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A simple method for estimating radiated emissions

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A simple method for estimating radiated emissions

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I recently received the following question:

How to calculate the radiated E field with following test conditions with an antenna placed 1 meter away from the test setup?:

1. A commercial equipment under test with metal housing
2. Equipment placed on the grounded metallic table/plane
3. LISN installed (and also placed on mentioned metallic ground plane)
4. Cable length between LISN and equipment under test = 1.5 m (so length > lambda/4 i.e. 1.5 m > 1 meter so cable is electrically long)
5. Cable height above ground plane = 5 cm
6. Frequency of interest/measurement = 75 MHz

What will be the equation to find the radiated E field with high degree of confidence?

My reply is copied below:

Assuming we are testing a mains cable with live & neutral power conductors (plus, perhaps, a safety earth wire) all very close to each other inside the cable's jacket: then below about 300MHz its CM currents can be assumed to make a much larger contributor to its radiated emissions than its DM currents, see [1]. Also from [1], the maximum CM emissions from an electrically-short straight monopole (the 'accidental antenna structure' of the mains cable as described above) are given by:

$$E_{\text{CMmax}} = 6.283 \times 10^{-7} \, (f \times L \times I_{CMprobe})/R \quad \text{Volts/metre} \qquad (1)$$

Where:

f = frequency — in Hz

L = length of mains cable — in metres

$I_{CMprobe}$ = total CM current, for example as measured by an RF current probe on the entire straight conductor, in Amps rms

R = antenna distance — in metres, perpendicular to the route of the mains cable

> ***Note 1:*** a LISN measures the noise currents in each L, N, or E mains wire *individually*, and the CM currents are assumed to divide up equally amongst the number of wires in a bundle, so for an N-wire power cable the overall CM current, $I_{CMprobe}$ is N times the CM current measured by the LISN on an individual wire. E.g. for a three-wire mains cable (say, L, N, E) $I_{CMprobe}$ is $3 \times I_{CMLISN}$.

Because in the situation described above, the ground plane is so very close to the mains cable, the reflection at 75MHz from the ground plane will add almost exactly in-phase to the direct emissions, doubling them. This gives us:

$$E_{\text{CMmax}} = 2 \times 6.283 \times 10^{-7} \, (f \times L \times I_{CMprobe})/R \quad \text{Volts/metre} \qquad (2)$$

A monopole antenna creates its maximum emissions when it is $\lambda/4$ long, and 1.5 metre long straight monopole antenna structure has its first $\lambda/4$ resonance at 50MHz.

Substituting f = 50MHz, L = 1.5m and R = 1.0m in (3) gives:

$$E_{\text{CMmax}} = 2 \times 6.283 \times 10^{-7} \, (50 \times 10^{6} \times 1.5 \times I_{CMprobe}) \ \text{Volts/metre}$$
$$= 94.245 \times I_{CMprobe} \quad \text{Volts/metre}$$

E.g. an RF current probe measurement of 2µA rms CM current at 50MHz on that straight mains cable would cause a maximum field strength of 188.5µV/m, i.e. 45.5 dBµV/m, at the measuring antenna as described in the original question.

The above discussion is based on the simple equations in [1] that assume 'electrically-short' accidental antenna structures. At frequencies for which a straight conductor (which might be a close bundle of several conductors all sharing the overall CM current) is exactly $\lambda/4$ long, CM emissions are maximised, but as the conductor's length increases beyond $\lambda/4$ emissions decrease until they reach a minimum at $\lambda/2$, then as the length continues to increase they increase again to the same maximum as $\lambda/4$ but at $3\lambda/4$, and then they decrease again until they reach a minimum again at λ, and so on for ever (well, almost).

The simple equations (1) and (2) can't tell us what the emissions are in general for straight conductors longer than $\lambda/4$, but we <u>can</u> say:

i) For frequencies for which a straight conductor is exactly $N\lambda/2$ long – where N is an integer (1, 2, 3, etc.) – the CM emission levels are *minimised*, approaching zero in the idealised case.

   But please note that for N=2 and higher – these 'nulls' will only occur at certain distances/angles from the straight conductor. In other words, the emissions patterns for various values of N will not be uniform (isotropic, omnidirectional), instead they will exhibit different 'lobing' behaviours depending on the value of N.

ii) For frequencies for which a straight conductor is exactly $M\lambda/4$ long – where M is an odd-numbered integer (1, 3, 5, 7, etc.) – the CM emission levels are *maximised* and are always the same amplitude as for $\lambda/4$, i.e. when M = 1.

   But please note that for M=3 and higher – the maximum emissions will only occur at certain distances/angles from the straight conductor. The emissions pattern will not be uniform (isotropic, omnidirectional), instead they will exhibit different 'lobing' behaviours depending on the value of M, that will also be different from the patterns for the 'nulls' above.

Now, the question asked about 75MHz, but because at this frequency the actual 1.5m mains cable is *longer* than $\lambda/4$, the simple equations used above cannot be accurate. However, because 75MHz lies below the $\lambda/2$ resonance of a 1.5m monopole ($\lambda/2$ at 100MHz), we can expect its E-field emissions to be somewhat lower than those for the mains cable at its $\lambda/4$ resonance of 50MHz.

These days, there are several low-cost 3-D field solvers that should provide more accurate estimates, for any frequency, and even for any shape of cable and location of measuring point. However, something as simple as misplaced decimal point when filling in a computer form, can give wildly inaccurate results that people often believe simply because they came out of the computer. So – when using any computer calculation/simulation techniques – it is always important to have first performed a crude estimate (such as the above) to "sanity check" the computer's results.

Uncertainties:

Obviously, there are a number of assumptions made in applying the simple equation in (1) for an idealised straight monopole antenna to the real-life 'accidental antenna' behaviour of a mains cable between an item of equipment and a LISN.

However, when we measure the *actual* CM current on the mains cable with a suitable RF Current Monitor Probe, of the sort that can be purchased (for example) from https://www.fischercc.com/product/current-monitor-probes/ – taking their calibration factors into account – or home-made and self-calibrated as described in slides 18.4.2 – 18.4.5

of the training course available from: https://www.emcstandards.co.uk/cost-effective-uses-of-close-field-probing1.

Actually measuring the real-life cable's CM RF currents with an RF Current Monitor Probe (and correcting for the probes' calibration factors) takes many of the uncertainties into account, and in this case I would expect the result measured by the antenna to be within ±6dB of the value calculated by (1) above for 50MHz. But no guarantees!

Please note that current monitor probes with lower insertion impedances are preferred because adding them to a circuit has less effect on the RF behaviour of that circuit. But there may need to be a trade-off, because lower-impedance probes are less sensitive so – if the levels of radiated emissions that need to be met are low – they may need to be used with spectrum analysers that have lower noise floors.

Applying this simple guidance to different situations:

Where there is a groundplane very close (i.e. < λ/30) to the cable concerned, or where measurements are made with the item under test spaced λ/10 or more above a large metal groundplane with the measuring antenna in the far field and using height-scanning to maximise the measured emissions (e.g. as in the Open Area Test Site method used by CISPR 22), use equation (2).

Where there is no groundplane *and* measurements are made in an anechoic environment, use equation (1).

When other cables are present, their emissions will reach the measuring antenna by different path lengths. If the noise source that is causing the problematic emissions from the mains cable, is also emitting significant emissions from one or more of those other cables, then the two or more identical types of emissions will combine in the measuring antenna – adding together according to the different phase angles caused by their different path lengths.

They might add substantially in-phase, causing the overall measured emissions to increase, or they might add substantially out-of-phase causing the overall measured emissions to fall – even vanishing altogether if they are exactly out of phase.

This is why in general (unless we have good reason to) we never rely on a single measuring orientation, angle, or height.

Where the measurement is made over normal pavements or soils *without* a metal groundplane, the reflectivity of the 'ground' surfaces can vary widely – even day by day depending on rainfall and humidity. Even with height-scanning, errors of 9dB from one day to the next have been observed in practice. So, use a metal groundplane if measuring outside of a chamber, even if it is just a simple roll of wire-mesh of the sort used to make chicken cages.

Reference:

[1] Clayton A. Paul. Introduction to Electromagnetic Compatibility, Second Edition, Wiley, 2006, ISBN-13: 978-0-471-755500-5, ISBN-10: 0-471-75500-1. See particularly section 8.1.3 on pages 514-518, and equations (8.16a) and (8.16b).

I also recommend:

https://www.emcstandards.co.uk/close-field-testing-for-every-project-stage
https://www.emcstandards.co.uk/diy-emc-testing-series-2001
https://www.emcstandards.co.uk/estimating-the-overall-emissions-of-combined-it
https://www.emcstandards.co.uk/emc-testing
https://www.emcstandards.co.uk/complying-with-the-emc-directive1
https://www.emcstandards.co.uk/additional-resources