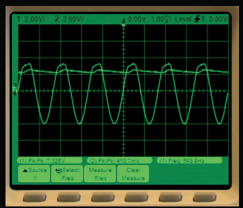
VISIR Handbook

Analog Electronics with the VISIR Remote Lab: Real Online Experiments



In 2006, the Signal Processing Department at Blekinge Institute of Technology and Axiom EduTECH in Sweden worked with National Instruments Corporation in Texas, USA to set up the Virtual Instrument Systems in Reality (VISIR) Project, which operates as a remote laboratory for electric and electronic circuits.

The VISIR remote laboratory is currently the only system that delivers practical experiments with electronics without the need to go to a traditional lab. This is of increasing importance given the expansion of online education. There is a mass of scientific literature that collects results on the use of VISIR remote laboratory, however, there is currently not a single reference work that provides an in-depth exploration of the laboratory's performance and potential.

VISIR Handbook acts as a reference guide for future users, demonstrating many of the real (remote) experiments that can be achieved and replicated with this laboratory. Most importantly, this book demonstrates how VISIR can be used in the classroom with students as a learning tool. The approach of the book is designed on two levels, with an administrator/researcher approach and a teacher/student approach.

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Gustavo R. Alves

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Preface

Remote experimentation and remote experiments have been around for more than 25 years, being commonly used in universities and other educational institutions. A remote experiment is a real experiment in which the learner is not at the same location of the experiment and the interaction is mediated by the Internet. A remote experiment is a learning tool and its main characteristics are scalability, sustainability, educational quality, and equity.

The VISIR Handbook focuses on one particular remote laboratory: Virtual Instruments Systems In Reality (VISIR), which is undoubtedly the best remote laboratory, the most widely used and deployed in more institutions other than the one that developed it, the Blekinge Tekniska Högskola (BTH). This book is a detailed guide to its qualities and capabilities so the reader can get to know it if he or she does not have one or exploit it in depth if he or she already has one.

VISIR is almost 25 years old now (1999–2023). It was designed by Professor Ingvar Gustavsson and it focuses on electrical and electronic circuits: assembling, measuring, and analyzing circuits created with real components and wires. From the beginning, Professor Gustavsson shared the design with the academic community. As a result, VISIR is now available in 12 countries and its design and capabilities continue to improve. This book is a compendium of everything that has been developed around the VISIR laboratory, both from a technical and didactic point of view.

The authors of this book are VISIR experts in its design and use, as well as in research around this remote laboratory. The University of Deusto (Spain) was the first to deploy a VISIR outside BTH (Sweden), while IPP/ISEP (Portugal) was the first to have two VISIRs accessible to the students. Overall, over the past 13 years, hundreds of teachers and thousands of students have used VISIR to assemble and measure several millions of circuits. It is this experience that is brought together in the book.

The reader interested in this book has three reasons or scenarios for reading and using it. The reader who is only interested in using VISIR will find in Part 2 a set of ready-to-use classroom and laboratory activities. But if the reader also wants to master VISIR as a whole so that he or she can decide which circuits to use and how to create them, then Part 1 will be perfect for his or her interests. In addition, VISIR's success and longevity allow the reader to reflect in Part 3 on various aspects of electronics education and to ask technical and didactical questions that will place him or her at the cutting edge of VISIR research. This book can therefore be read in order, but the reader can also organize his or her reading according to his or her interests.

This book considers the use of this online laboratory to support the acquisition of experimental competences. An expression of the relevance of this topic is corroborated by the recent edition of the International Handbook of Engineering Education Research (2023), which includes a chapter dedicated to "Online Laboratories in Engineering Education Research and Practice". In short, online laboratories, like VISIR, do have a role to play in better preparing engineering students for an ever-increasing online world. And even if this book focuses on remote (real) experiments for electrical and electronic circuits, a companion book also available from World Scientific Publishing entitled *Remote Laboratories: Empowering STEM Education with Technology* will provide the reader with a wider notion of how online laboratories can impact STEM education.

About the Authors

Unai Hernández-Jayo is a Telecommunications Engineer and holds a PhD in Computer and Telecommunications Engineering from the University of Deusto. He is currently a lecturer and researcher at the University of Deusto. His publications are mainly in the area of e-Learning, specifically in the design and development of remote laboratories, an activity he carries out within the framework of the DEUSTEK research group. He has participated in more than 50 research projects, being the principal investigator in more than 20 of them. He is an author/a co-author of more than 150 research publications, mainly in the area of engineering education and remote laboratories.

Javier García-Zubía is a professor at the University of Deusto since 2015 and is a member of the DEUSTEK research group. He was involved in 50+ national and international R&D projects and has authored or co-authored 250+ publications, including book chapters, conference, and journal papers with a referee process. He was invited as a keynote speaker in 10+ conferences and he was awarded in 10+ events. He edited three books around remote labs and he is the author of the book *Remote Laboratories: Empowering STEM Education with Technology* recently published by World Scientific Publishing.

Gustavo R. Alves obtained his PhD and the Habilitation in Computers and Electrical Engineering, from the University of Porto, Portugal, in 1999 and 2023, respectively. He is affiliated with the Polytechnic of Porto – School of Engineering, since 1994, where he now holds a position as an Associate Professor. He was involved in 19 national and international R&D projects, has authored or co-authored 270+ publications, including book chapters and conference and journal papers with a referee process, and has delivered 70+ invited webinars/keynotes at national and international levels. His research interests include engineering education and remote laboratories.

Dr. Alves currently serves as the Head of the Innovation Centre for Engineering and Industrial Technology (CIETI), an R&D unit supported by the Portuguese Governmental Agency for Science & Technology (FCT). He also serves as the Associate Editor for the IEEE Journal of Latin-American Learning Technologies.

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Part 1

VISIR Remote Lab Description

Chapter 1

Introduction to Remote Labs in Electronics

1.1 Introduction

Let's start at the beginning... is it necessary to experiment in order to learn? And, if so, how can we develop experimental work in the teaching–learning process?

In the field of Science, Technology, Engineering, and Mathematics (STEM) education, the answer to the first question is clearly affirmative. In order to develop scientific-technological competences, students must be able to bring the theoretical concepts introduced by the teacher into the laboratory, to set up the proposed models and empirically verify their validity.

The typical place to carry out these experiments is the laboratory. It is a dynamic place where students can touch, connect, configure, move, observe, and listen; in short, configure their experiment, analyze its evolution, and reach conclusions through the analysis of the data obtained. Therefore, it is known as a hands-on laboratory.

In order to conduct a laboratory session in the hands-on laboratory, the teacher must first define the practice that the students will carry out. They must also prepare the laboratory, i.e., the equipment and materials that the students will need. Finally, they must also plan the time the students will need to complete the practical. The teacher should even have replacement equipment or materials, in case something breaks down or stops working due to a specific failure, or simply because it runs out of batteries, for example.

While it is true that these tasks are part of the teacher's work, there is also a multitude of applications, platforms, or services aimed at helping the teacher in the development of theoretical lessons; in the case of practical activities, the most common are simulators or virtual environments. In general, they are software applications that represent in a certain way the real experiments that the student could carry out in the hands-on laboratory. Simulators or virtual environments can play a very important role in the learning process, as they allow teachers to show their students variations of basic experiments that, due to lack of time, materials, and other resources (or even safety), cannot be carried out during practical sessions.

However, there are certain skills or competences that cannot be introduced via these non-real scenarios, where the responses of the experiments, given their own software-based nature, are previously defined by the developer of the simulator. That is, the responses of the experiments are always the same for the same experiment set-up and rarely give rise to failures or erroneous situations where the learner has to analyze why the results are not as expected.

Although these characteristics are not essential at basic educational levels (primary or secondary) since the aim is to bring scientific culture closer to the students, at higher levels, such as at high school and even more so at university, they are essential. At these levels, students should learn to consider concepts such as precision or accuracy in measurements or results, characteristics of a real experiment that oblige the student to employ different criteria to validate or not the starting hypothesis of the experiment.

If we focus this analysis on a specific STEM field such as electronics, a multitude of software such as Falstad, Orcad/PSpice, or Proteus, among others, is available to analyze anything from simple circuits to complex electronic systems. These tools are very helpful and widely used in the educational and professional field, but to understand how they work and why they provide the results they do, students require practical hours physically building the circuits that they will later be able to analyze using these or other programs.

The learning phase based on the manipulation, wiring, configuration, and measurement of electronic circuits is fundamental and necessary in the training process for engineers and even for beginners in secondary or high school. There is therefore a need for alternatives to simulators that could complement and assist teachers in this phase of learning, and remote labs are the technological solution.

A remote laboratory can be defined as a set of hardware and software technologies that allow a user to connect via the Internet from anywhere in the world to real equipment also located anywhere, and to carry out an experiment with almost the same performance as if they were in the hands-on laboratory. Thus, it is presented as a didactic tool that enables active learning to be carried out telematically within the framework of experimental work.

But we can also define a remote laboratory by describing precisely what it is not. A remote lab is neither a simulator nor a virtual environment. Generally speaking, in these environments, the experiment response is pre-coded or programmed by a designer and will always be the same for a given configuration. However, in a remote laboratory, the response of the experiment can also be influenced by the conditions in which the experiment is carried out, as in the hands-on laboratory: room temperature, errors introduced by the measuring equipment, tolerance of the components, etc. Thus, the user also has to analyze the response of the experiment from the point of view of the accuracy or repetitiveness of the results obtained. Concepts that move from the manual laboratory to the remote laboratory.

Although many different remote laboratories focused on various STEM disciplines can be found in the literature and are available on the Internet (García-Zubía, 2021), in this book, we will focus exclusively on the analysis of the world's best-known remote laboratory in analog electronics: the VISIR remote laboratory.

The following sections of this first chapter will contextualize the origin of, need for, and possible alternatives to the use of VISIR, emphasizing its advantages and also describing its weaknesses. Its usefulness will be analyzed with respect to what the authors have defined as "the ten commandments of remote laboratories". Before doing so, however, we will first outline the structure of this book.

1.1.1 *Structure of This Book*

This book is targeted at various audiences, who may at any given time be the same: Teachers who find in the VISIR laboratory an opportunity to offer their students a teaching tool that has been widely tested and validated throughout the world (especially during the COVID pandemic); teachers who already have a version of VISIR and who do not have a reference manual to improve its operation and take advantage of its potential; or finally, researchers who can develop research work using VISIR as a technological reference or as the basis for their research.

This book is structured in three different parts:

- **Part 1 — VISIR remote part description:** First of all, the context of this book is introduced as well as the VISIR laboratory in the field of remote experimentation and the laboratories framed in the area of analog electronics in particular. The following chapter is the technical description of the architecture and fundamental elements of the VISIR laboratory. This part is especially aimed at all those who have a VISIR laboratory and need to know how to maintain it, how to add new experiments, or how to solve possible errors. It is also a part especially aimed at all those researchers who want to make contributions in the field of remote experimentation and require in-depth knowledge of the technological structure of a remote reference laboratory, such as the VISIR.
- **Part 2 — Teaching with VISIR:** This part is especially dedicated to showing real examples of how VISIR can be used in the classroom. A set of complete practices are proposed that can serve as a reference for teachers who want to include the VISIR in their portfolio of teaching tools. It also includes detailed information on how to configure the VISIR from its technological perspective to be able to deploy these experiments.
- **Part 3 — Research and reflections on VISIR:** This last part aims to summarize the history of the VISIR and provide a complete bibliography of the research work carried out about this laboratory. It is presented as a starting point to continue adding and improving the functionalities of this remote laboratory. Also in this part, the pedagogical impact of the VISIR is analyzed through the studies carried out by users during these last years.

1.2 Remote Labs in Electronics

As has already been discussed in multiple articles and references available in the literature, real experiments are indispensable in engineering teaching, as they contribute to developing skills that help understand, design, measure, and characterize physical processes. It is for this reason that laboratory experiments are integrated into the vast majority of engineering courses.

Chapter 6

The Road Ahead: To Infinity and Beyond

6.1 Introduction

The vision of the VISIR federation, as expressed in Salah (2017), is as follows:

> "*One experiment for all students*
> *All experiments for one student*"

Questioning this vision, what exactly does "all students" mean? And, what about "all experiments"?

The first question links to how many potential users can benefit from VISIR, at any given moment. Considering that VISIR makes it possible to perform experiments with basic-to-complex electrical and electronic circuits, there is a broad range of potential users, including:

- upper secondary school teachers and students, teaching and learning about physics (electricity) (Claesson, 2014),
- teachers and students engaged in undergraduate science and engineering courses that include these sorts of experiments.

According to Statista (2020), in 2019 there were 1.024 million students enrolled in electronics and electrical engineering degrees in India. Given that India awarded 25% of first university degree awards, broadly equivalent to a bachelor's degree, in S&E fields, in global terms, as indicated in Science & Engineering Indicators 2018 (National Science Board, 2018), a simple estimate gives 4.1 million undergraduate students enrolled in electronics and electrical engineering degrees, around the globe. We consider this initial indicator to be the most relevant one, compared with IF (Intensity–Frequency) dimensions, i.e., these students are likely to perform many experiments that can be implemented in VISIR. Students enrolled in upper secondary schools and in Vocational Education Training (VET) programs are likely to perform fewer experiments (frequency↓) but, on the other hand, numbers scale up (intensity↑). According to OECD (2019), on average, around 50% of students that conclude upper secondary education will enter tertiary education. This means the number of students taking Physics in upper secondary schools (in both general and vocational training programs) is in the range of several hundred thousand. Students enrolled in vocational training programs related to electrical and electronic disciplines, however, are likely to benefit more from VISIR, so, for this group, the frequency dimension may be higher.

In addition, Marques *et al.* (2014) provide evidence of VISIR being used in other engineering degrees, such as mechanical and computer engineering. Considering a full semester (15 weeks), VISIR was used for 14 weeks in mechanics and 6 weeks in computer sciences. Again, this would represent a scenario of increased intensity, i.e., according to Statista (2020), the sum of students enrolled in electrical and electronic degrees is 60% smaller when compared to the sum of students enrolled in both mechanical and computer science engineering, and slightly reduced frequency. Furthermore, besides traditional educational contexts (i.e., face-to-face teaching and learning inside formal educational institutions), VISIR has also been used in non-traditional, i.e., informal, and non-formal contexts, for instance, through Massive Open Online Courses (MOOCs), as indicated in Blázquez-Merino *et al.* (2018).

Thus, in conclusion, several hundred thousand students may perform experiments in VISIR every year.

As for the second question, i.e., "how many experiments", this book already presents a first order of magnitude in Part 2, i.e., considering the range of experiments with DC and AC circuits, diodes, transistors, and operational amplifiers, an initial estimation would give slightly over 30 experiments. However, this is an underestimated value simply because the range of possible experiments with both transistors and operational amplifiers, and even with a combination of both, is likely to be in the range of several tenths. Another aspect is the range of possible values for different resistors, capacitors, and inductors (not to mention electronic components). Figure 6.1 shows a typical storage room associated with traditional laboratories for experiments with electrical and electronic circuits. If we consider the number of drawers (in the figure), and that each drawer may contain up to 4 divisions with one component type per division, then a simple calculus of 19 (vertical count) × 33 (horizontal count) gives 627 drawers, which means several hundred components.

Even considering a VISIR matrix with 10 boards, the number of components that can be accommodated is typically in the range of no more

Figure 6.1. A typical storage room associated with traditional laboratories for experiments with electrical and electronic circuits. Top: Piles of 9-drawer electrical and electronic component storage cabinets. Bottom: Detail on drawers with 1, 2, and 4 divisions.

than a few tenths simply because one must also consider the number of shortcuts that need to be installed to measure the current in circuit branches and to allow for different circuit topologies. Again, therefore, in conclusion, it takes more than one single VISIR system to support all possible experiments with electrical and electronic circuits.

6.2 Moving Towards the VISIR Federation

The previous section described one motivation behind the implementation of the VISIR federation, i.e., serving all possible experiments with electrical and electronic circuits to all potential students. However, there is a second motivation based on a model named DIKAR, i.e., Data–Information–Knowledge–Action–Results. Basically, the DIKAR model, as proposed by Venkatraman (1996), provides a framework for achieving results by monitoring the relationship between data, information, knowledge, and strategic actions. In the case of the VISIR federation, the raw data correspond to every experiment performed, i.e., **what** the experiment (circuit topology, components used, instruments configuration and readings, etc.) was; **who** performed the experiment (although these data may be anonymized, there is a unique identifier that may be used to track all experiments made by the same individual); **when** it was performed; and **how long** it took. As for **why** it was performed, the answer may require moving up one step to the information level, i.e., it may require understanding the didactic implementation associated with the experiment performed and the agent.

In sum, having access to all the XML (eXtensible Markup Language) files exchanged with the experiment server of every VISIR node, in addition to the <components.list> and <maxlist> files, provides **data** to obtain **information** on how every VISIR node is being used. Note that ongoing works like Cuadros *et al.* (2021) and Hernández-Jayo *et al*. (2023) already provide tools for extracting information on how many different circuits are being experimented with on a VISIR system and how many correspond to correct or incorrect experiments. This information is important because it helps understand how well VISIR is serving students in their learning process. Performing an incorrect experiment is not necessarily a bad thing if it helps a student discover the path towards performing it correctly. Of course, there is an associated cost (time spent) but, again, there is also an associated gain (learning).

Gathering this information allows the VISIR federation to build **knowledge**, supporting future **actions** and leading to desired **results**. For instance, how close to saturation is one VISIR node? Should a given experiment be replicated in two or more VISIR nodes to distribute the server-access load among those nodes? Should a VISIR node focus on one particular range of experiments to optimize its <component.list>, avoiding unnecessary matrix configurations, or should it try to support a wide range of experiments, in an attempt to support all potential experiments required by the teachers/students using that node?

6.3 The VISIR Roadmap

An alternative application of the DIKAR model, proposed by de Vos (2009) and named RAKID (Results, Actions, Knowledge, Information, Data), makes it possible first to look into a given **result** and then follow the model in the inverse direction, i.e., what **action(s)** should be taken to obtain that result, what **knowledge** is needed to carry out those actions, what **information** is necessary to form that knowledge, and, finally, what sort of **data** are needed to build that information. In fact, this alternative approach has been followed in Alves *et al.* (2022), which describes a roadmap (i.e., a desired result) for VISIR. Quoting the authors:

> The proposed roadmap and its guidelines establish a sustainable strategy and framework to support the future of VISIR and enlarging its community.

The roadmap was defined following a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis performed by 15 experts, with extensive experience in VISIR deployment, and their perceptions in three categories: technical, pedagogical, and educational. In each of these categories, future directions have been defined to tackle VISIR weaknesses while not compromising any of its strengths and considering possible opportunities and threats. An aspect worth mentioning is that some of the proposed future directions are in fact already being pursued by ongoing research, such as that of Cosic (2021) and Larbaoui, Naddami, and Fahli (2021). While new researchers are starting their PhDs, addressing specific aspects of VISIR that have been identified in the proposed roadmap, the goal will inevitably be to have the VISIR federation supporting “All experiments for all students”, in electrical and electronic circuits.

6.4 An Open Conclusion

In an article entitled “Virtual Laboratories — A historical review and bibliometric analysis of the past three decades”, Raman *et al.* (2022) list the top contributing institutions based on publications and citations (referring to articles about virtual laboratories) — see Table 3, page 10 in this volume. Among the top-10 institutions included in that list, six (including the top 2) institutions have a VISIR system installed on their premises and use it with their students. The paper presents further evidence of the relevance of VISIR, including the most cited paper “VISIR: Experiences and challenges” by Javier García-Zubía, who has authored the most publications on the subject (see Table 4, page 12). Table 4 lists the top authors based on publications, citations, and Altmetrics. Taking the column ordered according to the number of total publications, the top 4 authors work with VISIR.

The previous paragraph provides evidence of how VISIR has become a widely disseminated and successful example in terms of remote laboratories.[1] Presently, remote laboratories have attracted the attention of many educational institutions and stakeholders because of the COVID-19 pandemic. In fact, and considering a general audience, speaking of remote laboratories before and after the COVID-19 pandemic represents two entirely different scenarios. The number of emergency remote teaching responses reported in the literature that include the use of remote and virtual laboratories is a simple and undeniable sign. Another piece of evidence, which connects to VISIR, comes from Pablo Orduña, co-founder and CEO of LabsLand,

> The usage of LabsLand remote laboratories has increased substantially since the beginning of the pandemic. In 2020, both the number of sessions and users was 7 times higher, and it is maintaining the growing trend in 2021 (Personal communication, November 5, 2021).

[1]Although Raman *et al.* (2022) use the expression “Virtual Laboratories” in the paper’s title, a closer look into the keywords used in their query reveals the following: Virtual lab*, online lab*, **remote lab***, virtual experiment*, online experiment*, **remote experiment***, UN SDG*, COVID-19*, and higher education.

LabsLand is a spin-off company of the University of Deusto (Spain), which offers access to VISIR remote laboratories installed at different locations and has the potential to serve as a provider of the VISIR federation. This company has opened access to its remote laboratories, including VISIR, during a large part of the lockdown caused by the COVID-19 pandemic. The growth observed means that many teachers had the opportunity to resort to VISIR to allow their students to perform remote (real) experiments with electrical and electronic circuits. In other words, the lockdown caused by the COVID-19 pandemic created an opportunity for a wider dissemination of the educational value of remote laboratories (and VISIR). In the words (inspired by Max Planck) of Ingvar Gustavsson, creator of VISIR:

> Experimenting could be compared to a conversation with nature. The experimenter asks and Nature answers. The tricky thing is formulating a useful question and above all interpreting the answer. The only way to learn the language of nature is performing many experiments in laboratories that can be hands-on or remote.

Ingvar's words were written before the COVID-19 pandemic. Yet, despite all the evidence reported in Chapter 5 on the educational value of VISIR, there is no doubt the pandemic enlarged the number of teachers, students, and many other stakeholders in education who now understand, and hopefully endorse, Ingvar's words.

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