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Screening attenuation of coaxial cables determined in GTEM-cells

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Abstract. This paper describes the determination of the screening attenuation with a GTEM cell. An analytical part gives the link between the voltage at the cell port and the total radiated power. The next section investigates the optimal cable setup in the cell. With a measurement of the common mode current on the cable and a simulation of the radiation resistance the loop antenna characteristic of the cable setup could be verified. It is shown that the use of ferrit cores decrease the difference between the maximum and the minimum screening attenuation. The determination of great screening attenuation could be improved with the use of N-type measurement cables. A comparison between this GTEM cell method and the standard methods shows a good agreement.

1 Introduction

The main topic of this paper is the screening attenuation a_s of coaxial cables. The first section introduces its definition and the boundary conditions. The next section describes the special characteristics of a GTEM cell and the last sections present the determination of the screening attenuation in the GTEM cell. The definition for the screening attenuation of coaxial cables is given by Eq. (1):

$$a_s = 10 \cdot \log\left(\frac{P_1}{P_2}\right) \qquad (1)$$

In Eq. (1) P_1 is the feeding power and P_2 is the radiated power (see Fig. 1 left and middle). The screening attenuation suggested that this value is a measure depending only on the screen of the cable. For a better understanding of Eq. (1), the screening attenuation is now considered for a more general case (Fig. 1 right).

The word screening attenuation implies that it is a measure for the screening effectivness of the screen only. It bases physically on reflection and absorption of the screening material. In a general case (Fig. 1 right) the screen or enclosure should have no equipment inside that absorbs a part of the power. To obtain the power P_1 that comes as an orthogonal incident wave to the screen the orthogonal incident power density vector has to be integrated on an envelope area near by the screen. This could be done analytically, but not in practice. To obtain only the screening effecivness of the cable screen, the screen has to be tested under insertion loss conditions. With this considerations it becomes obvious that the screening attenuation for cables (Eq. 1) depends not only from the screen. a_s varies with the geometry, material and the surroundings of the cable.

The standard methods absorbing clamp and triaxial method determine the maximal radiated power P_2 via the common mode current that flows on the screen. It is a possibility to obain the worst case radiated power. The question which part of this power is really radiated depends e.g. on the terminating resistors of the primary (inner) and the secondary (outer) circuit (Fig. 1 middle) and the surroundings. In this paper the radiated power is measured in the GTEM cell.

2 GTEM cell

The Gigahertz TEM cell (GTEM) is a special 50 Ω TEM waveguide that is used for emission and immunity tests. The cell is terminated with absorbing material and a mesh of resistors that form the characteristic impedance (Fig. 2).

The part of the cable that is placed in the cell, radiates some power. Unfortunately the power that could be measured at the cell port is not the half of the radiated power, because at this port only the TEM-part of the radiation could be measured. In Wilson (1993) a method is presented to determine the total radiated power P_2 with a sequence of 3 orthogonal measurements. The cable set is characterized by an equivalent multipole model. With this model the link

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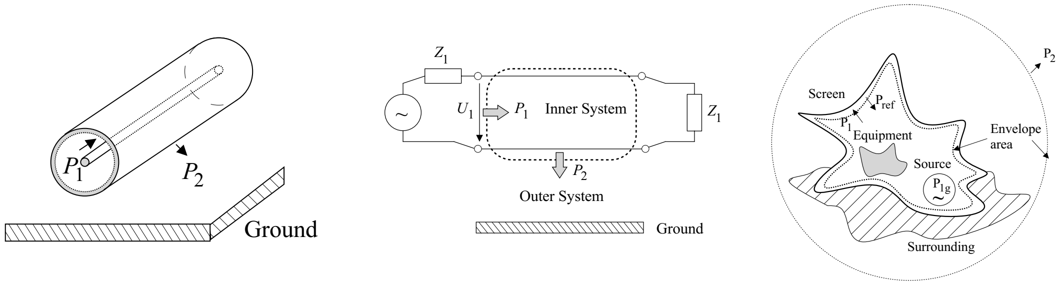


Fig. 1. Left: Coaxial cable. **Middle:** Equivalent circuit. **Right:** General screening attenuation.

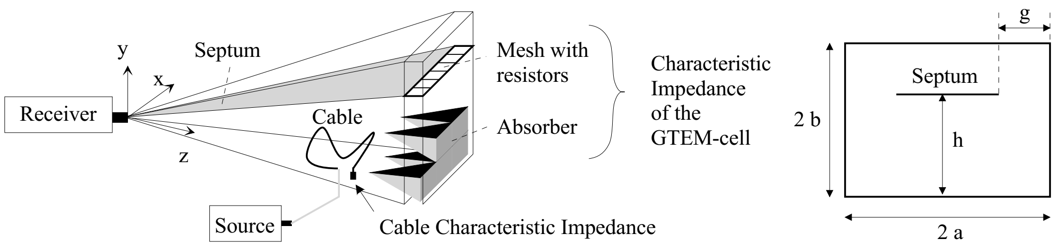
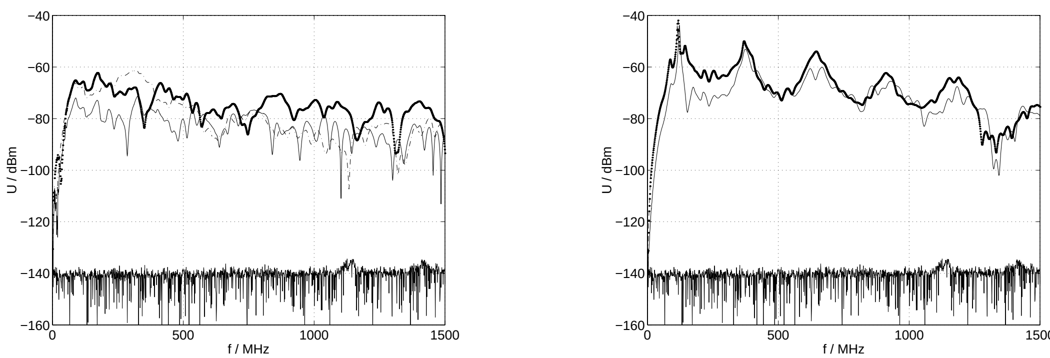


Fig. 2. GTEM cell.



Legend: Pos.1:line point, Pos.2:bold dotted, Pos.3: line

Fig. 3. Voltages of the 3 cable setups: **Left**: Loop antenna, perimeter = 1 m, **Right**: Monopol, length = 0.57 m.

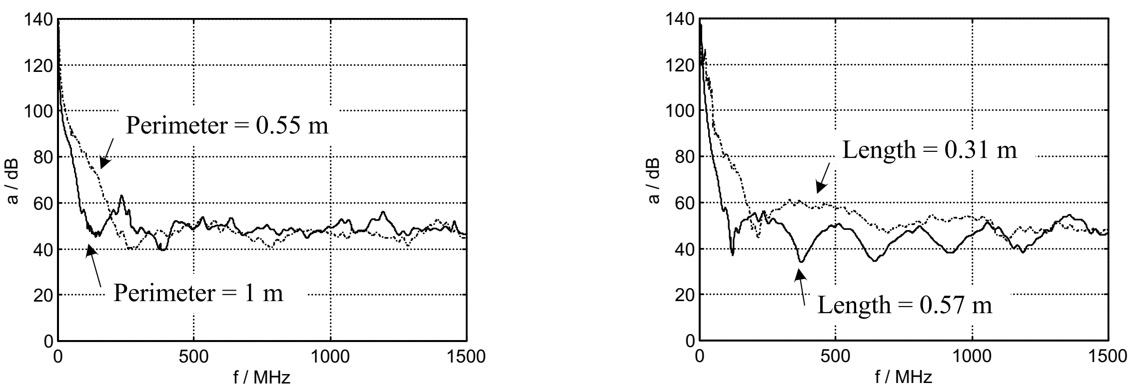
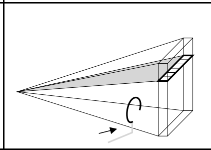
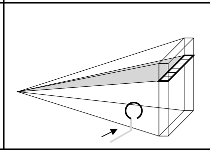
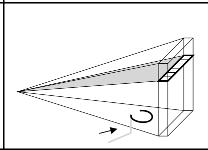
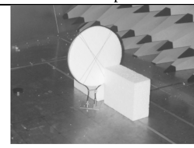
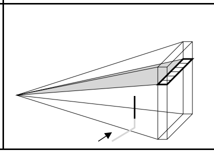
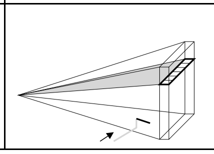
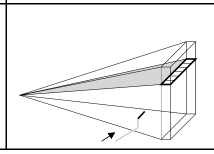
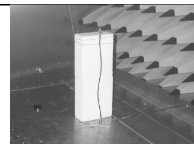
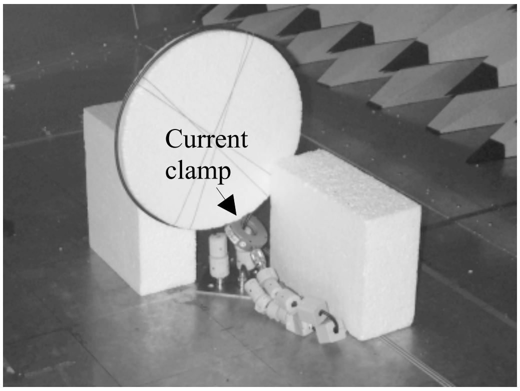


Fig. 4. Screening attenuation a_S: **Left**: Loop antenna, **Right**: Monopol.

Table 1. 3 orthogonale cable setups.

	Position 1	Position 2	Position 3	Example
Loop antenna				
Monopol				



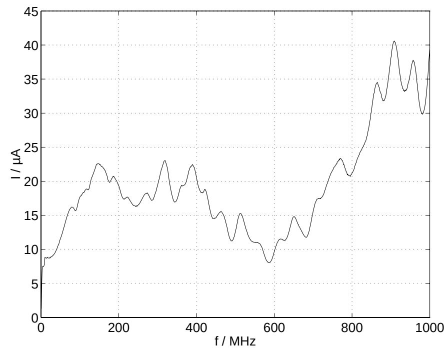
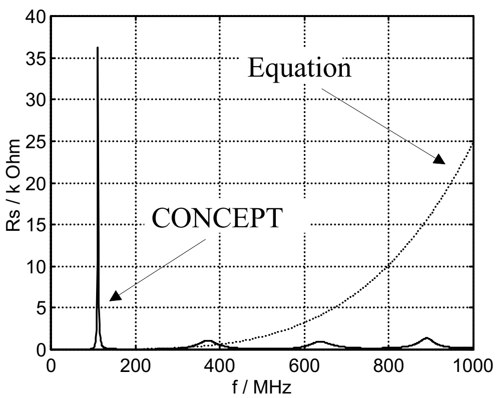


Fig. 5. Left: Current clamp, **Right**: Current on the screen.



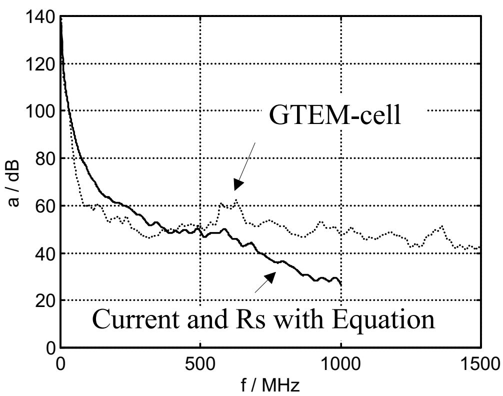


Fig. 6. Left: Radiation resistance **Right**: Screening attenuation.

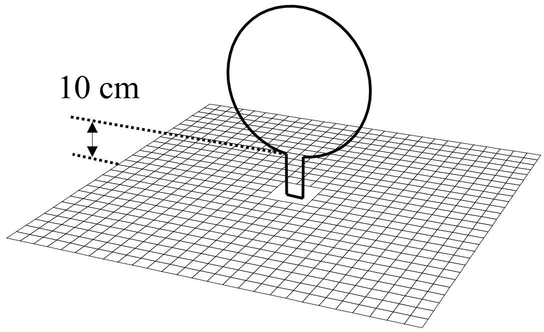
between the voltage at the cell port and the total radiated power is (IEC 61000-4-20, 2003):

$$P_2 = \frac{\eta_0}{3\pi} \cdot \frac{k_0^2}{e_{0y}^2 Z_c} \cdot \sqrt{U_{m1}^2 + U_{m2}^2 + U_{m3}^2} \quad (2)$$

In Eq. (2) η_0 is the field impedance of free space, $k_0 = 2\pi/\lambda$ is the wave number, Z_c is the characteristic impedance of the waveguide, U_m is the voltage, where the index m belongs to the 3 cable setups and e_{0y} is the normalized field vector that depends only on the geometry of the cell and the positon of the cable under test (CUT) in the cell. A good approximation for the normalized field vector is:

$$e_{0y} = \frac{4}{a}\sqrt{Z_c} \cdot \sum_{m=1,3,5...}^{\infty} \left(\frac{\cosh(M \cdot y)}{\sinh(M \cdot h)} \cdot \cos(M \cdot x) \cdot \sin\left(M \cdot \frac{a}{2}\right) \cdot J_0(M \cdot g)\right). \quad (3)$$

For the parameters a, b, g and h and the coordinate system x, y and z see Fig. 2. J_0 is the zero order bessel function and M is an abbreviation for $m\pi/a$ with $m = [1, 3, 5 \ldots \infty]$.



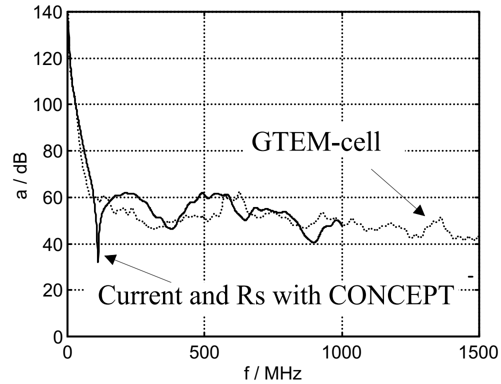
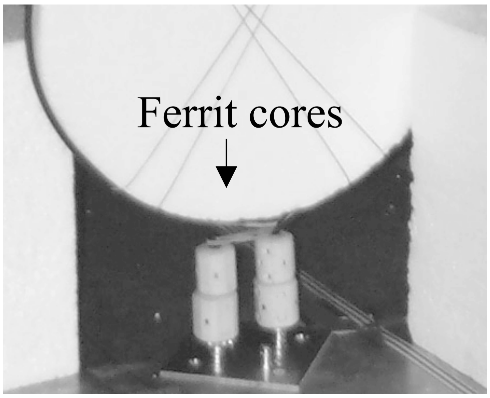


Fig. 7. Left: Simulation model, **Right**: Screening attenuation.



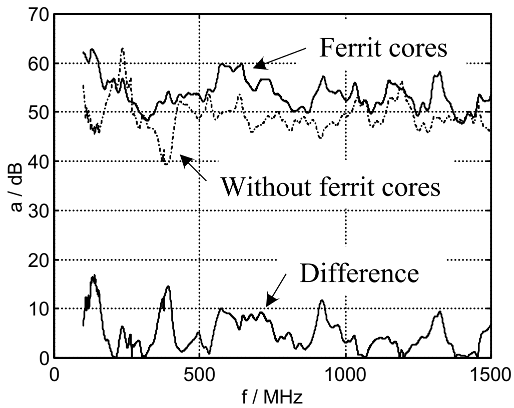


Fig. 8. Left: Ferrit cores, **Right**: Screening attenuation.

3 Cable setup

The measurements are done with a RF-Generator SMT02 with a source power of 13 dBm. A Spectrum-Analyser FSP07 steps from 1 MHz up to 1.5 GHz in 1 MHz increments. To obtain a good signal to noise ratio the resolution bandwidth is 30 Hz and the video bandwidth and span are 1 kHz. The preamplifier is on and the used detector is at auto peak. The measurement is controlled with a PC via the GPIB connection. The used GTEM cell type is 1250.

To determine the total radiated power in the GTEM cell the CUT has to be placed in 3 different setups that are orthogonal to one another. With respect to a minimum modification of the cell it would be good to have only one additional hole. With this restrictions two setups are possible a loop- or monopol antenna. Table 1 shows three possible orientations for each setup. To hold the cable in the optimal position it is fixed with elastic bands on a polystyrene circle. The test cable is a RG 58 coaxial cable (Alcatel).

Figure 3 shows the three voltages of the different cable setups and the noise level. As expected the voltage for position 2 of the loop antenna is maximal approximately over the whole frequency range, because the electric and the magnetic fields of the cell and the antenna have the same orientation. In the voltage curve progression of the monopol the antenna resonances could be seen.

With the three voltages the total radiated power is calculated with Eq. (2). The screening attenuation a_s results with Eq. (1). To see the influence of different setup sizes, a_s is determined for 2 different perimeters and lengths.

Each curve in Fig. 4 is the mean of two measurements. For both setups the screening attenuation decrease from 0 Hz up to 100 or 200 MHz. After that it stays more or less constant, except the resonance or antenna effects varies the curve. This characteristics could be explained with the radiation resistance of an antenna (see next section). With respect to obtain a measure that is more or less independent of a special antenna characteristic the loop antenna shows a more constant screening attenuation over the whole frequency range. The loop antenna has the additional advantage that it could be used for the determination of the coupling attenuation. Therefore a longer cable is needed to consider the unbalanced attenuation. So the loop is advantageous, because on the one port the feeding power could be very near to the source without a great attenuation and on the other port the long cable could follow to have the effect of the unbalanced cable. In this paper the cable perimeter of 1 m is choosen to determine the screening attenuation.

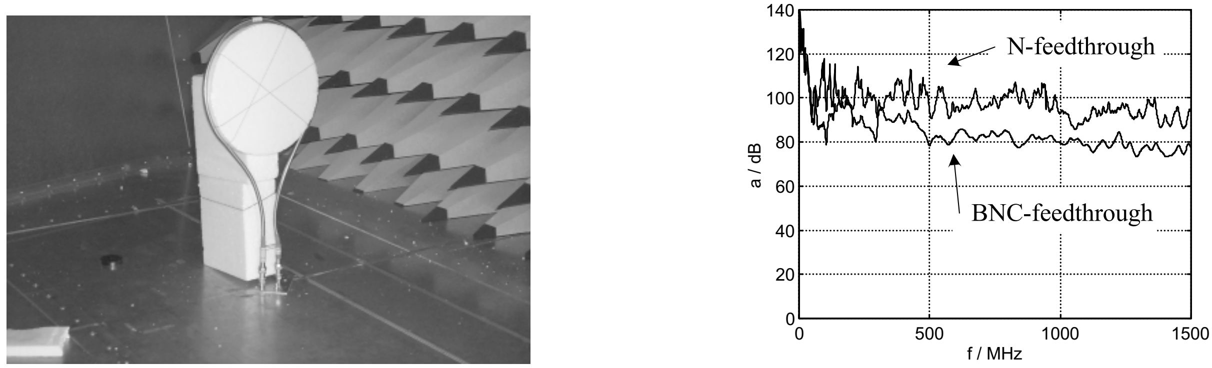
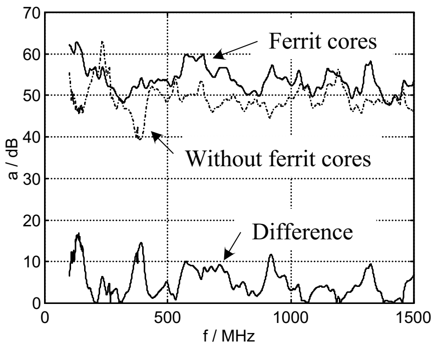


Fig. 9. Left: Sucoflex 104B, **Right**: Screening attenuation.



	m/dB	s/dB
Alcatel with ferrit cores	55.2	3.0
Alcatel without ferrit cores	52.3	3.7
Suhner with ferrit cores	53.7	3.1
Suhner without ferrit cores	49.2	3.3

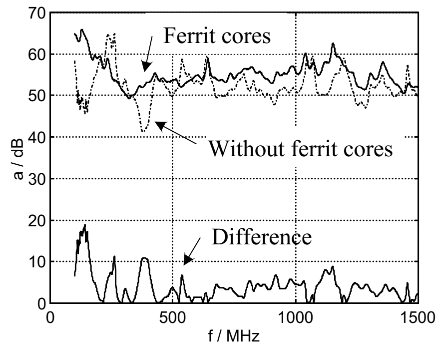


Fig. 10. Left: RG 58 Alcatel, **Right**: RG 58 Suhner.

4 Antenna characteristic of the cable setup

To investigate the antenna characteristic of the loop antenna the common mode current an the cable screen is measured.

To avoid further interference in the test lead, ferrit cores on the cable are used (Fig. 5). The curve of the measured current is plotted in Fig. 5. With this current and the radiation resistance of a loop antenna (Simonyi, 1989)

$$R_s = 20 \left(\frac{2\pi}{\lambda}\right)^4 (r_0^2 \pi)^2 \quad (4)$$

the total radiated power could be calculated to $P_2 = I^2 \cdot R_s$. In Eq. (4) λ is the wavelength and r_0 is the radius of the loop antenna. In Fig. 6 the radiation resistance and the comparison of screening attenuation is presented.

The condition for Eq. (4) is that the loop antenna dimensions are small in comparison to the wave length. With a loop antenna radius of $r_0 = 0.159$ m this condition will be approximatly fit up to 90 MHz. This approximation could be confirmed with the radiation resistance and the screening attenuation in Fig. 6. To improve the model the radiation resistance is simulated with an electromagnetic field simulation tool CONCEPT. Therefore the loop antenna is simulated with wires and the GTEM cell wall is considered with patches (Fig. 7).

In Fig. 6 the radiation resistance of the simulation shows resonances and has a flat frequency response in comparison to the dependence of Eq. (4). With this radiation resistance and the measured current the calculated and the measured screening attenuation fits very well (Fig. 7).

5 Influence of ferrit cores

In the standard absorbing clamp method ferrit cores are used to avoid unwanted surface wave propagation. Now the influence of ferrit cores should be investigated for the GTEM cell method. Therefore ferrit cores are clamped on the cable (Kitagawa: $2 \cdot$ RFC10 und $2 \cdot$ RFC13) as it is shown in Fig. 8.

There are two effects of the ferrit cores. In Fig. 8 the screening attenuation is plotted without the beginning part. The resonance effects at 147 MHz, 235 MHz and 382 MHz are damped very well, but the whole curve shifted a little bit form the mean value 52.3 dB to 55.2 dB with ferrit cores. As a result one could see that the damping works, but now the screening attenuation is a function of the used ferrit cores.

6 Influence of Cable connections

To see the influence of the cable connections a special screened coaxial cable (Sucoflex 104B) is measured for two different feedthroughts. The supporting documents for this cable indicate a screening attenuation of 120 dB and better.

Figure 9 shows the measured screening attenuation for 2 different feedthroughts in the GTEM cell. An N-feedthrought improves the screening attenuation approximately 10 dB compared with a BNC-feedthrought. This shows a great the influence of used cable type.

7 Comparison with standard methods

In Breitenbach (1998) the screening attenuation of a RG 58 cable is determined with the absorbing clamp and the triaxial method. The values vary between 48 and 52 dB for the frequency points f=200 MHz, f=800 MHz und f=3 GHz. In the frequency range up to 1.5 GHz the measured screening attenuation fluctuate approximately ± 10 dB.

For the comparison two RG 58 cables from different manufacturer are measured with and without ferrit cores in the GTEM cell. The used cable setup is a loop antenna with the perimeter of 1 m. Figure 10 shows the screening attenuation. The mean screening attenuation without ferrit cores is approximately 3 dB smaller. The advantage in the use of ferrit cores is a smaller difference between the maximal and the minimal value. Compared with the standard methods the GTEM cell method shows a good agreement.

8 Conclusion

This paper gives an analytical way and method to determine the total radiated power of a cable in a GTEM cell. With this power the screening attenuation a_s could be calculated. A loop antenna is the optimal cable setup with respect to a minimum modification in the cell and the outlook to determine the coupling attenuation with the same setup. With a measurement of the common mode current and a simulation of the radiation resistance the screening attenuation could be verified with a good agreement. Measurements with and without ferrit cores show that the difference between the maximum and the minimum value of the screening attenuation decrease. To determine great screening attenuations N-cables improve the results. A comparison between this GTEM cell method and the standard methods shows a good agreement. Further measurement has to work out the upper boundary of the GTEM-cell method.

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