shields terminated at one end only; single-point/star earthing/grounding schemes; too few PCB layers, etc.).

Generally, the more attention was paid to using good EMC techniques during the design process, the fewer modifications are needed to make it compliant, saving considerable amounts of time and money.

I can't emphasise enough the great importance of designing-in good EMC techniques from the start – especially because since 2000 *time-to-market* has been the main determinant of whether a new product is financially successful, not the BOM cost, see [8].

2 Simple example: several uncorrelated noise contributions

Because we measure EMC emissions in a logarithmic scale (i.e. in dB), we can solve one of the ten (say) EMC design problems and notice no benefit. We only start to notice benefits when we have solved 70% or more of them.

A simple numerical example should make this clear. Imagine – at a frequency of concern – we have 10 uncorrelated contributions to the measured emissions, all at about the same level. Totally eliminating any one of these contributions reduces the total emitted noise power to 90% of what it was at first, i.e. reduces the measured emissions by about 0.5dB.

Anyone who has tried modifying equipment to improve its EMC in an EMC test laboratory will know what removing the Equipment Under Test (EUT) from the test set-up, then putting it back *without making any changes to it at all* and remeasuring its emissions, can easily cause differences of more than ±1dB to occur seemingly at random across the frequency range.

Generally, these changes are caused by slight disturbances to the positions of the attached cables, but they can also be caused by variations in contact resistance and other variables. For some reason this variability seems to be worse when measuring emissions in a GTEM cell.

So if we modify the EUT by applying each good EMC design practice in turn, usually starting with the easiest or least costly, remeasuring the emissions each time in the hope that we have got the emissions down below the limit lines. But if we remove each modification when the measured result doesn't show that it gave a significant benefit – we will only ever see small fluctuations that could easily be caused by disturbing the cables – and we will go around and around in circles and never get anywhere!

This is what tends to happen when we apply normal fault-finding techniques to EMC fixing, and I'm certain that many readers are nodding their heads at this point, muttering "Been there, done that" to themselves.

Because we generally need to make several (perhaps as many as twelve) modifications *all at once* to fix the problem, the only approach that works is to apply each good EMC design practice in turn, *leaving that modification in place even if it made no benefit* and going on to the next modification until the emissions are reduced by enough.

We generally need to reduce emissions by 3dB to consider that we have made a difference that is larger than the natural variability between tests, and going back to our ten-equal-contributors example we can see that we need to have totally suppressed five of them, to achieve this.

Completing six of the ten (say) EMC design improvements would win about a 4dB reduction in emissions overall, completing seven would win about 5dB, eight about 7dB, and completing nine of the ten would win about 20dB – which is often sufficient. Figure 1 tries to show this graphically.

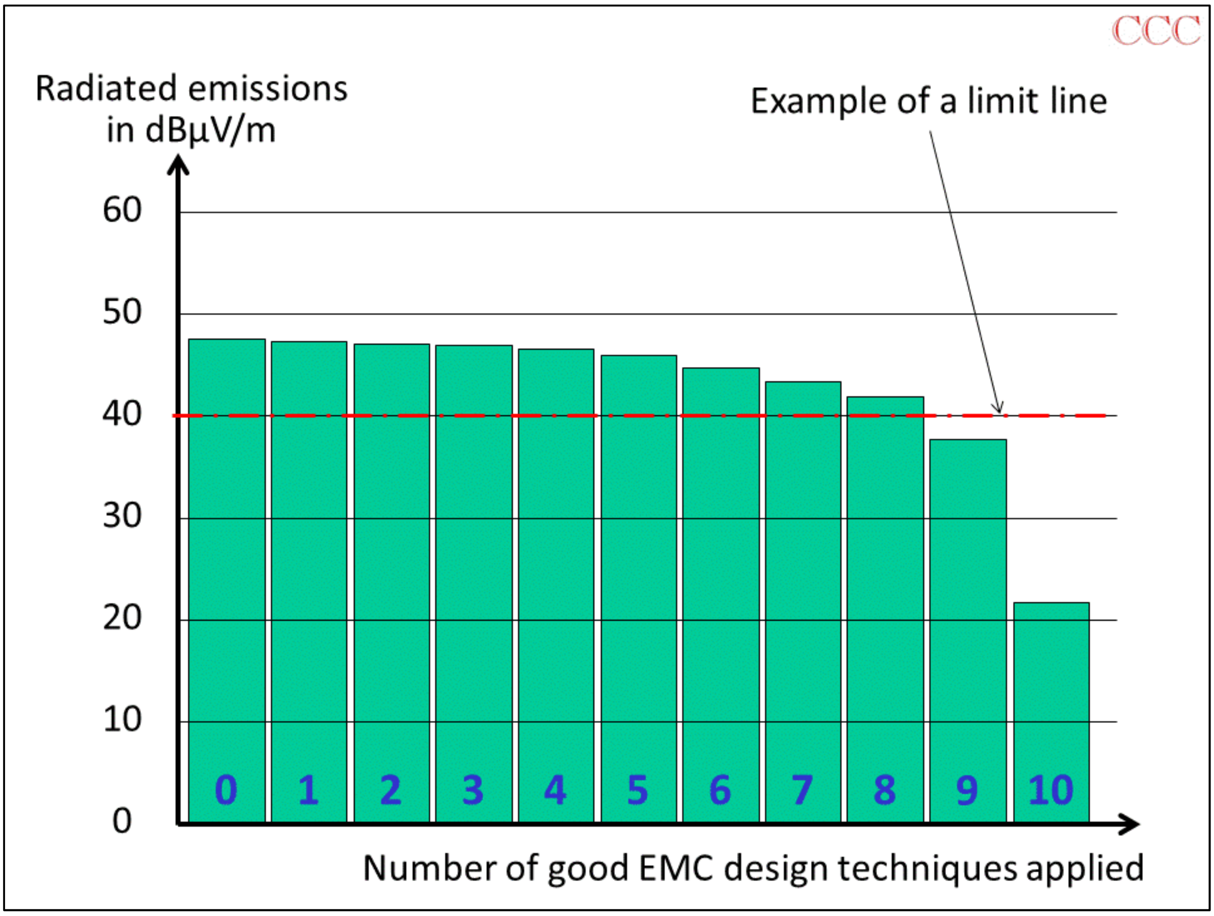


Figure 1 Example of ten types of uncorrelated emissions to fix

Of course, noise suppression is never perfect, so we generally find that we have to apply every one of the ten (say) EMC design issues. If we don't achieve sufficient suppression for any/all of them, we have to go back around and improve them all in turn until we do achieve an overall emissions result that is comfortably under the limit line. (Most experts recommend at least 6dB under, to cope with variability in series manufacturing, and I know some companies who go for 10dB under).

Only when the emissions have been reduced to acceptable levels do we try to reduce the costs of making the changes in serial manufacture, by going back and removing modifications that seemed to have no effect when they were applied. It is often found that they are all necessary, but sometimes it is found that one or two of the ten (say) modifications that were done were not as essential as the others, and their cost can be saved.

The above example is an oversimplification, intended to show how the natural variability inherent in EMC testing, plus measuring in dB units, obscures the fact that a real source of emissions has been suppressed.

In this simplified example, the good EMC design practice modifications all have equal importance, but in real life there is usually one design modification that is essential, and without which the others won't work at all. (This is usually the creation of a good RF Reference Plane or enclosure shield.)

3 Example with correlated noise contributions

Also, many real-life situations don't behave like the above example because some of the contributions to the overall emissions are correlated with each other, which means that phase cancellation will occur between them in the measuring antenna.

In practice, this means that as we apply the ten (say) EMC design improvements that will be needed, one at a time, *emissions can actually increase* as phase cancellation is reduced.

Even though a modification may have caused emissions to increase, just as in the simplified example above *we never remove a modification that follows good EMC design practices until after we have got the emissions adequately below the limit line*.

This interesting effect occurs because there is a source of emissions, such as a microprocessor's internal clock, that is "leaking" emissions to the measuring antenna via two or more different coupling paths. The source is the same for these "leakage" paths, and so they are correlated.

Some clock noise is being conducted along DC power busses, some along some signal traces as digital transitions (and some along all signal traces as ground-bounce common-mode noise), some clock noise might be coupled directly into the metal enclosure due to stray capacitance between the microprocessor and the enclosure causing a stray current to flow in the metalwork, etc.

When a measuring antenna picks up the clock noise emissions, at each frequency (fundamental plus harmonics) the measured emissions is the sum of the emissions that all started out at the same small area of the microprocessor, but which have all travelled to the antenna by different paths.

Some will have radiated from external power and signal cables, having previously travelled along different lengths of PCB traces and cables all having propagation velocities slower than free space (due to the dielectric constants of their insulators). And some of the cables will be further away from the measuring antenna than others.

Some will have been radiated from slots and joints in the metal enclosure as the stray surface currents induced by the microprocessor flows around them.

The result is that each different coupled noise, from the same source (the microprocessor clock) will arrive at the measuring antenna with different delays, which means their phase angles will all be different from each other, and some phase cancellation will occur in the antenna as a result.

When this happens, as it does quite often, suppressing one of the paths from the noise source – for example by improving the filtering of the power cable – can cause the overall, measured emissions to rise!

Things get really interesting when the phase angle is 180° – anti-phase. Significant cancellation will occur if the two emissions from the same source have similar levels. At 300MHz, for example, a 180° phase shift can is created by a 500mm path length difference in air, or a 300-400mm path length difference in a cable, and such dimensions are typical of test set-ups.

If we go around improving each aspect of the EMC design in turn, but removing any modifications that appear to have no effect, or are seen to cause an increase in emissions, we will just go around and around in circles and never get the EUT compliant.

We must understand what good EMC design practices are, apply them as modifications one at a time until the emissions are adequately below the limit line. If any good EMC design modification increases the total emissions, we *leave it in place*.

We can use close-field probing techniques (see Parts 1 and 2 of [1]) to see if we have successfully suppressed one of the paths by which noise couples to the measuring antenna, but there can be so many noise sources and coupling paths that this method might not be as useful as it often can be.

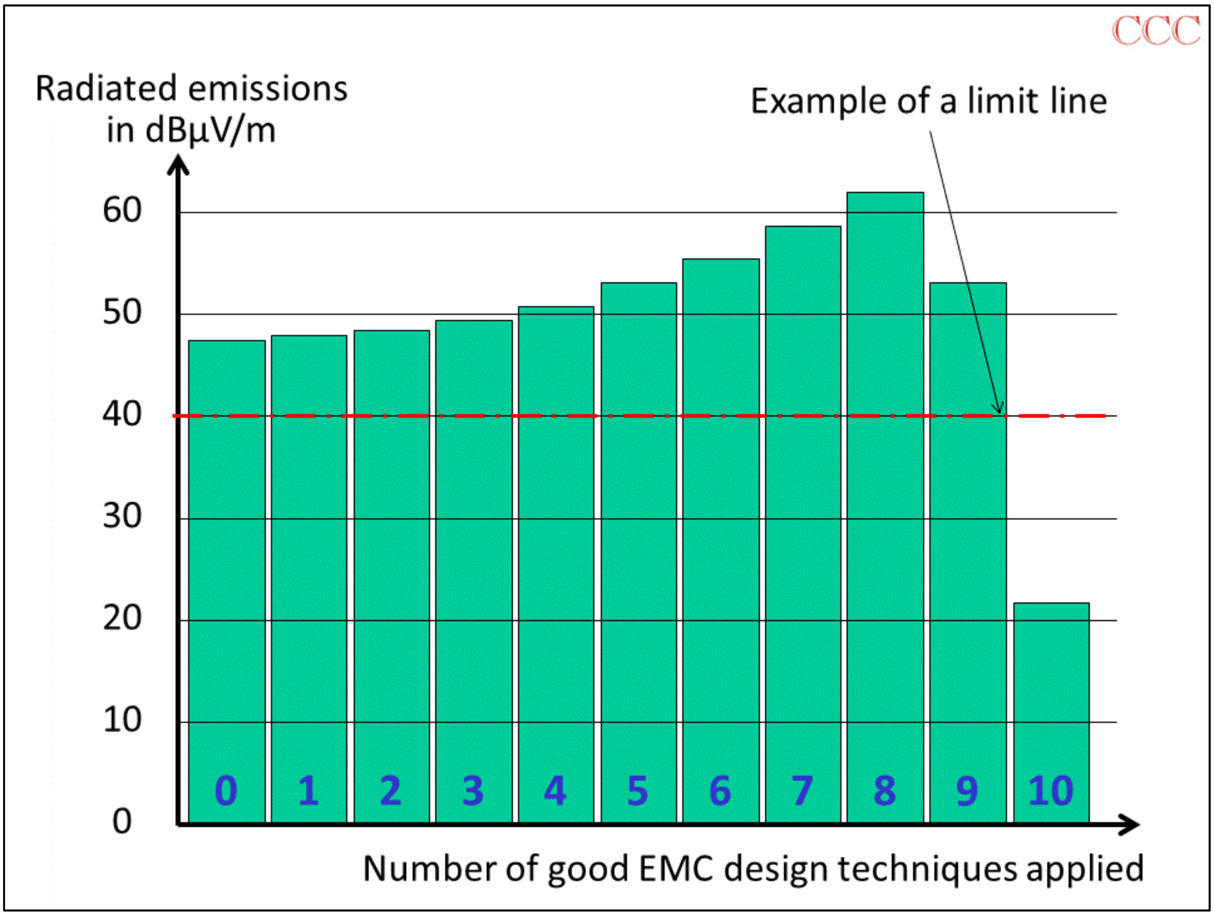
We just have to have faith in our ability to implement modifications that follow good EMC engineering practices and principles, although it has to be said that some original designs do not make it easy to modify them accordingly. It is usually much easier to modify a design that has taken account of what good EMC modifications might be needed to pass EMC tests!

Eventually we get to the point where, with the last one or two EMC design improvements to be made, each additional EMC design improvement reduces the overall emissions that are measured. I have often seen RF emissions increase with each modification right up until the very last one!

When customers were present during these times they generally became more upset because all they could see was that I was making emissions worse with every (costly) modification I applied.

But when the very last modification had reduced the emissions to below the desired level, I could show the customers that removing any of the good-EMC-design modifications that I made – which had made the emissions worse when I had applied them – *now made emissions worse again*.

Figure 1 shows an example of this phase cancelling effect, when all ten contributions to the emissions at a given frequency are correlated (the opposite of Figure 1, in which all ten contributions were



assumed to be uncorrelated).

Figure 2 Example of ten types of correlated, phase-cancelling emissions to fix

As before, only when the emissions have been reduced to acceptable levels do we try to reduce the costs of making the changes in serial manufacture, by going back and removing modifications that seemed to have no effect – or made emission worse – when they were applied.

Good EMC design techniques are described in practical detail in [2] [3] and [4], also, for systems and installations, in [5] [6] and [7].

It is important to understand that the huge benefits of the above approach in saving time and cost requires using good EMC design principles and practices. It is not at all effective when trying modifications at random, or using “fixes” that are not based on good EMC design practices and principles.

For example, sometimes it is possible to make a change that is actually a bad EMC practice (such as disconnecting one end of a cable shield) and find that it fixes a problem emission frequency. What is actually happening is that additional emissions are being created that, with this exact test set-up, happen to phase-cancel the problem emissions. However, it is almost always the case that in a different (but equally valid) test set-up, for example using different cable types, lengths or layouts, this lucky phase cancellation will not work as well, and may even make emissions worse. Real-life installations are unlike any EMC test set-ups, and so lucky phase cancellation techniques that use bad EMC design practices to pass EMC tests usually increase the likelihood of causing/suffering significant interference in real life, annoying customers (reducing future sales potential) and increasing warranty costs.

4 Conclusions

EMC problems can be fixed quickly and cost-effectively by modifying the EMC-failed design by applying as many good EMC design techniques as it takes.

Sometimes as many as ten, and possibly more, good EMC design techniques have to be applied before the EMC tests are passed, and the EMC test failure might even get worse until all of the necessary design improvements have been made.

The above discussions have tended to focus on fixing radiated emission problems, but exactly the same approaches apply for conducted emissions, and radiated and conducted immunity problems.

5 References

[1] "EMC testing", By Tim Williams and Keith Armstrong, published as a series in the EMC Compliance Journal during 2001/2002, available from the archives at www.theemcjournal.com

[2] "EMC Design Techniques for Electronic Engineers", Keith Armstrong, Armstrong/Nutwood UK Nov. 2010, ISBN: 978-0-9555118-4-4, from www.emcacademy.org/books.asp.

[3] "EMC for Printed Circuit Boards – Basic and advanced design and layout techniques", Keith Armstrong, Nutwood UK 2010, ISBN: 978-0-9555118-5-1, www.emcacademy.org/books.asp. Note: this is the same text as the 2007 edition (ISBN: 978-0-9555118-0-6 or 978-0-9555118-1-3) repackaged in a different format.

[4] "EMC for Product Designers, Fourth Edition", Tim Williams, Newnes 2007, ISBN 0-7506-8710-5, available from www.newnespress.com, various electronic component distributors and www.emcacademy.org/books.asp

[5] "Good EMC engineering practices in the design and construction of industrial cabinets", Keith Armstrong, published by REO (UK) Ltd, free download from: www.reo.co.uk/knowledgebase. (Applicable to any metal box that contains two or more electronic units interconnected by wires or cables, not just industrial cabinets, but also, for example: some domestic appliances; some IT and telecomm's equipment; and most road, rail, aerospace and marine vehicles.)

[6] "Good EMC engineering practices in the design and construction of fixed installation", Keith Armstrong, published by REO (UK) Ltd, free download from: www.reo.co.uk/knowledgebase

[7] "EMC for Systems and Installations", Tim Williams and Keith Armstrong, Newnes 2000, ISBN: 0-7506-4167-3, www.bh.com/newnes, RS Components part number: 377-6463

[8] "The Consumer Electronics Boom — How Semiconductor and Consumer Electronics Companies Can Improve Cost, Time-to-Market, and Product Quality", by KPMG LLP's Information, Communication and Entertainment (ICE) Practice, 2008, www.kpmg.de/docs/20080701_The_Consumer_Electronics_Boom.pdf

Important: [2] and [3] are not available (as new copies) from Amazon or other resellers, who often incorrectly list them as being out of print. They are only available from www.emcacademy.org/books.asp, where they are printed on demand.