# 1

# Introduction



## 1.1 Background

The concept of the Reverberation Chamber (RC) was first proposed by H. A. Mendes in 1968 as a novel means for electromagnetic field strength measurements [1]. The RC can be characterised as an electrically large shielded metallic enclosure with a metallic stirrer to change the field inside the chamber that is designed to work in an 'over-mode' condition (i.e. many modes). It has taken some time for the facility to gain universal acceptance, but by the 1990s, their use for performing Electromagnetic Compatibility (EMC) and Electromagnetic Interference (EMI) measurements was well established and various aspects were studied [2–11]. An international standard on using the RC for conducting EMC testing and measurements was published in 2003 [12]. The RC is now used for radiated emission measurements and radiated immunity tests, as well as for shielding effectiveness measurements. It was in this role that the facility was known for a long time and in part still continues to be [13, 14]. More recently the RC has been employed for antenna measurements due to the rapid development of wireless communications.

It is clear that the role and function of wireless technology in everyday life have reached unprecedented levels as compared to 20–30 years ago. For this change to take place, it has meant that antenna designs and their characterisation have had to evolve also. A question exists as to how the RC has risen to prominence to be proposed

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and also to be used for antenna measurements, which represents a brand new capability for the chamber that diverges from its initial intended use. To answer this question, we must partly examine the nature of antenna designs and their operational use.

Traditionally, antennas have always been orientated, and their communication channels configured in a Line of Sight (LoS) manner. For example, we have terrestrial antennas mounted on roof tops, and other directive types of antenna that are employed in satellite communications. The characterisation of these types of antenna for use in LoS communications are widely defined by the application of an equivalent free space reflection-free environment, which is typified by the Anechoic Chamber (AC). In a real application environment, reflection, scattering and diffraction effects may still exist to a certain extent, which brings about the creation of additional wave paths within the communication channel. However, the AC is still the preferred environment to characterise these types of antennas as their radiation patterns (and other subsequent parameters of interest) are of prime importance to the LoS scenario.

When we consider the modern mobile terminals (such as the mobile/cell phone), they do not operate under the premise of an LoS scenario. The antennas inside mobile phones might seldom 'see' the base station and they are expected to work perfectly in Non-Line of Sight (NLoS) environments. This type of environment will readily give rise to signals that will be exposed to reflections caused by large smooth objects, diffraction effects caused by the edges of sharp objects and scattering effects caused by small or irregular objects. When these effects occur, they will cause the creation of additional wave paths which will eventually add at the receiving side. These wave contributions have independent complex amplitudes (i.e. magnitude and phase information), such that at recombination, they may add constructively or destructively or anything in between these extremes. The wave paths and their complex amplitudes are also subject to rapid changes with time, with the terminal moving or parts of the environment (communication channel) changing. This brings about variations in the signal at the receiver and is commonly referred to as fading. The largest variations occur when there is a complete block on the LoS, which is more accurately referred to as small- scale fading, as opposed to large-scale fading, which is usually applied to variations only in the distance from the transmitter or due to part shadowing [15].

As it is important to characterise any antenna in a manner befitting its operational scenario or intended use to accurately reflect the performance merits, another measurement facility is required that can emulate this type of fading environment – this is where the RC comes in. The antenna measurement inside an RC can be closer to a real-world scenario than inside an AC. Furthermore, some measurements, such as the antenna radiation efficiency measurement, may be more efficient and accurate if preformed in an RC than in an AC as we will see later in the book.

When the regulations of the American Federal Communications Commission (FCC) released the unlicensed use of the Ultra Wide-Band (UWB) frequency domain between 3.1 and 10.6 GHz in 2002 [16], a vast amount of interest and industrial/academic research followed. The RC offers little restriction concerning large operational frequencies while also allowing for a vast range of device types and sizes.

Financial implications have also played a part in the subsequent rise to prominence of the RC. With the construction and operation of an AC (here we will only specifically compare with far field ACs), large amounts of anechoic absorber must be purchased to line the walls in order to suppress reflections, and this can be expensive. The RC requires no such absorber, leaving the walls purely metallic to actively encourage reflections – a trait which allows for a cost saving. Furthermore, if one was to compare the relative size of each facility against the lowest frequency of operation, it is possible to conclude that the RC can be constructed smaller in size than its far field anechoic counterpart – again offering a potential cost saving.

The RC is a unique, stand-alone facility, in the sense that it will allow a user full control over the time frame and uncertainty inherent in a given measurement; this distinguishes itself from any other facility. The operational principles for the RC allows for the measurement resolution to be clearly defined which in turn controls the overall measurement time. Mathematical procedures can be defined which link the expected uncertainty to the resolution and thus the time frame. Therefore, before a measurement commences all the parameters can be defined accordingly.

Perhaps one of the more important factors that led to the increasing popularity of the RC concerns the ease of measurement. Due to its unique operation of multiple reflected waves, the angle of arrival of these waves reaching any receiving antenna or device is uniformly distributed over three-dimensional space [17]. What this effectively means is that the angle of arrival and wave polarisation is equally probable which can simplify the characterisation of any device, as in such an environment, their performance is then insensitive to their orientation – this aspect is particularly acute for EMC and antenna measurements.

## 1.2 This Book

The RC is a very powerful tool for EMC and antenna measurements and has many advantages to offer. There have been many journal articles published over the years on the subject which signifies its increasing popularity; however, few published reference books exist. The most relevant ones are probably references [18] and [19]. They have provided an excellent and comprehensive coverage on the electromagnetic theory on cavities and RCs, and a very good introduction to EMC tests and measurements using an RC. But very limited information is on the RC design and its application to antenna measurements. There are still some important issues on how to use the RC for EMC and antenna measurements in practice.

This book is different from other works on RCs. It is designed to encompass both EMC and antenna measurements together which is important as there are subtleties between how the RC facility is used with respect to these different domains – it is crucial therefore to understand what these are and how to apply the operational principles of the chamber for the benefit of the intended measurement.

The book is also designed to take a reader from the very basic theory of the chamber to a more complicated stirrer design and measurements. It is written to include both detailed theory and practical measurements so a reader can appreciate and understand not only what the theory means, but also how to apply and configure it in a practical manner to complete a desired measurement. With all this information in one place, this book aims to ensure that the reader has a comprehensive yet compact reference source so that the RC can be studied and understood without needing to access a number of different sources which may not be well correlated.

The material covered in this book is underpinned by accepted theory on the RC that is published worldwide along with our own detailed research which covers many of the very latest and cutting-edge trends. The information in the book is also used as part of the Antennas (antenna measurements section) and EMC modules for students at the University of Liverpool. This subsequently is also where all of the measurement work for the book has been wholly conducted. A major feature of this book is to apply the theory to practice.

The book is organised as follows:

*Chapter 2: Reverberation Chamber Cavity Theory.* This chapter details all the important theoretical concepts that uphold and support the use of the RC as a measurement facility. In this chapter, all the theories are explained, all equations detailed and these are supplemented with practically measured quantities from the RC at the University of Liverpool, to illustrate the magnitude of the quantities derived.

*Chapter 3: Mechanical Stirrer Designs and Chamber Performance Evaluation.* This chapter presents a general method that can be employed to go through the process of designing mechanical stirring paddles for use in the chamber. New mechanical stirring paddles are designed and presented in this chapter. Also detailed are the complete equations and practical procedures of how the performance of any given chamber may be assessed in an accurate and robust manner.

*Chapter 4: EMC Measurements Inside Reverberation Chambers.* This chapter focuses specifically on EMC tests in RCs. The relevant standards for EMC tests in RCs are discussed, after which immunity and emission tests are introduced. Practical procedures of how to conduct EMC tests are explained which is followed by practical tests. A comparison between RCs and ACs for EMC radiated emissions is also presented to benchmark both facilities.

*Chapter 5: Single Port Antenna Measurements*. This chapter is dedicated solely to single port antenna measurements in RCs. The measurements are based around some of the very latest trends in the antenna field with the use of textile antenna which is selected as an example to demonstrate measurement procedures. This chapter not only shows how to measure single port antenna quantities in free space conditions, but also shows how body worn antennas can be measured that include the use of live human beings in the chamber. The radiation efficiency is the major concern of the measurement. This chapter also includes some of the subtle measurement issues that should be avoided when conducting such measurement work in addition to a comprehensive uncertainty assessment, including both procedures and equations.

*Chapter 6: Multiport and Array Antennas*. This chapter discusses how multiport and array antennas can be measured using the RC. The multiport section includes all measurement procedures and equations for quantities such as diversity gain, correlation and channel capacity and details the performance merits of a new multiport (diversity) antenna for Multiple Input Multiple Output (MIMO) applications. The array section shows how the efficiency of large-scale arrays can be measured using the chamber and develops a new equation to allow this characterisation to take place.

*Chapter 7: Further Applications and Developments*. This chapter presents and discusses some of the very latest research in RCs that includes how to measure antenna performance parameters without reference antennas. Also included is the use of the RCs for emulating different 'channel' characteristics which is important for many over- the-air measurements.

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