

Advanced microwave equipment simulator for engineering education

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Abstract

A novel approach to computer simulator development of microwave measurement equipment is presented. The main feature of the software is an interface of the simulator, which is an interactive image of the real equipment allowing to manipulate the keys and other elements of the front panel by the computer mouse. For the measurement procedure, the simulator allows to use analytical formulas or upload the data from the computer models of the microwave devices and from the real measurements in *.s2p format. Implementation of the developed simulator into the educational process provides each student with an unlimited access to the measuring equipment and gives the opportunity not only to study the characteristics of microwave devices but also to gain experience with the real equipment due to interactive computer interface that is completely identical to real front panel.

Keywords

Computer simulator, microwave device, engineers training, realistic interface

Introduction

Engineering education should always be provided with modern measuring instruments and devices. This laboratory equipment, as a rule, is very expensive and does not have the educational analogs, especially in the field of microwave industry.

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Besides, recently the popularity of remote learning has been increasing in the field of the higher education. This type of education has certain advantages, but its implementation requires both the creation of laboratory workshops executed remotely and also the specialized software. Interactive laboratories are widely used at the universities of many countries,¹⁻⁷ and various international scientific projects are devoted to their design.⁵ The application of remote laboratories in the educational process made it possible to solve problems inherent in laboratory installations, and by means of virtual laboratories the problem of an almost simultaneous access to the “experimental” equipment for many students can be solved. In the paper,⁸ the authors give the examples of laboratories and show interesting diagrams of virtualization of infrastructure and remote laboratory. It is essential that the use of simulation models makes information more available. The study of special subjects by means of the analysis, observation, and comparison using the virtual packets raises the students’ rating.

Therefore, creation of virtual laboratories in which the functioning of all measuring equipment and also the studied elements and devices are described by means of computer models and the corresponding mathematical formulas is practically necessary and relevant. These laboratory works have considerably larger flexibility, capacity and can be effectively used in the educational process. At the same time, virtual laboratories can be used as an addition to or replacement of real laboratory works, which is confirmed by a number of publications. Virtual laboratory works are used for studying robotics,⁴ biochemical engineering, thermodynamics, and multiprocessor systems.⁸

The authors of the majority of published works generally pay attention to creating the laboratory works using computer modeling of various processes and their remote performance by means of modern Internet technologies. It allows to create laboratory works, laboratory stands with remote access⁷ and to provide scientific research using complex equipment. Therefore, some works are devoted to the creation of virtual scientific laboratories and application of various modern cloud computing. A combination of cloud and virtual computing provides new opportunities for remote education. In the paper,⁹ the problems of the education process in rural areas of developing countries and the ways of their solution are discussed, the application of remote laboratory for improvement of quality of education in these areas is shown. The survey among students and teachers and the analysis of the use of virtual laboratories have shown their positive influence on education process. The advantages of their use as interactive manuals have also been demonstrated.

The application of modern Internet Technologies allows to create laboratory workshops with remote access and to use the last achievements in cloud computing.¹⁰⁻¹² The papers^{11,12} are devoted to the cloud services used during the creation of virtual and remote laboratories. The primary benefit of the cloud services is the considerable cost saving of IT infrastructure, the occupied space and the free (arbitrary) runtime of the laboratory operation. Nowadays, various software for simulation and programming languages is used.^{13,14} The authors use

NI LabVIEW environment to create virtual laboratory workshops or develop applications in the JavaScript language with the web interface. Some authors use MatLab software for the electrical machine investigation.

Computer simulation is also being highly applied in the field of microwave industry.^{13,15,16} However, the main disadvantage of this software is that it is mainly focused on studying the microwave devices and practically ignores the measurement equipment used in the corresponding installation. As a result, these programs provide no experience in operating the real microwave equipment. To solve the problem, the computer simulator should have the interface identical to the real equipment. This could be achieved by implementing the interactive image of the front panel of the corresponding measuring device with the possibility to manipulate the keys and other elements of the front panel by the computer mouse.¹⁷⁻¹⁹

The development of the main software modules

In the developed program, all devices possess a series of input and output signals converting the signals by a certain algorithm or providing visualization. For the description of devices, the abstract method-function (Figure 1) processing the input signals based on their own parameters is developed.

The communication between functions is carried out as “many to many”. The function does not perform any operations until complete information about all input signals necessary for operation is obtained. Thus, the creation of chains and trees of functions where the first links are independent and subsequent ones recursively depend on all previous ones is possible. In Figure 2, the interaction of functions and signal transmission is illustrated. In such an approach, any studied device and the measuring instrument represented in the program are considered as a certain abstract entity with a certain property set (device type, input and output signals, the executed conversions, etc.) and the given behavior in relation to other devices.

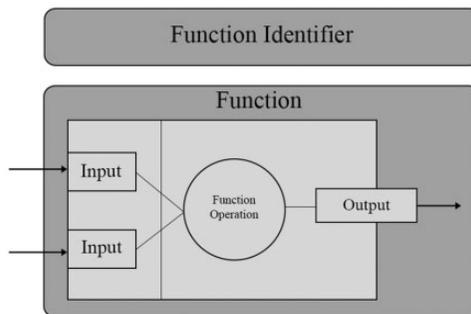


Figure 1. Signal and function organization.

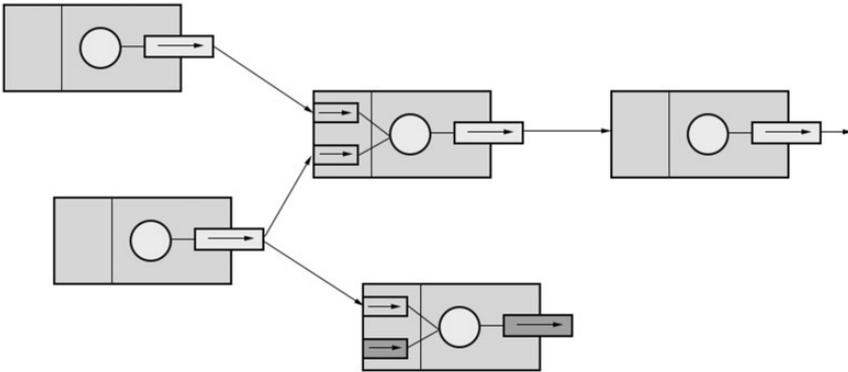


Figure 2. Interaction of signals.

If the devices are combined in the measuring chain or certain laboratory work, the association between input signals of the device-receiver and output signals of the device-source is set. Thus, any input signal of the device, unlike the output one, is not an independent object, but a pointer at an output signal of another device that allows to connect devices arbitrarily. The modules of the created devices in this case are dynamically connected libraries with the common exported interface.

The software is developed with the C++ language at Microsoft Visual Studio IDE 2015 and Digia Qt 5.6. Due to small volume of storable information and absence of heavy loads, the SQLite 3.7 database is used. The packet kernel responsible for creating and executing laboratory works are the user modules of the “compiler” and the “visualizer”, which are independent. The “compiler” is responsible for creating and editing laboratory works. Its initialization module, in turn, loads all available models of devices (dynamic link libraries), forms a temporal copy of an object for each of them and obtains all necessary information (device type, the name, a set of output signals, the list of available input signals). In such an approach adding a new device to the laboratory is reduced to developing a computer model of the device and copying the corresponding dynamic link library into the process directory of the earlier set shell program.

A mode of links installation is available after the selection of the devices. For this purpose, the user selects the device, its type and specifies the input and output signal devices, i.e. the receiver and the source. In this way, the connection of devices and creation of new laboratory work is implemented (the analog of connecting signals and functions, see Figure 2).

The “visualizer” obtains all necessary information from the database, gives an opportunity to select the laboratory work and displays its interface. The module addresses to the database which response contains information in the list of devices and all connections in between. Further loading of the required modules, creating the necessary number of device copies and their subsequent connection are

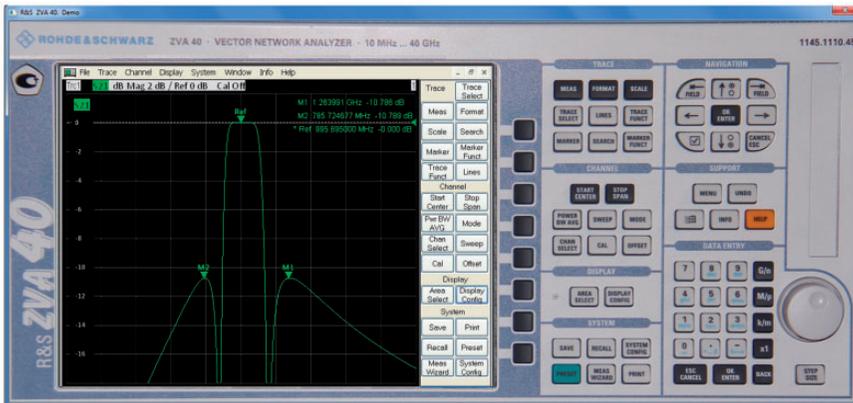


Figure 3. User interface of virtual network analyzer, Rohde&Schwarz ZVA 40.

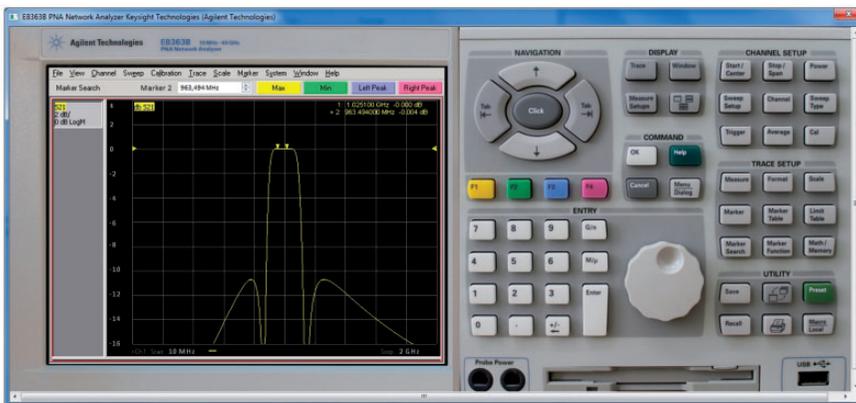


Figure 4. User interface of virtual network analyzer, Keysight Technologies PNA E8363B.

executed by the method specified earlier. Then, the user's device interface (laboratory work) is displayed and the control is transferred to these software modules.

Thus, the general functionality of a packet can be easily extended and depends only on a set of device modules, which are just as easily added into a system and represent the dynamic link libraries.

The examples of the computer models

As an example, the computer model of the Rohde&Schwarz vector network analyzer ZVA 40 is presented in Figure 3 and the computer model of the Keysight Technologies vector network analyzer PNA E8363B is presented in Figure 4.

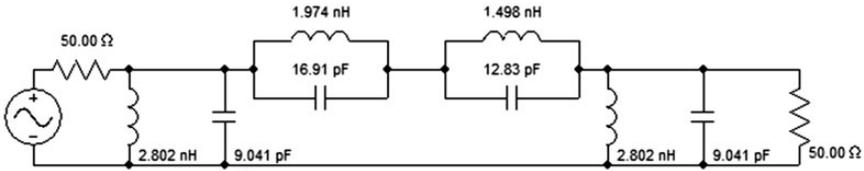


Figure 5. The band-pass analog filter model.

As was mentioned above, an education process is the main goal of the presented simulators. Therefore, all characteristics of the microwave devices should be stored in the software base before the operation. For simple circuits, the analytical formulas can be applied, and for more complex devices, various computer simulation programs are used. It is also possible to upload to the simulator the data already measured by the real equipment and stored in standard *.s2p files.

In this paper, an analog band-pass filter model (Figure 5) is applied as a device under investigation. To build a filter model, Nuhertz Filter Solutions software is used. It allows to synthesize a band-pass filter with given parameters and to obtain an approximate analytical formula for calculating its transfer function $K(f)$

$$K = \frac{1366 \cdot 10^9 f^5 + 112 \cdot 10^{29} f^3 + 2129 \cdot 10^{48} f}{\left\{ \begin{array}{l} f^6 + 3058 \cdot 10^9 f^5 + 1222 \cdot 10^{20} f^4 + 2456 \cdot 10^{29} f^3 \\ + 4823 \cdot 10^{39} f^2 + 4767 \cdot 10^{48} f + 6153 \cdot 10^{58} \end{array} \right\}}$$

and the corresponding transmission coefficient as an element of the scattering matrix

$$|S_{21}| = 20 \log_{10}(\text{abs}(K)) \tag{1}$$

Let us describe briefly the method of connecting the studied device to a virtual network analyzer. The input and output signal on ports P1 and P2 should be generated and processed for filtering. The connection between the studied two-port circuit and the analyzer is made using the software configuration tool with the following principles:

- each time the data are updated on the display, the device generates a request signal for the values to be displayed;
- the values of requested frequencies are placed in the range specified by the user of the network analyzer. The step of frequency scanning depends on the type of the studied device;
- the studied device is considered as a “black box”. The device responds to the input signal from the network analyzer by the internal algorithm and then returns an actual value of the transmission coefficient (1) back to the network

analyzer. The main role of the device is to return the necessary data to the network analyzer.

The computer models of the vector network analyzer have an interface with an interactive image of real device. All keys can be pressed by a computer mouse with the same effect as at the real unit. For example, the vector network analyzer can measure the magnitude and phase of S-parameters of the studied device.

It is known that analyzers described in this work have very wide measurement functionality; nevertheless, during the real operation a limited number of these functions are enough for general measurements and basic education. Let us briefly describe the main features of virtual measuring devices. The user can control the parameters of frequency scan: the center frequency and frequency span are controlled by keys "Start/Center" and "Stop/Span", respectively. When the key is pressed, the corresponding dialog window appears. In this window, the user can setup required frequency sweeping values. At the same time, the software checks if the new parameters are in the allowed frequency range or not. This range is obtained during the first data request from the studied device. After that the request of regular data of the device is performed and the frequency response graph appears on the display.

The user can also choose S-parameters to be displayed ("Measure" key) as well as their representation: modulus or phase of S-parameter or Smith chart ("Format" key). Moreover, for convenience the user can adjust the scale of the displayed data ("Scale" key), set up the grid size of the graph, the reference level, etc. Computer model of the network analyzer implements marker functions for measurement automation. In particular, there is a possibility to set markers on the curve of frequency response and to perform various measuring operations. During the curve plotting, all data are stored in the memory, hence both setting up the markers on the investigated curve and searching the extremum values ("Left/Right Peak") are performed very quickly. The keys F1–F4 are available for the user in the computer model of the network analyzer as in its real prototype. The functionality of these keys depends on the current operation mode.

Of particular interest is the representation of S-parameters on Smith chart. For receiving and displaying the data in this mode, it is necessary to send two requests per each frequency: the first one for getting modulus value of S-parameter and the second one for obtaining the phase. At the next stage, it is necessary to perform the calculation of the obtained values and display them on the screen. Data recalculation and the display of data on Smith chart are quite difficult. Firstly, the visualization consists of a family of circles of different radius with the centers in the different points of the screen grid. Secondly, this representation requires calculating the impedance and matching it to the coordinates of Smith chart.

Thus, the implementation of the developed simulator into the educational process provides each student with an unlimited access to the measuring equipment. It gives the opportunity not only to study the characteristics of microwave devices but also to gain experience with a much wider range of real measuring equipment

due to interactive computer interface that is identical to real front panel. Feedback was collected from students. Some samples of students' comments are as follows:

- 'The simulator really made me understand how to use the real vector network analyzer'.
- 'The labs provided with simulator were helpful for putting into practice what we learned'.
- 'Virtual Labs let me gain experience in operation with the measuring equipment that is not presented in fact in our University'.
- 'It was very comfortable to work with the simulator remotely. I felt greatly satisfied that I could use almost the real vector network analyzer on my computer. I saved a lot of time'.

These feedback results clearly indicate that students became more motivated in the laboratory work, and that the teaching and learning of the subject was enhanced.

We also collected the employers' feedback. The main point of the feedback is that the students who have successfully completed training in the virtual laboratory are better prepared for practical work and have greater chances in employment.

Conclusion

The developed computer simulator provides the novel approach to the organization of the engineering education process, which makes it possible to solve the problem with a limited quantity of expensive measuring equipment. Due to virtual models of the measuring equipment with a realistic interactive interface and the universal approach that allows to unite devices in arbitrary measurement circuits, it is possible to build an easily expandable virtual laboratory that works both with simple devices whose properties are described by analytical formulas and complex devices whose characteristics can be simulated or measured and saved as standard for engineering equipment *.s2p files.

Declaration of Conflicting Interests

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