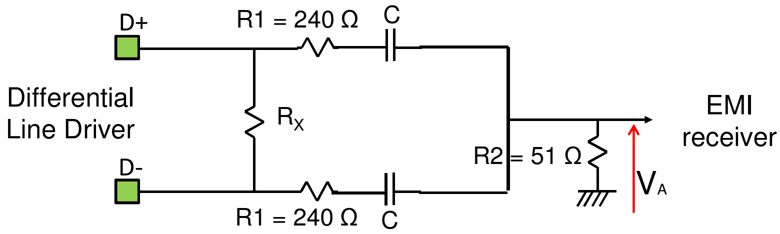
# BASIS OF ELECTROMAGNETIC COMPATIBILITY OF INTEGRATED CIRCUIT

## Chapter VIII - Standard measurement methods for IC emission

## Corrections of exercises

## I. EXERCISE NO 1 - Measuring conducted emission from a differential bus driver

The following diagram describes a 150 Ω matching network or probe for characterizing the conducted emission from a differential line driver (CAN bus, Ethernet, LVDS). A 50 Ω EMI receiver is placed at the output of the probe to measure the voltage $V_A$ induced by the driver switching.




1. What is the purpose of Rx? How is its value chosen?

2. If the driver is perfectly balanced, what should be the voltage $V_A$ measured at the output of the matching network? Is the probe dedicated to common or differential-mode emission?

3. What is the attenuation of the 150 Ω probe?

4. Select a value for the capacitor C to ensure a 3-dB cut-off frequency equal to 1 MHz.

5. With IC-EMC, simulate the transfer function of the matching network. Verify the answers to questions 3 and 4.

6. Let us consider a LVDS (Low Voltage Differential Signalling, TIA/EIA-644) driver. The usual termination resistance of this differential link is 100 Ω. In order to simulate the differential driver, it is modeled as two ideal and complementary square voltage sources which drive pins D+ and D-, i.e. the logical states of D+ and D- are always opposite and change simultaneously. The characteristics of both voltage sources are:

- offset voltage = 1.2 V

- amplitude = 350 mV
- signal period = 5 ns
- rise/fall time = 500 ps

Build an equivalent model of the LVDS driver terminated by the 150 Ω probe and simulate the voltage $V_A$ when the bus driver is perfectly balanced. Same question when rise and fall times are slightly different (e.g. 550 and 450 ps).

7. The tolerance on resistance R1 is now taken into account, and is considered to be 5 %. In the case of a perfectly balanced LVDS driver, what is the impact of the variability of R1 value on the voltage $V_A$?

8. Propose routing constraints to implement this matching network on a PCB.

**<u>Corrections:</u>**

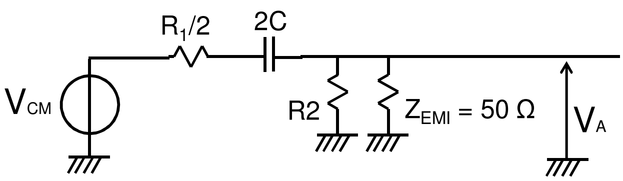
1. Rx ensures the bus termination for impedance matching purpose. It is chosen according to the bus specifications. If the bus has a differential impedance of 100 Ω, Rx must be set to 100 Ω.

2. The voltage $V_A$ is proportional to the common-mode voltage produced by the differential driver. If the driver is perfectly balanced, it does not produce any common-mode voltage, only differential-mode voltage. If the matching network is perfectly symetrical, no differential-mode voltage is converted into common-mode voltage. Thus, the voltage $V_A$ cancels in this condition.

This probe is dedicated to the measurement of common-mode emission of bus driver, which is a more important issue than differential-mode emission as explained in chapter IV.

3. Refer to part 2.3 and equation 8.2: the attenuation of the probe is frequency dependent. It acts as a high-pass filter. Above the cut-off frequency, its attenuation is about 15 dB.

4. The following picture presents the equivalent electrical schematic when the matching network is excited by a common-mode voltage. Rx disappears as it is shorted in common-mode excitation.




According to equation 8-2, the relation between the output voltage $V_A$ and the common-mode voltage excitation $V_{CM}$ is given by:

$$\frac{V_A}{V_{CM}} = \frac{jR_{out}2C\omega}{1+j\left(\frac{R_1}{2}+R_{out}\right)2C\omega}$$

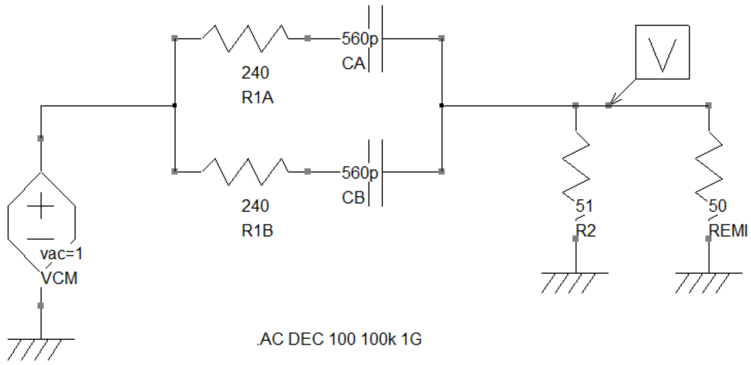
with $R_{out} = \frac{R_2 Z_{emi}}{R_2 + Z_{emi}}$ where $Z_{EMI}$ is the EMI receiver input impedance.

The cut-off frequency $f_0$ of the matching network is given by:

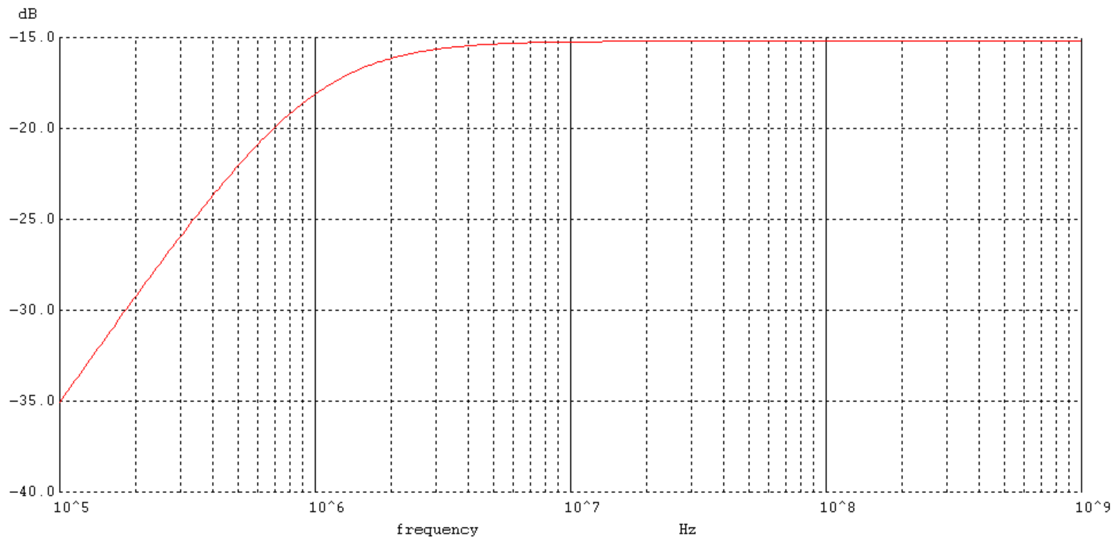
$$f_0 = \frac{1}{2\pi\left(\frac{R_1}{2} + R_{out}\right)2C}$$

To set the cut-off frequency to 1 MHz, the capacitance C must be equal to 549 pF, i.e. 560 pF if a normalized capacitance value is chosen.

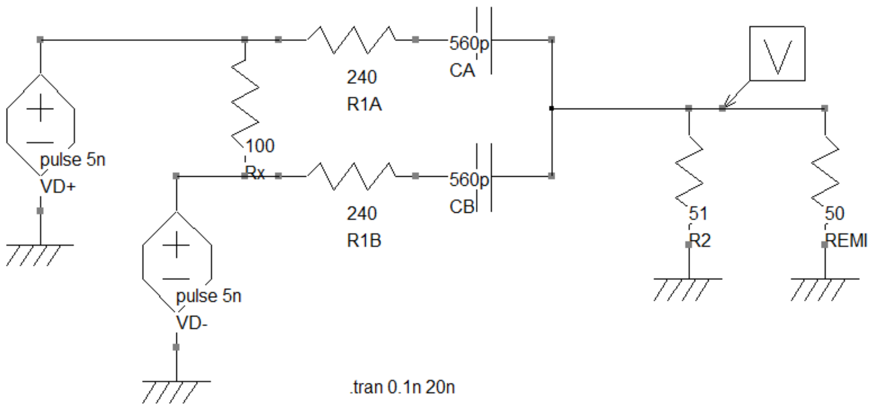
5. The schematic diagram of the 150 Ω probe is shown below and is given in the file TransferFunction_150ohm_Probe.sch. A voltage source VCM is connected at its input. The EMI receiver is modeled as a 50 Ω resistor $R_{EMI}$. A voltage probe is placed at the output to plot the voltage captured by the EMI receiver.



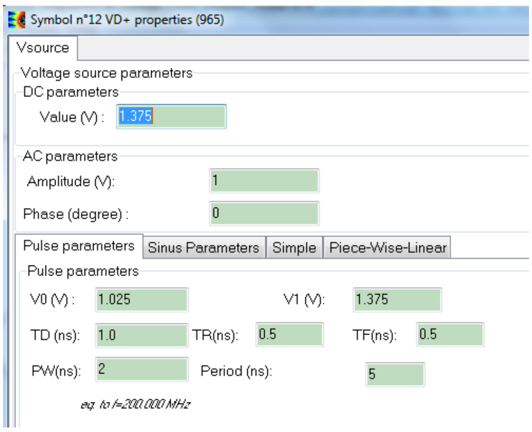

An AC simulation is configured.The AC voltage source amplitude is set to 1 V. The voltage across $R_{EMI}$ gives directly the amplitude of the transfer function of the matching network. The simulation result is shown below. The attenuation is nearly constant above several MHz, where it reaches -15.2 dB. The 3 dB cut-off frequency is nearly equal to 1 MHz.

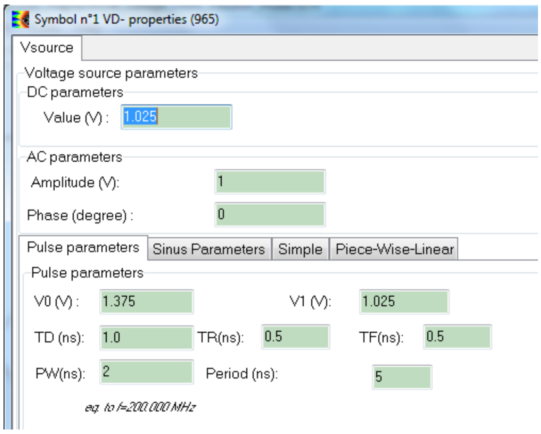



6. The schematic diagram of the 150 Ω probe is shown below and is given in the file CM_voltage_LVDS_150ohm_Probe.sch. The LVDS driver is modeled by two voltage generators that operated in phase opposition. The bus termination resistor Rx is added and set to 100 Ω.



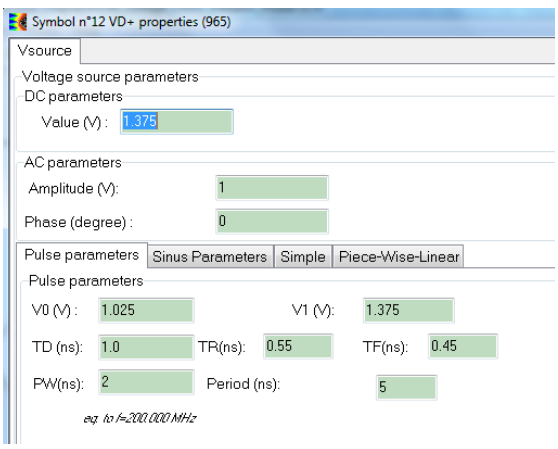

Configurations of voltage sources VD+ and VD- when the driver is perfectly balanced:

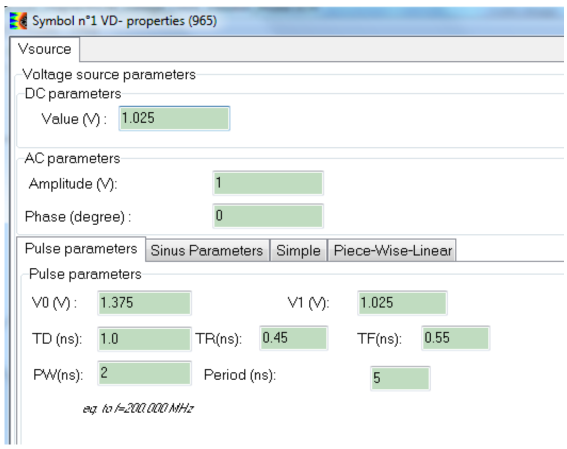


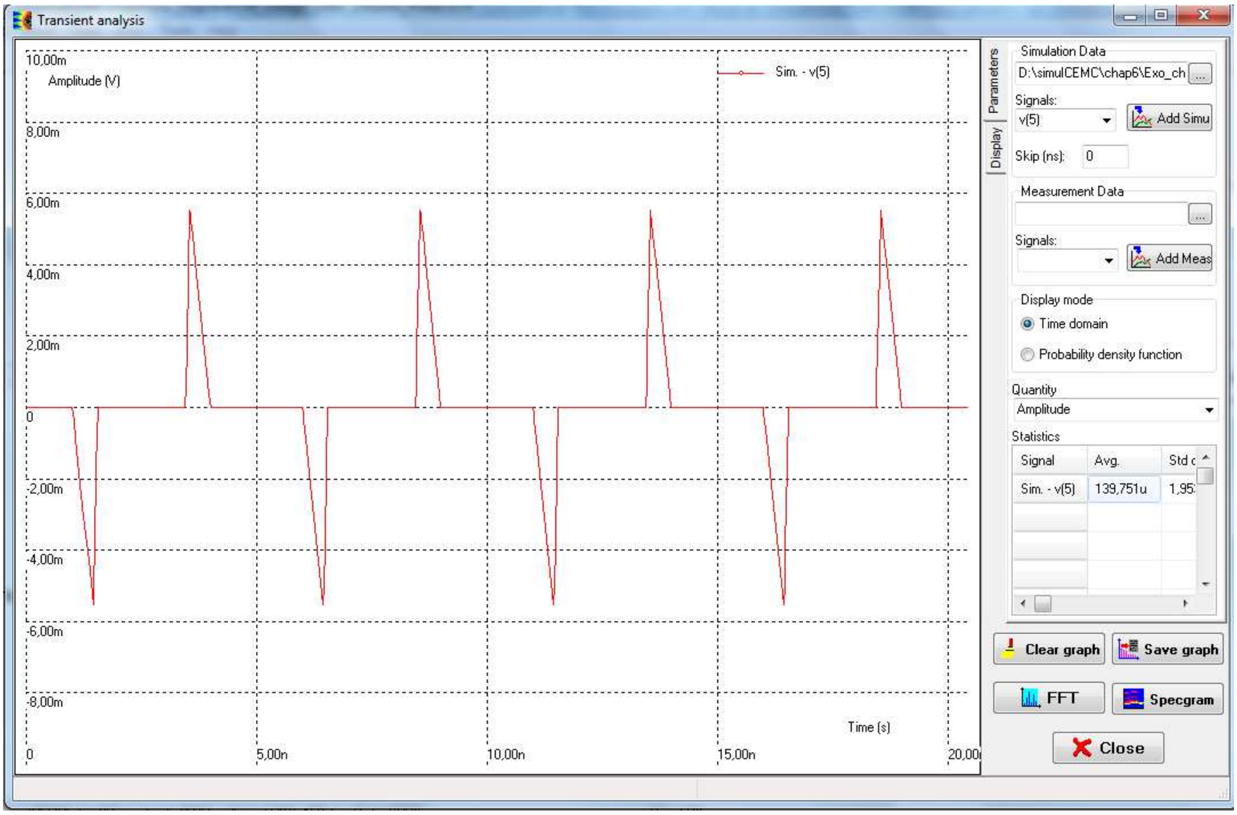




A transient simulation is configured to simulate the evolution of the common-mode voltage produced by the bus in time or frequency domain (FFT). Click on to generate the netlist and launch the SPICE simulation. Click on to plot the common-mode voltage in time-domain and on to plot it in frequency domain.

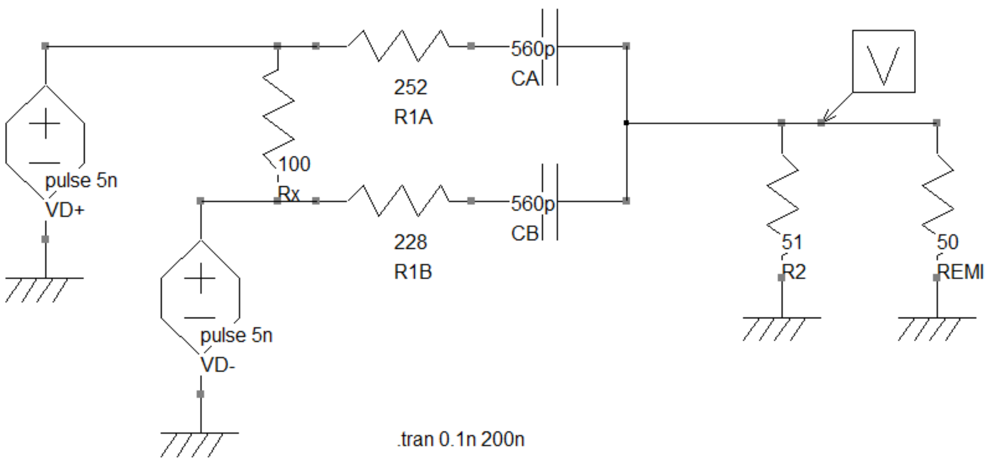
When the LVDS driver is perfectly balanced (totally complementary), the voltage $V_A$ cancels. Any unbalance, such as a differences in rise and fall times (see the configuration below) leads to common-mode voltage, as shown in the result below. The imbalance of the driver leads to voltage peaks at each bus signal switching.



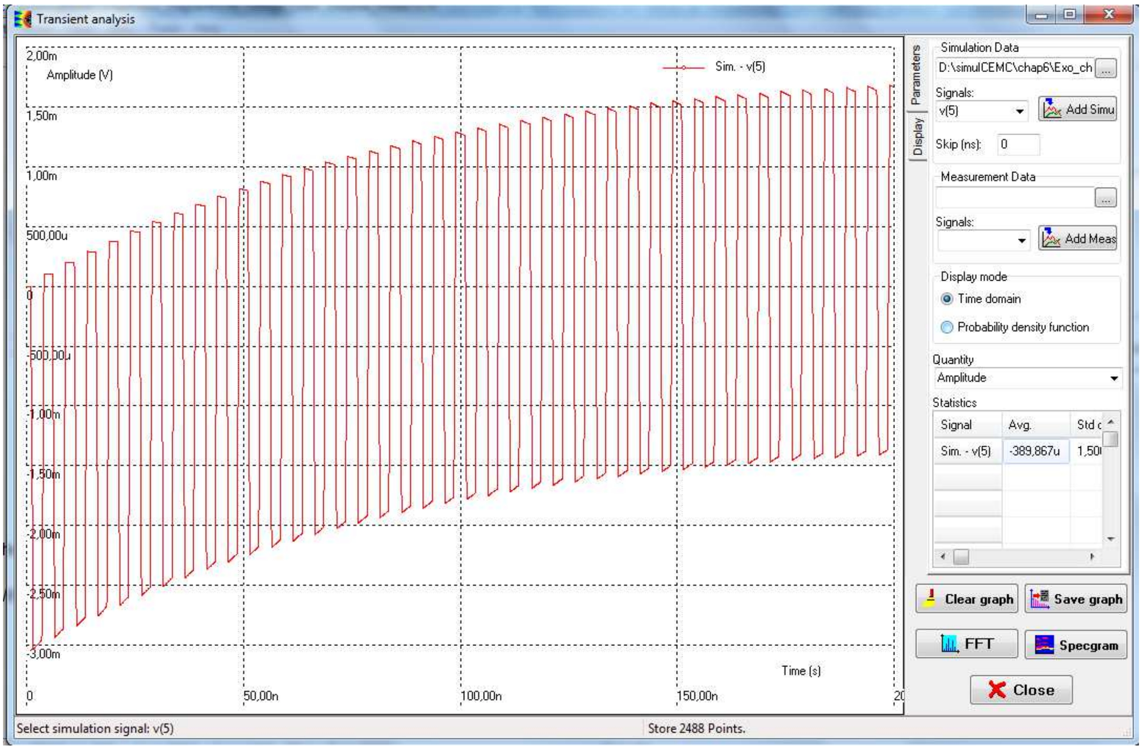






7. Any dissymmetry in the matching network leads to a conversion of differential to common-mode voltage. Even if the LVDS driver is perfectly balanced, a dissymetry of resistances R1 (or also capacitance C1) leads to the generation of a common-mode voltage. The schematic CM_voltage_LVDS_150ohm_Probe.sch is reused to simulate the effect of a dissymetry of resistances R1. According to the given tolerance, the maximum variation on the resistance value reaches 12 Ω. The worst case is obtained with the couple 228 Ω and 252 Ω. The resulting schematic diagram is shown below.



Click on to generate the netlist and launch the SPICE simulation. Click on to plot the common-mode voltage in time-domain.




8. The design of the matching network has to:

- ensure symetry to prevent from differential to common-mode conversion (route both R1-C branches as symetric as possible, use passive devices with low tolerances, e.g. 0.1 % on R1, 1 % on C)
- design 50 Ω adapted PCB traces after R2
- place the probe as close as possible to the source to limit the attenuation of the PCB traces
- limit the trace length between the different passive devices to reduce the parasitic influence on the probe response.

## II. EXERCISE NO 2 - Radiated emission limit in TEM cell

The purpose of this exercise is to verify if the compliance of a circuit to the limits of emission in TEM cell defined in Fig. 8-13 [BISS] ensures compliance to radiated emission at equipment and system levels. The radiated emission limits at 1 m defined by EN55022 are considered in this exercise. These limits, given from 30 to 1000 MHz, are shown in Fig. 7-8. The TEM cell model described in Fig. 8-9 is considered.

The device under test is an integrated circuit mounted and isolated on one side of an IEC61967 test board. It is assumed electrically small and can be assimilated to either an electric dipole (case A), or a magnetic dipole (case B). In case A, we suppose that the electrical dipole is related to a short 1 mm-long interconnect. In case B, we suppose that the magnetic dipole is associated to a small loop with a surface of 1 mm².

1. For cases A and B, give the relations between the maximum voltage measured on the TEM cell port defined by the limits in Fig. 8-13 and the equivalent electric or magnetic dipole moments of the circuit.

2. For cases A and B, compute the maximum electric and dipole moments to comply with the emission limits in TEM cell at 30 and 1000 MHz. In each case, give the maximum current that excites the equivalent electric and magnetic dipoles.

3. For cases A and B, compute the maximum electric field that the circuit may produce at 1 meter if its emission in TEM cell reaches the limit. Far-field and free space conditions are assumed.

4. Compare the electric field limits computed in question 3 with the radiated emission limit set by EN55022 to 1 m. If the emission of a circuit in TEM cell is compliant with the limit defined in Fig. 8-13, is there a risk that, as a consequence, an Information Technology (IT) equipment embedding it should not be compliant with EN55022 ? Conclude about the contribution of a circuit to the radiated emission of an equipment.

**Corrections:**

1. According to equation 8-18 and if the DUT is electrically small, the maximum voltage measured on TEM is expressed as: $|V_{TEM\max}| = \frac{1}{2}\frac{Z_C}{h}|P_y + jk_0 M_x|$, where Py is the equivalent electric dipole moment of the DUT and Mx its equivalent magnetic dipole moment.

- ✓ Case A: $|P_{y\max}| = \frac{2h}{Z_C}|V_{TEM\max}|$
- ✓ Case B: $|M_{X\max}| = \frac{2h}{k_0 Z_C}|V_{TEM\max}| = \frac{c.h}{\pi f Z_C}|V_{TEM\max}|$

2. In Fig. 8-13, three classes for emission limits are defined: class I (36 dBµV), class II (24 dBµV) and class III (12 dBµV). The emission limits are constant between 30 and 1000 MHz.

Case A: the electric dipole dominates. The results are not frequency dependent. The maximum current Imax circulating in the equivalent electric dipole is deduced according to the relation $|P_{Y\max}| = |I_{\max}|dl$ where dl = 1mm.

| Class | 30 MHz or 1000 MHz | |
|---|---|---|
| | $\|Py\|_{max}$ (dBµAm) | Imax (µA) |
| I | -18.9 | 113 |
| II | -30.9 | 28 |
| III | -42.9 | 7 |

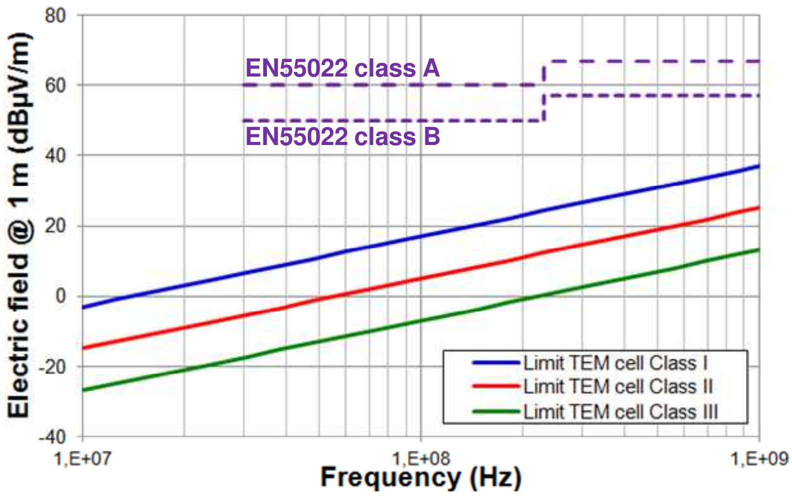
Case B: the magnetic dipole dominates. This time, the results are frequency dependent. The maximum current Imax circulating in the equivalent magnetic dipole is deduced according to the relation $|M_{X\max}| = |I_{\max}| dS$ where dS = 1mm². The results show that the excitation current required to induced the same TEM cell voltage decreases linearly with frequency.

| Class | 30 MHz or 1000 MHz | | 1000 MHZ | |
|---|---|---|---|---|
| | $\|Mx\|_{max}$ (dBµAm²) | Imax (mA) | $\|Mx\|_{max}$ (dBµAm²) | Imax (mA) |
| I | -14.9 | 180 | -45.3 | 5.4 |
| II | -26.9 | 45 | -57.3 | 1.4 |
| III | -38.9 | 11 | -69.3 | 0.34 |

3. Equation 8-23 gives a relation between the TEM cell voltage produced by an electric or magnetic dipole and the electric field radiated by the same dipole in far-field and free space conditions:

$$|E_{\max}| = AF_{TEM} \cdot |V_{TEM\max}| = \frac{\eta_0 f}{r.c} \frac{h}{Z_C} |V_{TEM\max}|$$

The following figure shows the evolution in frequency domain of the maximum electric field produced by either an electric or magnetic dipole, whose emission in TEM cell reaches the limit defined previously.




4. In the previous figure, the maximum radiated electric field of an equivalent electric or magnetic dipole whose emission in TEM cell reaches the limit is compared with the limit defined by EN55022. The figure shows clearly that the radiated emission of the equivalent dipole is far less than the

EN55022 limit. The differences between the limits are larger than 50 dB at 30 MHz and more than 20 dB at 1 GHz.

EN55022 is an harmonized standard for emission characterization of IT equipment. Although the assumptions that have been done (small circuit, far-field and free space conditions) are not fully verified, it seems unlikely that the circuit radiated emission make the IT equipment non compliant to EN55022. The compliance of the circuit to TEM cell emission test is a guarantee that the circuit will not create directly radiated emission issues at PCB and equipment level. Its conducted emission should also be verified, to ensure that it cannot excite long interconnects which could radiate more efficiently.

The previous comparison proves that the contribution of the radiated emission of the circuit alone is negligible compared to the maximum admissible overall radiated emission of the IT equipment that embeds this circuit. Due to their small physical sizes, integrated circuits are electrically small and thus inefficient parasitic antenna up to several GHz, contrary to PCB traces or cables. Nevertheless, the previous figure shows that the radiated emission of a circuit tends to increase with frequency. Above several GHz, it can be cautious to reduce the limit of TEM cell emission to ensure that the contribution of circuit to the overall radiated emission of the equipment would remain negligble.