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EMC Testing

Conducted and Radiated tests from Maxwell's equations perspective

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Abstract

CISPR standards require testing each product from a conducted and radiated fields perspective. CISPR 11 and CISPR 32 require testing the conducted noise from 150KHz up to 30MHz. CISPR 25, addressing automotive products, requires testing the systems up to 108MHz. To complicate the understanding the MIL standards require testing the conducted noise up to 400MHz. Thus the question of what makes a noise conducted or radiated is legitimized. Things can get clarified if the Maxwell's equations are taken into account to better analyze the effects of the conducted and radiated noise and from where they come from.

The high level picture

If you check what conducted noise is, the answer gets close to:

Conducted noise is related to AC current that moves charges, and is in the bandwidth of interest.

We have seen that CISPR standards have different bandwidth of interest, thus the definition may not be that clear. On the other hand the "noise" is what can be identified as not being a signal, thus the noise is the energy that we do not want to be there. If this energy moves electrons or electrical charges in the bandwidth of interest, it is defined as conducted noise. Linking moving charges with conducted noise is a good high level understanding, but we need to be careful since the electric field that can move charges, and the magnetic field are connected together. The magnetic field can also move charges but only orthogonality to the direction they are already moving on. If the charges are not moving, the magnetic field cannot make them move (Lorenz force), while the electric field can let them move even if the starting condition has the speed equal to 0m/s.
The Maxwell's equations show that the electric field and the magnetic field are two manifestations of the same force, the electromagnetic force.

The radiated noise is what CISPR standards also ask tests for. The high level definition could be:

The radiated noise is what we capture with an antenna, so it is an electromagnetic wave that gets radiated from the system under test.

This noise has a different band of interest and typically starts after the conducted noise bandwidth and gets up to 1000MHz. If the system has any internal clock with a frequency higher than 108MHz, the bandwidth is extended up to 2000MHz. Farther extensions may be required if the system is operating at higher frequency.
The high level understanding, that can be used for the radiated noise, is that the energy does not move electrical charges. This means that the electromagnetic field can propagate in free space.

We have now a good separation between conducted and radiated noise, but if an electromagnetic field that got propagated in the free space, couples with a PCB trace, it will transfer part of its energy and what we have thought to be a radiated noise will be a conducted noise. To complicate the scenario, the opposite scenario is also valid, thus the conducted noise also generates radiated energy. Things are not that easy and to complicate the scenario farther, the noise can couple back and forth within the system due to the radiated and conducted noise.

Maxwell's equations

Maxwell had the nice idea to summarize all the equations that were describing the electric field E and the magnetic field B and were known during his time (1831-1879). The Electric and Magnetic fields were indeed studied as two different phenomena, while Maxwell realized that there was something more behind. Indeed the Faraday, Neumann Lenz equation, created the first link between the E and B fields that made Maxwell think that something more was hidden behind the E and B equations.

By merging all the equations it came out that the E and B fields were really deeply linked and they were the manifestation of the same force that would have been named the electromagnetic force.

The integral form of the Maxwell's equations are:

I) $\oint_s \vec{\boldsymbol{E}} \cdot u_n \boldsymbol{ds} = \frac{q}{\varepsilon_0}$ Gauss equation for the Electric field

II) $\oint_s \vec{\boldsymbol{B}} \cdot u_n \boldsymbol{ds} = 0$ Gauss equation for the Magnetic field

III) $\oint_s \vec{\boldsymbol{E}}\, \boldsymbol{ds} = -\frac{d\Phi(\vec{B})}{dt}$ Faraday Neumann Lenz equation

IV) $\oint_s \vec{\boldsymbol{B}}\, \boldsymbol{ds} = \mu_0 I + \mu_0 \varepsilon_0 \frac{d\Phi(\vec{E})}{dt}$ Ampere law with Maxwell correction

E and B fields are linked together via equations III and IV. In particular the link is made by variations of the fields or better variation of the flux related to the fields E and B. If the E and B field would be static, there would be no link between the E and B fields, unless you change the integration area over time. This is the reason why it is always better to speak of variation of the flux and not variation of the field.

This was also the reason why at the beginning, since the scientists were able to generate only static fields, they were studying E and B separately.

The electric field E can move charges, thus is the field behind the conducted noise. Nevertheless, a *non conservative* E field is also generated via equation III, thus the variation of the magnetic field's flux can generate a current.

In case there is no charge, we have the free space conditions that describe the electromagnetic field (radiated field). The energy is embedded in the field and not in the moving charges. Today we know that the energy is transferred via the photons. The

Maxwell's equations are modified as follow:

I[i]) $\oint_s \vec{\boldsymbol{E}} \cdot u_n \boldsymbol{ds} = 0$ Gauss equation for the Electric field

II[i]) $\oint_s \vec{\boldsymbol{B}} \cdot u_n \boldsymbol{ds} = 0$ Gauss equation for the Magnetic field

III[i]) $\oint_s \vec{\boldsymbol{E}} \boldsymbol{ds} = -\frac{d\Phi(\vec{B})}{dt}$ Faraday Neumann Lenz equation

IV[i]) $\oint_s \vec{\boldsymbol{B}} \boldsymbol{ds} = \mu_0 \varepsilon_0 \frac{d\Phi(\vec{E})}{dt}$ Ampere law with Maxwell correction

The new set of equations highlight the fact that the radiated field, which we call electromagnetic field, is clearly the link made by variation of E and variation of B, or better the flux of the fields over the time. But this link is the same of the first set of equations, that describe the case with moving charges (conducted noise). This means that actually the conducted noise includes both effects, the one we can see with the radiated field and the one with the moving charges.

The conducted tests, somehow may actually bring more information which are lost in the radiated field. But moving charges, if accelerated, create a radiating field, thus conducted noise can actually carry radiated field information as well if carefully interpreted. In particular many radiated problems may actually come from conducted noise that is not filtered out and gets propagated via the system power cord and radiates energy. Considering that a few meters cable can easily resonate in the range of 30-100MHz range, conducted noise in that frequency range will radiate part of its energy.

In particular the most problematic noise is the common mode part, since the magnetic field generated along the cable is summing up, while the differential portion of the conducted noise generates a field on the power lines that cancel out.

Thus, do not underestimate the info that conducted tests may carry and do not believe that only radiated tests, since they are more expensive to execute, will give you the right picture. To be sure whether or not your system will be CISPR compliant, both types of tests must be carried out. Since the conducted noise test is easier and cheaper than radiated tests, it is better to start with that. Indeed conducted tests can already show system weakness that will be reflected in bad radiated tests as well. Moreover the bandwidth of interest is different, thus passing one set of tests does not mean that you automatically pass the other.

Conclusions

The article has introduced the conducted and radiated tests from both the CISPR regulations perspective and from Maxwell's equations perspective. The introduction of the Maxwell's equations perspective allowed us to highlight the link between what we call conducted noise and what we call radiated noise. In particular the noise can get converted from one type to the other and vice versa. While the conducted tests and radiated tests typically cover different frequency bandwidth, with small overlapping, you should always try to get the best out of both, since the noise of one type influences the other.

Bibliography

[1] www.LaurTec.it: official site where you can download the "EMC Testing" series.

History

Date	Version	Author	Revision	Description
29. Nov. 2020	1.2	Mauro Laurenti	Mauro Laurenti	Minor reformatting and typos corrections.
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