Principle of Faraday Cages Applied to Avionics and Aircraft Radar

Wilson G. Salgado, Vladimir Sanchez Padilla, *Member, IAENG*, Javier I. Hidalgo, Paul A. Aguilar

***Abstract*—Faraday cage's postulate: "All electricity goes up to the free surface of the bodies with no production of diffusion inside". The application of this cage is used to eliminate the electric field effects in volumes, to protect electronic equipment from power outages and other electrostatic dischargers; thus, avionic, aircraft communication or radar systems are not affected. All this is known as electromagnetic shield.**

***Index Terms*—Avionics, electromagnetic shielding, Faraday cage, HIRF.**

I. INTRODUCTION

AVIATION, one of the most exciting developments for humanity, .detaches one from the safety of the ground to ascend to heaven and return to earth after receiving communion with the infinite. Since the days of the Wright brothers and the birth of aviation, when mankind successfully started controlling heavier aircraft, there have been several advances in engineering and technology to make the flying experience more secure. Among these advances are avionic communication systems and how they form technical, theoretical and practical solutions through multiple and independent systems [1][2], by applying positive knowledge (the way things have to be done), and negative knowledge (the way things cannot be done) [1][4].

An airplane sustained in a determined air route seems attached and immersed in an electric field generated by electric dischargers in a storm. The storm does not affect the navigation system of the aircraft nor communication systems, due to the electromagnetic shielding effect of canceling all production of electric fields inside [1]. According to electromagnetic theory, regions ended in peak produce the highest concentration of electric field in a very small area. This is why airplanes have something called "*widgets*" that allow conduction of the electric flow like a lightning rod. These lightning rods have a protective plastic for the radar called "*radomen*", a dielectric that does not allow the movement of charges and, at the same time, protects navigation systems from climatic conditions in its interior [3].

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The authors are with the Escuela Superior Politécnica del Litoral, ESPOL, Faculty of Electrical and Computer Engineering, Campus Gustavo Galindo, Km 30.5 Via Perimetral, P.O. Box 09-01-5863, Guayaquil, Ecuador (email: {wgsalgad, vladsanc, javihida, paaguila}@espol.edu.ec).

II. ELECTROMAGNETIC SHIELDING

The electric field positioned to an enclosed cavity arrives perpendicular to the surface and charges are induced in its interior, but the flow coming in is equal to the flow that goes out. If the cavity is enclosed by a conductive shell, there are no induced charges, and the electric field inside is zero (Fig. 1) [3][6]. This is what is known as electromagnetic shield, because it blocks all electric field $\vec{E}$ in the volumes that are produced by thunderstorms or loaded clouds, and at the same time blocks any magnetic field B in a space region, in order to protect electronic equipment from power outages and any other form of electrostatic discharge, known as Faraday`s Postulate [5]. In the case of aircraft surfaces, the electromagnetic field seeks to be rearranged, so the field inside is zero. Conductors facing mediums with electromagnetic fields block or shield these field lines in order to protect electronic equipment from power outages and any other form of electrostatic discharge during the period of flight [6].

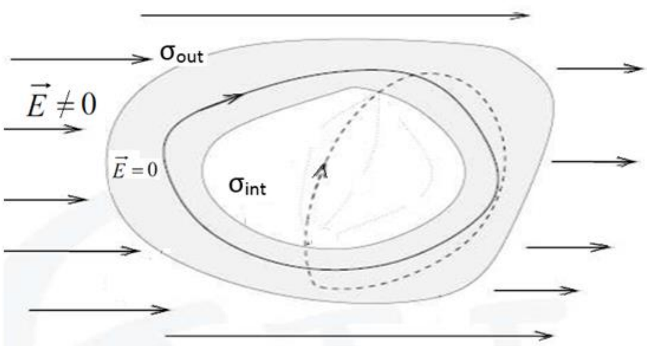

Fig. 1. Presence of external electromagnetic field in a surface.

III. FRONTIER CONDITIONS

In frontier conditions, the vacuum can be exploited through dielectric constant, so at the moment of inducing a wave with an impedance 377Ω (like the vacuum) the aircraft fuselage is considered a dielectric medium with zero conductivity, but with a higher electric permittivity. The propagation constants and the intrinsic impedance of the environment will be imaginary and pure real, respectively, leading to an effect of the theory of the light nature wherein the reflection coefficient will be negative with a positive transmission coefficient less than the unit. These coefficients will allow the air-dielectric boundary to behave as an electric wall, in order to cancel the electric field [3]. With the opposite case of having a positive reflection coefficient and

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the transmission coefficient greater than 1, the discontinuity will act as a magnetic wall, that is, it tends to cancel the magnetic field [8].

A conductive medium with a much higher conductivity than 1 must be considered. A very realistic reflection coefficient with a value of -1 and negligible transmission coefficient is obtained, so in this interface the electric field declines and penetrates a very small depth in the conductive material [3][8].

When a wave hits a surface with magnitude and direction defined, a reflection occurs (Fig. 2) [5][6], resulting in a change of both the original magnitude and original direction. In other words, with each reflection there will be a loss of energy. The efficiency of Faraday's cages depends on the relation between the exterior radius and the interior radius (Fig. 3). An effectiveness function depicts the protection level of a Faraday´s cages based on the radio relation (Fig. 4) [5].

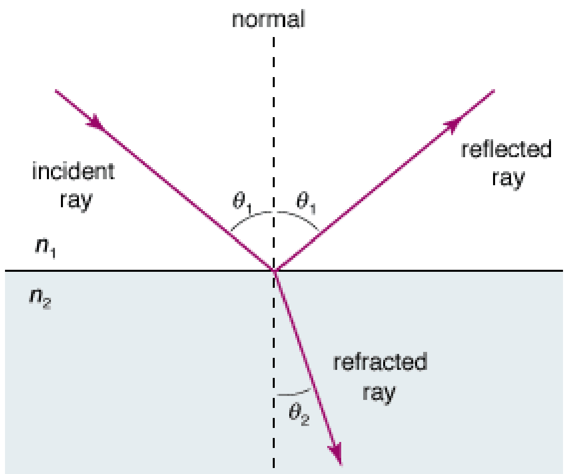

Fig. 2. Snell`s law.

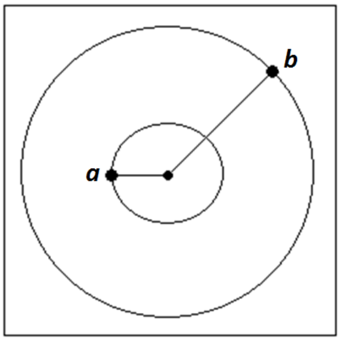

Fig. 3. Proportion between the exterior radius *b* and the interior radius *a*.

The electromagnetic shielding refers to the decrease of the electromagnetic field within a closed circuit. Depending on the intensity, an external electromagnetic field can cause errors in operation of the circuit, therefore it is necessary to reduce this field as much as possible. Integrated elements produce their own electromagnetic field as well, so total elimination of interference fields is not one hundred percent possible.

The electromagnetic shielding effectiveness depends on the material it is made of both in thickness and permeability. The dependence of these factors is crucial to ensuring the operation of a positioning system or a communication system. In aeronautics, a failure of this material would lead to high risk, so appropriate material has to be used, e.g., material too large (dense) requires more effort on the part of the aircraft (Fig. 5) [5]; material with high permeability (low density) can produce much fragility in the electromagnetic shield.

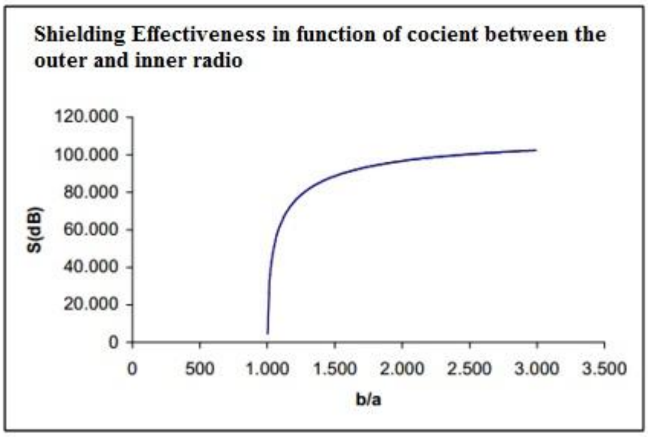

Fig. 4. Axis x proportion between the exterior radius *b* and the interior radius *a*. In the axis and the efficiency of the Faraday Effect.

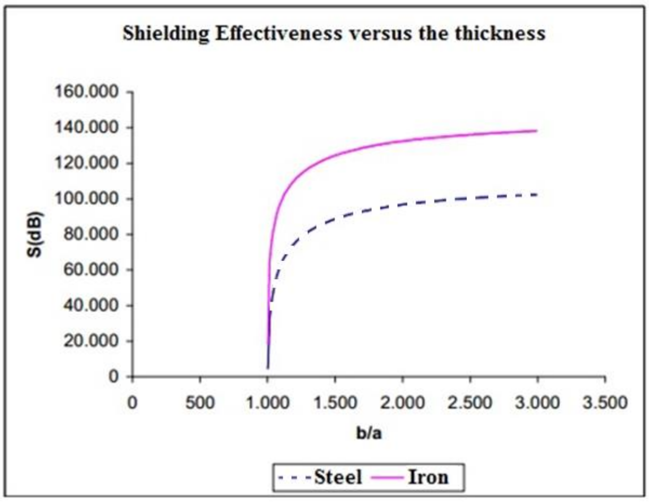

Fig. 5. Efficiency of the effect of Faraday's cages face to the magnetic permeability of the material. The representation of the iron curve is the continuous one.

IV. Gauss's Theorem Review

Applying Gauss's Theorem for Electrical Fields:

$$\oint_{S_1} \vec{E}.\vec{dS} = 0 \Rightarrow \frac{Q_{S_1}}{\varepsilon_0} = 0 \Rightarrow Q_{S_1} = 0$$

So it must be met:

$$\oint_{S_{\text{int}}} \sigma_{\text{int}}(\vec{r}).dS = 0$$

Theory affirms that imaginary lines of electrical field that go out of the source must return to a sump. Due to the fact that the Coulomb's force is a conservative force, it bears out that:

$$\oint_r \vec{F}(\vec{r}).\vec{dr} = 0 \Rightarrow \oint_r \vec{E}(\vec{r}).\vec{dr} = 0$$

For any closed circuit with limits from *A* to *B*:

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$$\oint \overrightarrow{E}(\vec{r}).\overrightarrow{dr} = 0$$

The line integral of Gauss's Law can be only zero if the electrical field is zero, due to the fact that if the field is parallel to the line, its inner product leads to an electrical field value of zero in any place of its interior. This is a reason why a conductor operates as an excellent blockade in countering electrical external fields [5][6]. This theory is useful in understanding a Faraday cage, showing the absence of an electrical field in the interior of a potential conductor.

V. High Intensity Radiated Fields (HIRF)

Recent technological advances have given place to applications in the design of electronic systems that carry out the necessary functions for the safety continuation of an airplane, both flight and landing. Due to the use of sensitive components of advanced solid state, analog and digital circuits, presently-used systems are easily sensitive to transitory effects of induced electrical current and tension caused by HIRF. This type of intensity can degrade the performance of electronics systems and produce damage in components or disturbing its functionality [3].

In addition, the ambient of HIRF has suffered a transformation that was not foreseen when the current needs were developed. Highest energy levels are radiated from transmitters that are in use for radar, radio and television. There is an uncertainty on the fuselage shielding efficiency for HIRF. Effective measures against the effects of the electrical and electronics vulnerability must be provided in the design and installation of these systems. Maximum accepted energy levels in which system facilities of civil aircraft must be capable of operating safely are based on surveys and analysis of radio frequency transmitters. These special conditions require the aircraft to be evaluated under these energy levels for electronics systems protection and the associated wiring. Levels of external threats, which are lower than previously required values, represent the worst cases where an aircraft is exposed in the operative environment [6].

VI. Analog Digital Converter

An Analog to Digital Converter (ADC) is an electronic device that turns a continuous analogical voltage input in digital binary values of 0 and 1. ADCs are very useful in electronic devices, such as computers, video consoles, telecommunications equipment, and aircraft radars, among others. These converters have two signal entries referred as +Vref and –Vref, and determine the range into which a sign input will turn. The converter establishes a relation between its analog signal input and its digital signal result depending on its resolution. This resolution can be known, as long both the maximum value of the information input and the maximum quantity of the output in binary digits are known [3][8].

VII. Avionics

Avionics is a term that relates aviation (or aeronautics) to the electronics systems. Nowadays, navigation systems of aircraft, satellites and space ships use indicators and management elements that refer to avionics, which includes several systems with individual tasks. These systems include ignition, rotation, calling, or more complex landing networks. The term avionics started to be used more by airlines in the 1970's [1]. Until then, navigation instruments, such as radio navigation, radars, engine control, or automatic fuel systems were independent of each other, normally associated with mechanical features. By 1970, the military industry needed to improve the aviation systems concerning emergencies (e.g. assault), giving priority to the study and design of avionics issues. Military aviation efforts for unifying systems with several electronics equipment and platforms have become a great challenge; civil commercial aviation has made breakthroughs in electronics [7].

Electronic flight's system control, like fly-by-wire (Figures 6 and 7, courtesy by the authors) allows for a safer flight according to international standards agreements. With the use of devices as actuators and sensors; mechanical devices and the need of improvements teach upcoming aeronautical generations that the costs of this technology are notably expensive, which could be interpreted as a "penalty" for having less risk for flight experiences.

Fig. 6. Airplane's communication system.

The more transcendental change has been the interest of airlines to acquire fourth generation technologies, which can include automatic landing systems through satellite communication [4]. Air flight is in high demand as a fast and safe way of transportation necessitating complex methods to control and reduce aircraft accidents, avoiding distrust among users. Both guidance and navigation systems have become more exact and autonomous because of technological advances in devices parts construction [1][7].

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Fig. 7. Airplane’s Fly-by-wire.

VIII. Conclusion

Applications of electromagnetic theory and communications are very diverse in the fields of engineering and information technology. In avionics and the aircraft industry, a Faraday cage produces a “screen” effect, where an aircraft influenced by different meteorological inclemencies, including unloaded electrical beams, rainfall, cutting winds canceling electromagnetic external fields. For the specific case where an airplane is seen as a continuous material system in the presence of electrical fields, this effect makes all the electricity go to the free surface of the fuselage, completely diffusing the interior electric charge, displacing the electric fields in to open spaces in order to protect the electronics equipment from voltage failures or electrostatics discharges. With the Faraday cage, navigation systems will not be affected, due to electromagnetic screening.

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