Part I
Identification of fuel cells and electromagnetic reverberations chambers

1. Fuel cell

1.1. Fuel cell technology use

Fuel cells belong to the group of galvanic elements, which, as electrochemical energy converters, can convert the chemical energy of a fuel into electrical energy. Since fuel cells can generate electricity directly from chemical energy, they are much more efficient than internal combustion engines [1]. The principle of the fuel cell was discovered in 1838 by Christian Friedrich Schönbein and soon after, Sir William Grove, along with Schönbein, recognized the reversal of electrolysis and power generation. With the invention of the electrical generator by Werner von Siemens, the invention known as the "gas battery" fell into oblivion. It wasn't until the 1950s that the idea was revived due to the need for compact and portable power sources in space travel and the military. Global warming and air pollution gave research into this technology decisive impetus that continues to this day.

1.2. Principle of operation

A fuel cell consists of a cathode, anode coated with catalysts such as platinum or nickel and a membrane Fig 1.

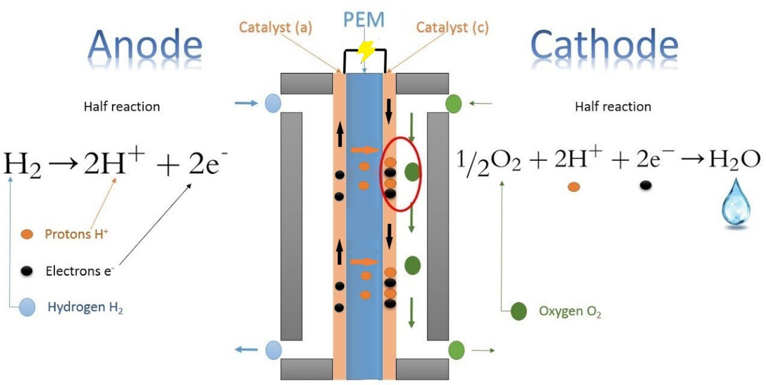

Figure 1: Basic structure and functioning of a fuel cell [2]

The anode is supplied with hydrogen $[H_2]$, which oxidizes to protons $\left[2H^+\right]$ on the catalyst layer, giving off electrons $[2e^-]$. The proton exchange membrane (PEM) is only permeable for ions, so only the ions flow to the cathode via PEM. The electrons flow from the anode to the cathode via an external circuit and form the electric current. Both hydrogen protons and electrons migrate to the cathode, where they react with the supplied oxygen [O_2] to form water [H_2O]. Depending on the operating point, a single cell delivers a certain voltage between 0.5 and 1.0 volts. For higher voltages, individual cells are connected in series and a so-called stack is obtained as the core element of the fuel cell.

1.3. Types of fuel cells

There are different types of fuel cells, which differ in the electrolyte used, in the operating temperature, in the fuels that can be used and in the power range and thus the areas of application Fig 2.

Fuel Cell	Electrolyte	Operating Temperature	Electrical Efficiency	Fuel 'Mixture'
Alkaline Fuel Cell (AFC)	Potassium hydroxide (KOH) solution	Room temperature to 90°C	60-70%	H_2 - O_2
Proton Exchange Membrane Fuel Cell (PEMFC)	Proton exchange membrane	Room temperature to 80°C	40-60%	H_2 - O_2 or Air
Direct Methanol Fuel Cell (DMFC)	Proton exchange membrane	Room temperature to 130°C	20-30%	CH_3OH - O_2 or Air
Phosphoric Acid Fuel Cell (PAFC)	Phosphoric acid	160-220°C	55%	Natural Gas, Biogas, H_2 - O_2 or Air
Molten Carbonate Fuel Cell (MCFC)	Molten mixture of alkali metal carbonates	620-660°C	65%	Natural Gas, Biogas, Coalgas, H_2 - O_2 or Air
Solid Oxide Fuel Cell (SOFC)	Oxide ion conducting ceramic	800-1000°C	60-65%	Natural Gas, Biogas, Coalgas, H_2 - O_2 or Air

Figure 2: Different fuel cell types [3]

AFC are among the earliest researched fuel cell types and were mainly used in space travel deployed. Operating efficiency: about 60% to 70%. Proton Exchange membrane fuel cells (PEMFC) use membrane foil called Nafion and Electrodes with platinum layers as catalysts. They are powered by hydrogen or finely purified reformate from simple hydrocarbons such as natural gas, LPG or alcohols. These cells are used in home power supplies, power plants, submarines and space travel and have an efficiency of 40-60%. Direct methanol fuel cells (DMFC) are operated with liquid methanol and a membrane foil is used as the electrolyte. Due to the low power density, these cells are mainly used as battery chargers. Molten carbonate fuel cells (MCFC) have a molten carbonate electrolyte. Because of the operating temperature of approx. 650°C and the resulting high reaction speeds, therefore no expensive noble metal catalysts are required. They are operated with desulfurized natural and coal gas or suitably cleaned biogas. MCFC systems are developed for the power plant range from 200 kW to several MW and have an efficiency of 50% to 65%. Solid oxide fuel cells (SOFC) are operated with a solid ceramic metal oxide as the electrolyte. The operating temperature of 800°C enable that no expensive noble metal catalysts are required. These cells can be operated with fossil gases or biogas. SOFC systems are developed in the power range from 1 kW to 200 kW and have an efficiency of 60-65% [4].

1.4. Challenges and solutions

The fuel technology is mature in many areas and in regular operation. In particular, passenger cars, forklifts and micro combined heat and power plants (CHP) for residential buildings are among the mature applications and are already commercially available, followed by buses, emergency generators, industrial CHP plants and various network services. However, there are many possible ones Hydrogen and fuel applications Cells where no comparable experiences have been made so far and which are still in the research and development phase. These include, for example Trains, waste disposal vehicles and delivery vehicles, but also heavy duty trucks as well airplanes and ships. The challenge for the use of the technology also remains in terms of infrastructure as well as expanding the filling stations for hydrogen. In addition to the infrastructure The further development of the production facilities is a challenge, especially in the transition to serial production. For this reason Know-how transfer is essential for the market ramp-up, to reduce existing reservations and gaps in knowledge [5].

2. Electromagnetic reverberations chamber

2.1. Application of a reverberations chamber

Electromagnetic reverberations chambers (ERCs, alternatively mode stirred chambers, MSC) was first proposed in 1968 [6][7] and they are used for various electromagnetic compatibility (EMC) test procedures, e.g. immunity test, radiated emissions or screening effectiveness tests. MSCs consist of a electromagnetic cavity resonator fed by an RF source. Inside any electromagnetic cavity resonator both electric and magnetic field are spatially arranged in so called resonant modes based on standing waves. Additionally, an asymmetric metal piece, the so-called mode stirrer, is mounted in a wall of the resonator, which can be turned to modify the boundary conditions for the electric field.

Resonators which are operated at a frequency at which a sufficiently large number of resonant modes are excited are called overmoded. In the case of an overmoded reverberation chambers equipped with a moving mode-stirrer, it has been demonstrated that the statistic of the field amplitude is supposed to be uniform in the working volume. Using a mode-stirring object, the main objective is to produce a statistically uniform electromagnetic field in the sense of homogeneity (uniformity with regard to the location - spatial uniformity) and isotropy (uniformity with regard to the orientation - polarization uniformity) of the field. The latest properties are directly linked to the number of significantly excited modes, the quality factor Q, often estimated as a composite quality factor, which quantifies the amount of energy stored in the reverberation chamber, their bandwidth $BW_q = f/Q$ and finally the stirring efficiency S_e. More details can be found in [8].

A DUT placed inside the working volume of a functioning chamber is exposed to an electromagnetic field with constant magnitude and normally distributed angle of incidence and polarization plane.

ERCs became one of the focuses of research in the electromagnetic compatibility community some 15 years, and many investigations did show that the ERC enables the characterization of electronic devices in a statistically evaluated electromagnetic field which exists in a subvolume of the resonator's interior, the so called test volume. Subject to random variables, the description of a stochastic exposure requires the modeling of physical phenomena related to the electromagnetic source and the physical properties of the device under test (DUT). One of the test environment, which allows the simulation of stochastic process, is the Electromagnetic Reverberation Chamber (ERC) [9]. It's development was inspired from autistic reverberation chambers which are used for sound tests.

During the design process of a reverberation chamber, the size of the test volume will be defined so that the lowest usable frequency (LUF), the lowest frequency at which the resonator is overmoded) cover the frequency band of interest for the susceptibility evaluation and that the working volume can host the device under test taking into account a minimal distance between the device under test and the walls at a quarter of the longest wavelength. Many studies have been dealing with the ideal and efficient way to create the required uniform and isotope fields . Readers can refer to [8] and to [10] regarding mechanical mode-stirrers comparison. The validation of the test environment is defined in [10]. Interestingly, later studies have leveraged the use of chaotic processes in fixed environments to improve the mechanical stirring approach (hybrid techniques) in order to obtain an efficient test environment [11].

2.2. Technical challenges

In an ERC it is desirable that the DUT is evenly irradiated from all sides. This is achieved by a statistically uniform and isotropic field in the chamber. Factors such as the broadband bandwidth of the antenna, the nature of the walls (surface geometry and conductivity), the size of the chamber and thus the frequency used as well as the shape and number of stirrers play a role. In practice, vivaldi antennas and logper antennas are mainly used as excitation antennas because of their broadband. As a rule, iron sheets are used to ensure good conductivity of the walls. Interesting objects of investigation are geometric shapes attached to the walls, which specify irregular boundary conditions for the field and the shape and number of stirrers that swirl the field. These aspects ensure a homogeneous field quality and consisted of many works.

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