How Large is a Large EuT? Influence of the DM-CM Conversion to Radiation

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***Abstract*— The contribution to radiation of wires and cable, which are attached to equipment under test (EuT), will be discussed in this paper. Based on [1], where the effects of single , not intentional feeded wires like antennas have been discussed, now the effects of active driven symmetrical lines like power cables and data lines shall be investigated. Rules of thumbs to convert emission measurements performed on alternative test sites to standard Open Area Test Sites (OATS) will be given in this paper.**

Key words: emission, alternative test sites, GTEM, reverberation chambers, FAR, OATS

I. INTRODUCTION

Considering the radiation from large EuTs on different test sites the question arises for the contribution of the attached cables and wires. The effect of a not directly fed wire was discussed in [1]. The outcome was, that for frequencies where the effective length of the wire becomes smaller than the wavelength, the effect of the wire decreases. For high frequencies the effect of the attached wires can be neglected. This is in line with the exponential current distribution along a lossy line (For a judgment, the attenuation factor is needed).

On the other hand along an active line we have an impressed common mode current generated by the LCL of the not perfect symmetrical transmission line. The present paper shall answer the following points:

- Modeling of the CM-distribution with a numerical field calculation program
- Radiation effects of a wire with the same current distribution
- Approximation of an effective radius a of a sphere containing radiating structures of the EuT.

II. CONVERTING RESULTS FROM ALTERNATIVE TEST SITES TO EQUIVALENT OATS-MEASUREMENTS

There is an ongoing discussion in international standardization to allow emission measurements on alternative test sites. This discussion is driven by economical and technical questions. All this boils down to the fact that the limits for emission are given for OATS-measurements as performed on test sites like Fig. 1.

The limits are given as the maximum field strength E_{max} in a distance of typical 10 m to the EuT and over a height of 1m to 4m for the receiving antenna. It is requested for alternative test sites that their measurement result will be converted to this equivalent OATS result.

Instead of E_{max} the total radiated power P_{rad} of the EuT is measured in TEM-waveguides and reverberation. As shown in [1] the equivalent OATS field strength E_{max} can be predicted from P_{rad} measurements by (1).

$$E_{max} = g_{max} \cdot \sqrt{\frac{D_{max}\eta_0}{4\pi} P_{rad}} \qquad (1)$$

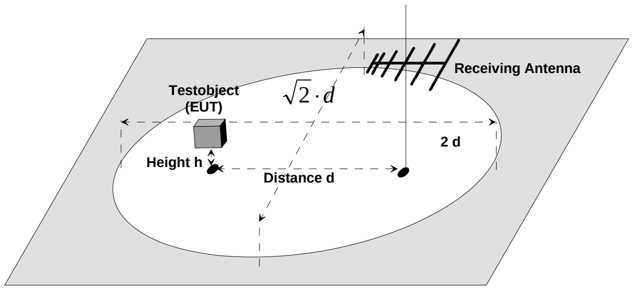

Fig. 1 Established emission test site (QATS

In general case the directivity D_{max} from (1) is unknown. Krauthäuser showed in [4], that the upper bound of D_{max} can be estimated from (2).

$$D_{max} \le \begin{cases} 3 & ka \le 1 \\ (ka)^2 + 2ka & ka > 1 \end{cases} \qquad (2)$$

a is defined as the radius of a sphere containing the radiating test object. It isn't a problem for small EuTs but how to handle EuTs with attached cables and wires as depicted in Fig. 2?

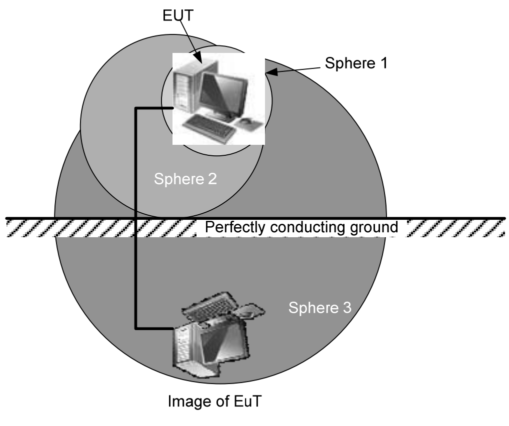

Fig. 2 Choosing the right sphere (from [1])

In a fist step we focused on attached wires, which were not actively driven [1]. The limiting of effect for the radiation was explained by assuming a lossy transmission line. During the presentation of [1] two questions arise which shall be investigated in this paper:

- How does the CM current distribution looks like?
- What's the effective radius a for a long wire with constant current distribution?

This concept is applicable to any other alternative test sites, on which P_{rad} is measured. A fully anechoic room (FAR) as shown in Fig. 3 can be treated in the same way.

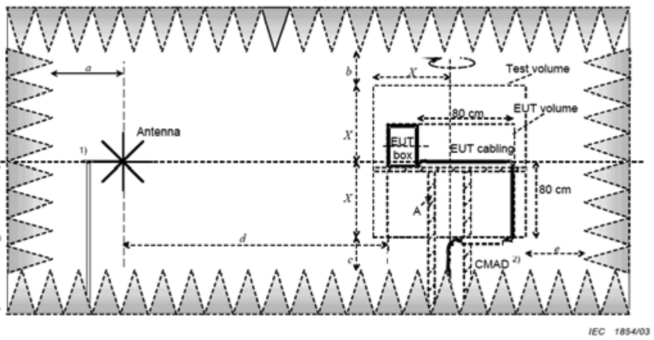

Fig. 3 Typical FAR site geometry [3]

The electric field strength is measured in a FAR but this field cannot be compared with E_{max} on an OATS because the directivity D_{max} is different although the cable routing is done in a similar way to OATS.

III. CM-DISTRIBUTION ON A TRANSMISSION LINE

To avoid any pre-assumptions a full wave simulator was used to model the two-wire transmission line. The numerical field simulations were done with the software code [2]developed by Brüns and Singer. This code CONCEPT II bases on the Method of Moments and is well suited to simulate antenna problems.

A. Symmetrical TL

1) Above perfect conducting ground (PCG)

In a first step a two-wire-transmission line above perfect conducting ground was considered. The coordinates of the wires in m, the radius in mm and the numbers of segments per wire are displayed in the following table:

```
2.30  wire 1   : coordinates
  -1.5000 0.1000E-01 0.1000        1.5000 0.1000E-01 0.1000
2.31  wire 1   : radius, no. of basis functions, RB, EP, MY
   1.0000  100
2.30  wire 2   : coordinates
  -1.5000 -.1000E-01 0.1000        1.5000 -.1000E-01 0.1000
2.31  wire 2   : radius, no. of basis functions, RB, EP, MY
   1.0000  100
2.30  wire 3   : coordinates
  -1.5000 0.1000E-01 0.1000       -1.5000 -.1000E-01 0.1000
2.31  wire 3   : radius, no. of basis functions, RB, EP, MY
   1.0000    5
2.30  wire 4   : coordinates
   1.5000 0.1000E-01 0.1000        1.5000 -.1000E-01 0.1000
2.31  wire 4   : radius, no. of basis functions, RB, EP, MY
   1.0000    5
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Each wire has the same height above ground. The configuration is fed by a voltage source in the middle of wire 3 and is nearly matched with 400 Ω in the middle of wire 4. All calculations were done for 300 MHz. For further details see Fig. 4.

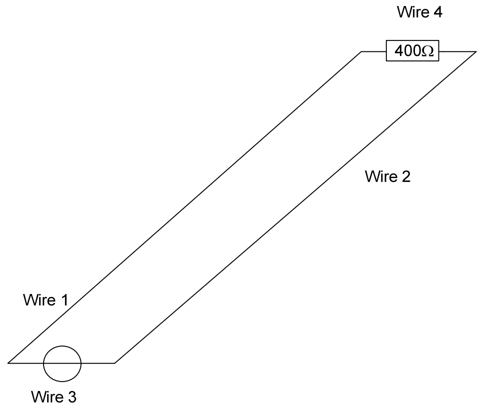

Fig. 4 Test configuration to study the CMDM-conversion

Fig. 5 shows the current distribution along wire 1 and wire 2. It can be seen that the transmission line isn't perfectly matched but it is quite good.

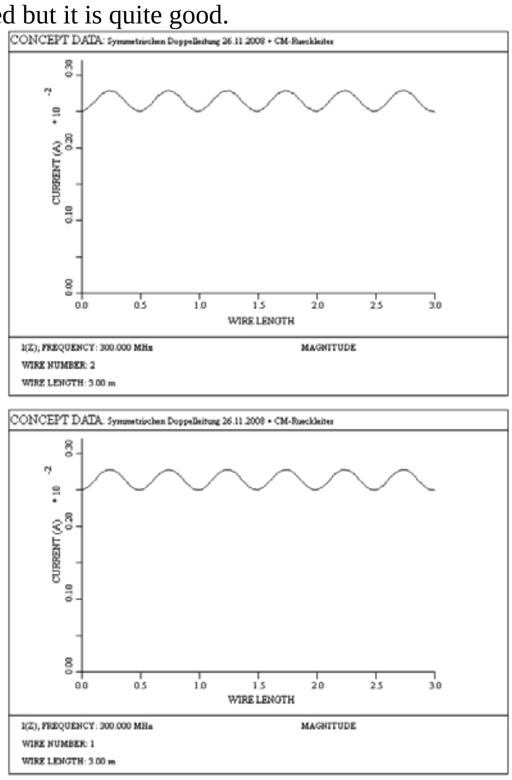

Fig. 5 Current distribution on the signal wires 1 and 2 @300 MHZ

As expected we get a symmetrical current distribution, but the problem occurs that the CM current has to be calculated from the data presented above by (3).

$$I_{CM}(x) = I_{wire1}(x) + I_{wire2}(x) \qquad (3)$$

Both wire currents are nearly identical but will have a different sign. Very small values have to be expected for a perfect symmetrical transmission line.

2) Wire instead of PCG

Therefore the PCG is replaced by a single wire placed on the x-axis to display the CM-current,. The wire has the same length as wire 1 and 2, but it hasn't discrete connections to wire 1 or 2. The calculated current, displayed in the Fig 6, is calculated by the software code itself. As expected the CM current is 14 orders of magnitude smaller than the current on the wire 1 and 2. This proves the assumption that we are allowed to use wire 5 to display the CM-current.

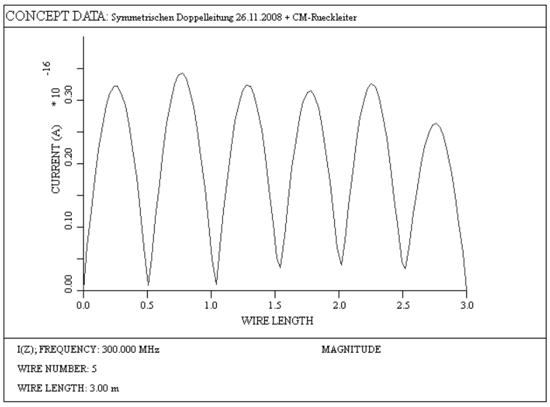

Fig. 6 CM-Current along wire 5

Another prove for the validity to use wire 5 to display the CM-current distribution along the x-axis is shown in Fig. 7 and Fig. 8.

The surface current density $\vec{S}$ on a PCG can be linked to the magnetic field via (4).

$$\vec{S} = 2\vec{n} \times \vec{H} \tag{4}$$

In Fig. 7 a constant current (= magnetic field distribution) is visible instead of Fig. 8. This is caused by the mismatch of wire 5. For an infinitively long wire a constant magnitude is expected.

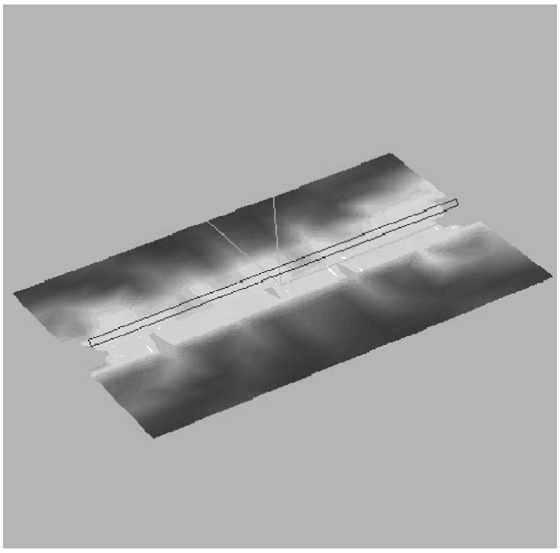

Fig. 7 H-field caused by CM-current distribution on PCG @300 MHz

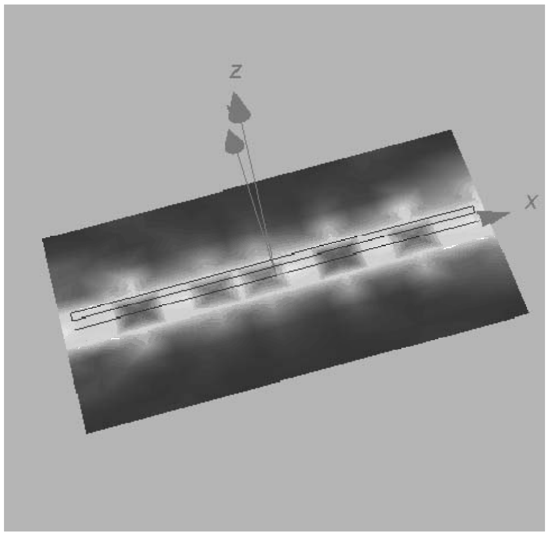

Fig. 8 H-field caused by CM-current on wire 5 @300 MHz

B. Unsymmetrical TL

To study the unsymmetrical case wire 1 was raised to the height of 15 cm. The resulting CM-current distributions for 300 MHz and 1000 MHz are displayed in Fig. 9 and Fig. 10.

```
2.30  wire 1   : coordinates
  -1.5000 0.1000E-01 0.1500        1.5000 0.1000E-01 0.1500
2.31  wire 1   : radius, no. of basis functions, RB, EP, MY
   1.0000  100
2.30  wire 2   : coordinates
  -1.5000 -.1000E-01 0.1000        1.5000 -.1000E-01 0.1000
2.31  wire 2   : radius, no. of basis functions, RB, EP, MY
   1.0000  100
2.30  wire 3   : coordinates
  -1.5000 0.1000E-01 0.1500       -1.5000 -.1000E-01 0.1000
2.31  wire 3   : radius, no. of basis functions, RB, EP, MY
   1.0000    5
2.30  wire 4   : coordinates
   1.5000 0.1000E-01 0.1500        1.5000 -.1000E-01 0.1000
2.31  wire 4   : radius, no. of basis functions, RB, EP, MY
   1.0000    5
2.30  wire 5   : coordinates
  -1.5000     0.0000     0.0000     1.5000     0.0000     0.0000
2.31  wire 5   : radius, no. of basis functions, RB, EP, MY
   4.0000  100
```

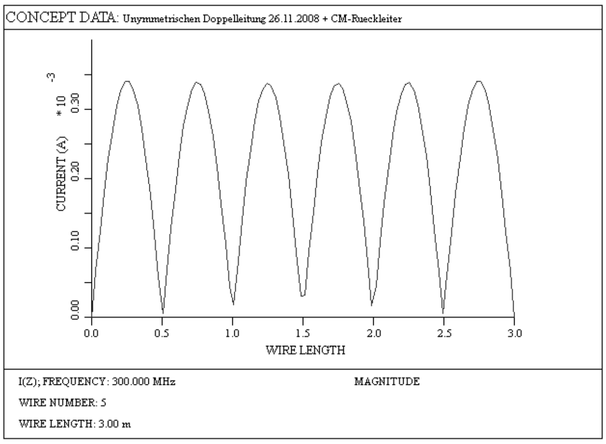

Fig. 9 CM-current distribution @300 MHz

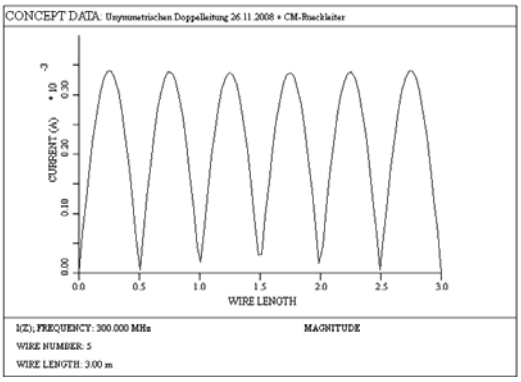

Fig. 10 CM-current distribution @1000 MHz

C. Common mode rejection factor

The common mode rejection factor can be used to validate the results. Using the partial capacitor C_{15} between wire 1 and wire 5 and C_{25} wire 2 and wire 5 respectively the CM factor can be approximated by (5)

$$\frac{I_{CM}}{I_{DM}} \approx \frac{2|C_1 - C_2|}{C_1 + C_2} \qquad (5)$$

C_1 and C_2 may be calculated for two parallel cylinders with radii r_0 and r_5 and a separation c by (6) from [5].

$$\frac{C}{l} = \frac{\pi\varepsilon_0}{\ln\left(\frac{c^2}{r_0 \cdot r_5}\right)} \quad \text{in F/m} \quad (6)$$

Using (5) and (6) we get for the factor $\frac{I_{CM}}{I_{DM}} \approx 0.0978$. This is equal to a LCL of 20.19 dB.

D. Conclusion for the unsymmetrical case

For both frequencies we get a DM-current of 2.7 mA and a CM-current with the mean value of 0.228 mA. A rough estimation for the LCL gives us 20 dB.

Furthermore it is notable that the mean value for the CM-current is constant along the wire. An exponential decrease as reported for an attached wire in [1] isn't visible.

IV. Radiating from one wire with a constant CM-current distribution

The goal of this chapter is to consider whether a similar limiting effect as reported in [1] is visible on an active transmission line. Therefore the radiation from wire 5 caused by an impressed constant current distribution was simulated.

The remaining problem is to get an estimation for the effective radius a. Following the procedure from [1] a single wire with a constant current distribution is simulated. The current phase varies with the speed of light. Five different lengths are investigated.

- 0.8 m as the typical length of a straight wire according to [3]
- 1.6 m as the typical overall length of the cable [3].
- 3 m as the wavelength @300 MHz
- 6 m and 10 m to study the effects of long cables / wires.

Fig. 11 shows an effective radius a between 9 cm and 30 cm at 1000 MHz. To convert measurements on alternative test sites to equivalent OATS results for 0.8 m and 1.6 m length are most important. It can be stated that an approximation for a as λ/4 would be a good choice.

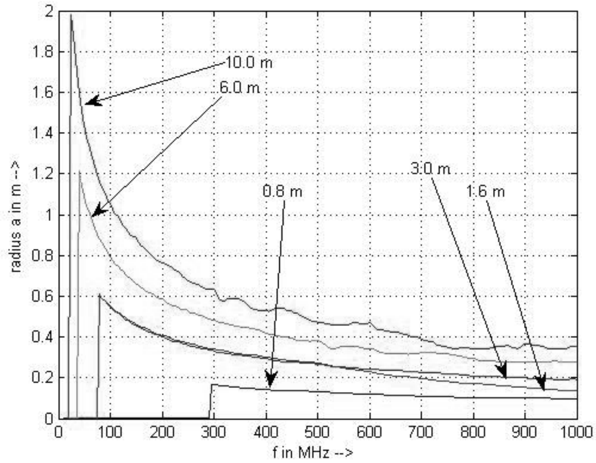

Fig. 11 Effective radius a for CM-current wire length (0.8m, 1.6 m, 3 m and 10 m)

The effective radius a starts with 1.1m / 1.2m and decreases to 20cm / 30cm. To predict the radius a, we can see that radius a is always smaller than the half of the actual wavelength. An active transmission line only contributes with a length of half a wavelength. This assumption is especially valid for frequencies above 100 MHz. We can conclude: Not more than 1.5 m cable contributes significantly to radiation of a wire.

V. Conclusion

The major findings of this paper are:

- The common mode current distribution is constant along the transmission line.
- Not more than 1.6 m cable at 30 MHz contributes significantly to radiation of a wire.
- D_{max} should be calculated for a radius of 0.4 m.

Acknowledgments

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