Study of Electromagnetic Shielding provided by Faraday's Cage

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Introduction

Free space electromagnetic wave propagation is an important physics topic essential for the development of a good technical background of high school students. Understanding of wave attenuation, reflection and refraction are best enhanced through the use of laboratory experiments specially if built by the students themselves.

The purpose of the experiment is to design/build a Faraday cage that attenuates signals at the frequency of 433MHz. The project's main challenge is reduced investment and use of low tech materials, so that it can be assembled by a person with no technological skills or deep electronics knowledge. The project took four months to be completed and costed around R$350,00, suitable for high school laboratories.

Theory

The theory states that Faraday's cage will attenuate signals of wavelength much larger than the size of it's grid, because for these wavelengths, from the point of view of the wave, the cage will behave like a massive surface.

As the wave is transmitted from the air to the metallic pattern, a reflected wave and a refracted wave appear. The refracted wave causes interference with the incident wave, as the frequency of the signal decreases. The refracted wave goes out in relation to the incident wave, until it is delayed by π rad, causing destructive interference.

As this phenomenon occurs, signal power inside the conductive material should fall to zero, that is, there is no refracted wave from the surface of the cage to the inside.

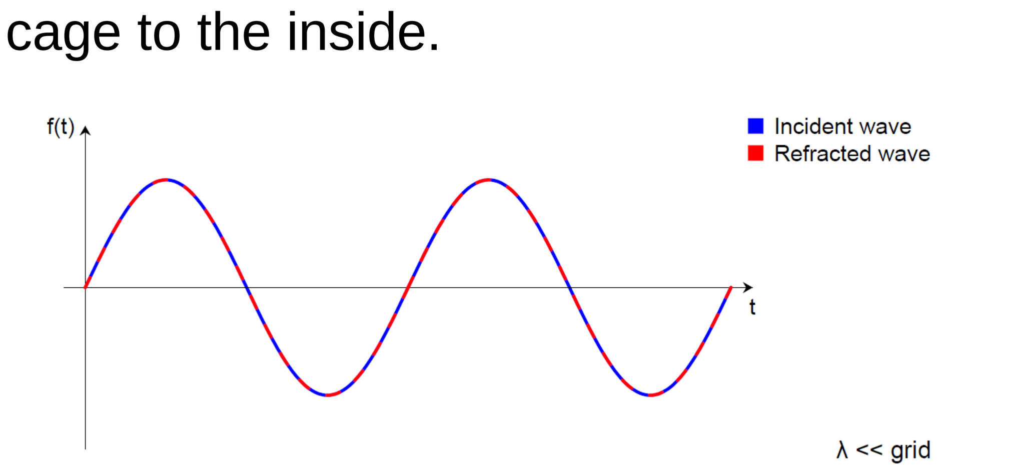

Fig 1 – Propagation of waves of a much smaller wavelength than the size of the grid through the surface

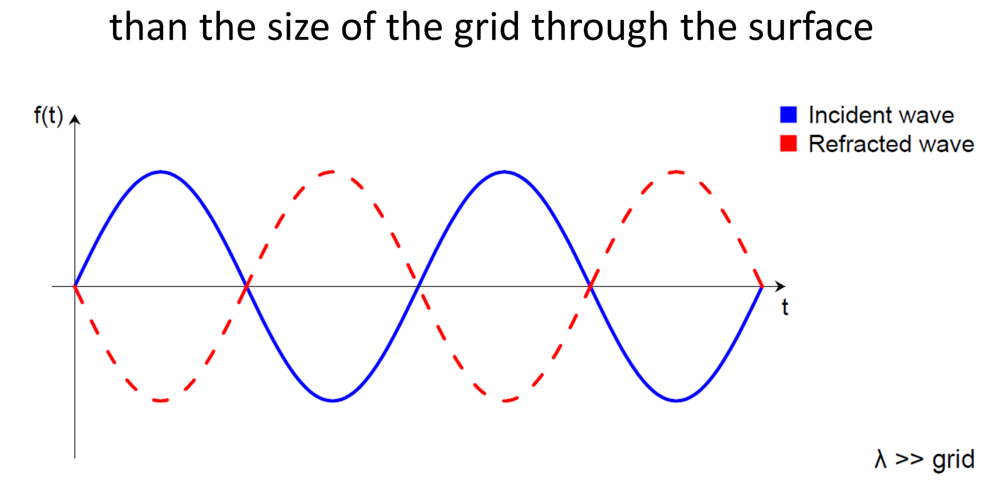

Fig 2 – Propagation of waves of a much larger wavelength than the size of the grid through the surface

For the frequency oh 433MHz, the wavelength is give by:

$$\lambda_{433\mathrm{MHz}} = \frac{c}{433 \cdot 10^6} = 0{,}69\mathrm{m} \qquad (1)$$

To enhance electromagnetic wave confinement, it was decided to build the cage with a 0,01m x 0,01m grid spacing (around 70 times smaller). That gives the cage a nominal cut-off frequency of:

$$\lambda = \frac{c}{0{,}01} = 30 \cdot 10^9\mathrm{Hz} = 30\mathrm{GHz} \qquad (2)$$

Design

The cage's structure is made of solid eucalyptus wood: cheap, strong and durable. The weaving is composed by multi-stranded 1,0mm² bare copper wires, and one of the faces has no weaving, so it's possible to locate an antenna or RF device inside. Underneath is placed a galvanised steal sheet to provide closing for the cage.

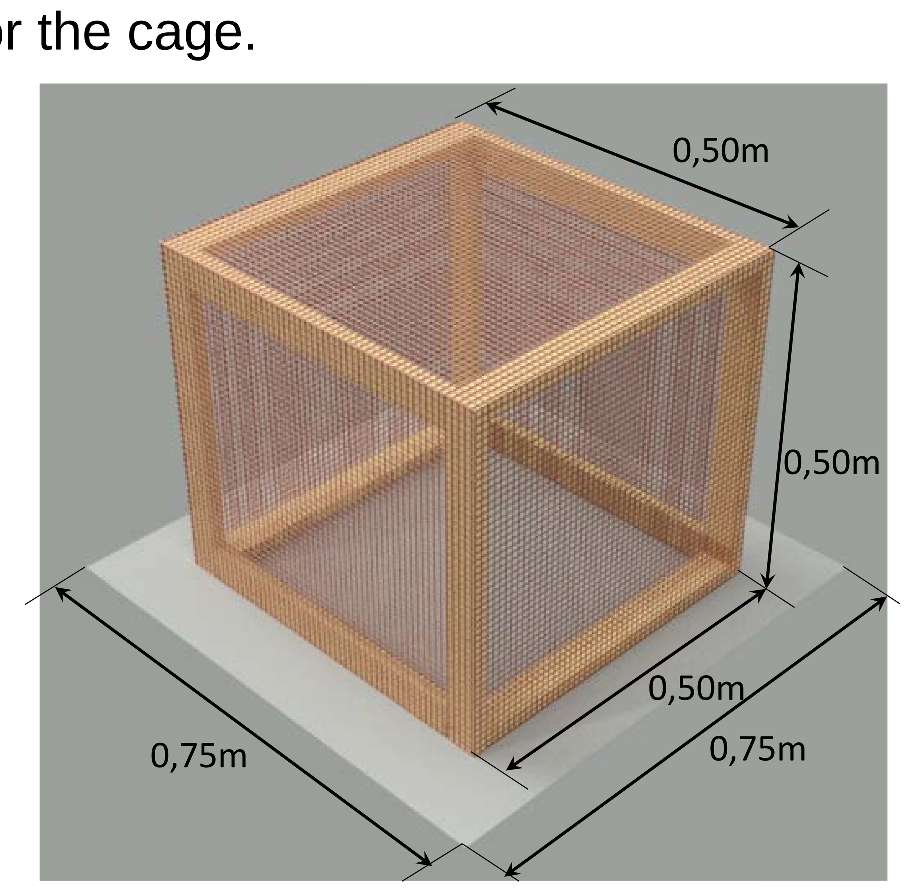

Fig 3 – The conceived Faraday cage

Experiment and Validation

The cage was tested with four signal frequencies, using a RF Generator and a Spectrum Analyzer. These are: 433MHz, 900MHz, 1,9GHz and 2,4GHz, all belonging to ISM radio bands.

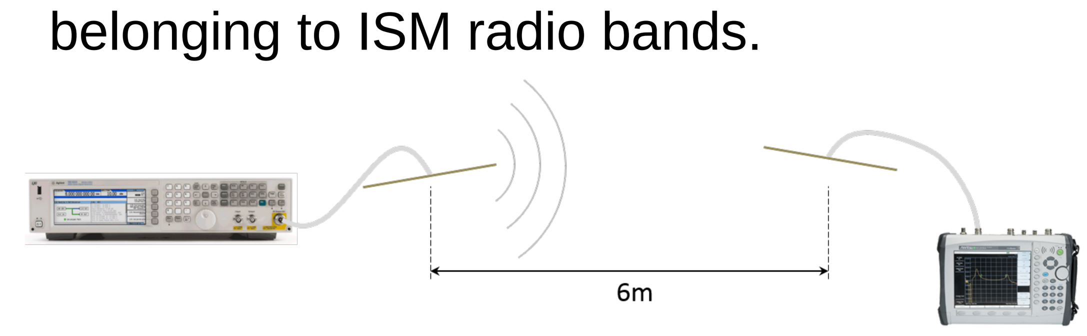

Fig 4 – Schematic of a measuring without cage

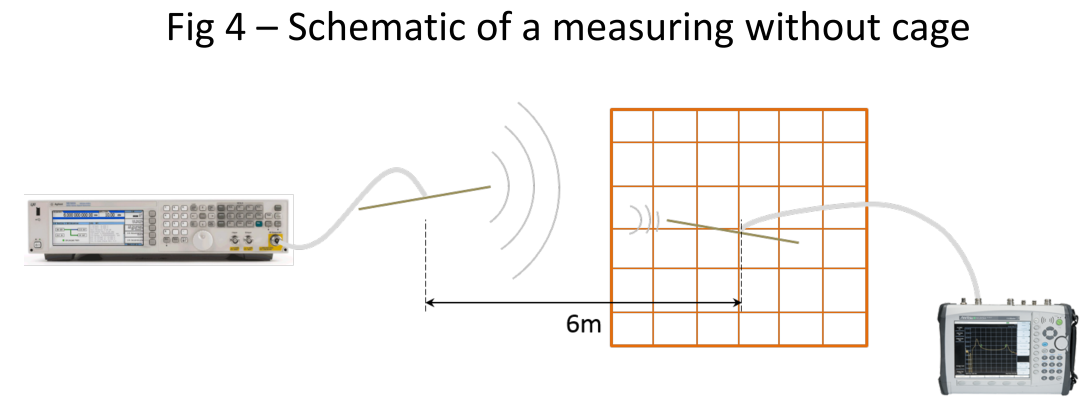

Fig 5 – Schematic of a measuring with cage

A 433MHz reference signal power was measured on the Spectrum Analyzer without the cage so the power of the RF Generator could be regulated. Then, the cage was placed and a signal power measure was taken. The reference power was defined to be -65,0dBm.

Fig 6 – Measuring signal power with cage

A graph was then obtained, relating the reception power with and without the cage:

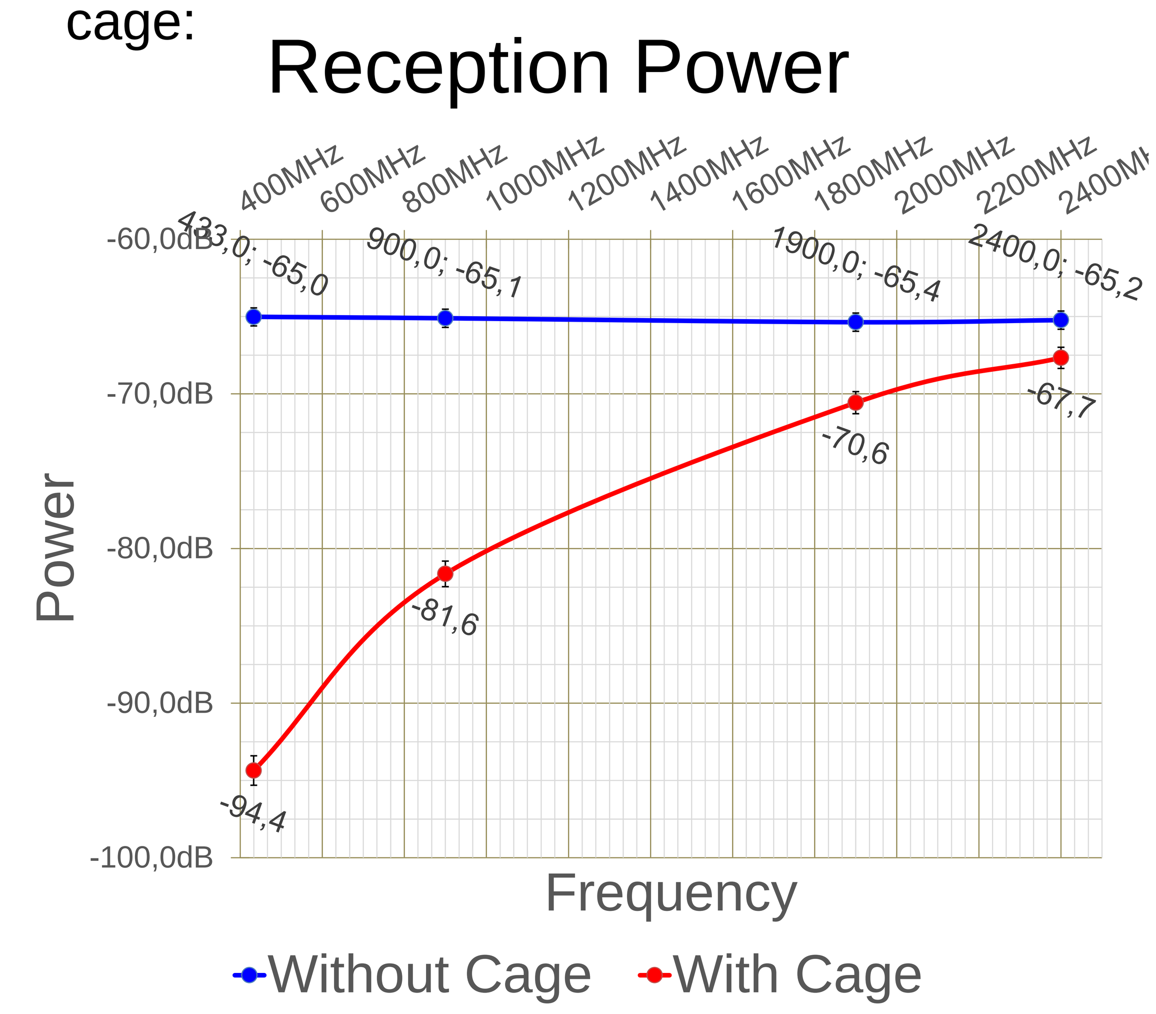

Fig 7 – Reception power with and without the cage

It is possible to perceive the effect of the cage on the reception power. Attenuation and frequency are related in an exponential way. If it is considered that the cut-off frequency has an attenuation of 3dB, this would be around 2,4GHz, which wavelength is 0,125m, about 12 times the grid size.

Final Considerations

Studying and understanding the effects of a Faraday cage is crucial for a telecomm professional, as it has a deep effect in RF signals.

Because the conception of the cage is fairly simple, and the materials can be found easily, this experiment is suited to be executed by instructors or students at a middle or high school too, using, for example, a FM radio (89,00MHz to 108,00MHz) or a cellular phone.

References

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