

# The Microwave Virtual Laboratory for RF Engineers Education

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**Abstract**—The method for computer simulation of microwave measurement units and a virtual laboratory workshop for RF engineers education are described. The front panel view and manipulation principles of the models are identical to those of the real units. As an example the simulation results of the Rohde&Schwarz vector network analyzer with microwave filter are presented.

**Keywords**—application virtualization, graphical user interfaces, engineering education, microwave measurement.

## I. INTRODUCTION

One of the main components of a qualified RF engineering education is studying up-to-date measuring equipment. The problem is usually solved by laboratory workshops that have to concentrate on studying the electrodynamic properties of widely used and essentially novel devices. However, the laboratory equipment, especially for microwaves, is typically expensive, which limits its application in the educational process.

In the last decade the computer simulation of the working principles of the measuring equipment and various microwave devices has leapt forward. The main advantages of the virtual laboratory are the lower price, unlimited number of working places, and remote access including local and internet networks. However, the most of existing software packages providing virtual laboratory workshops demonstrate only a conceptual matching of real and virtual device interfaces, in particular the front panel view and manipulation principles [1]. Furthermore, these packages are usually enclosed products, which make it impossible for the user to extend the laboratory work series or to add any new equipment or devices.

In this paper, a new method of computer simulation of microwave measurement equipment is considered and the modern software package of virtual laboratory workshop is developed. This package provides a front panel interface and manipulation of the devices equivalent to the real ones and enables the user not only to add new devices to the package, but also to arrange the connections between the devices in many different ways [2].

## II. LABORATORY STRUCTURE

The laboratory work comes with measurement units and test devices combined in a single installation. Each

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measurement unit could be described (fig. 1) with a set of input and output signals. The microwave test devices also have those functions and sets of signals [3].

A simulated laboratory has a module structure. The basis for constructing a model of a specific workshop is the concept of an abstract device with a front panel view and manipulation principles identical to those of the real units. The device behavior is described with notions of “signal” and “function”. Each device has a set of input and output signals, and it is possible to connect the devices to each other in a certain way.

Each device module is an autonomous software element. For this reason the functionality of the software package is easily expandable and depends only on a module set. Laboratory work in terms of a software package is the information about a set of essential modules, the number of copies of each device, and the way they are connected with each other. Package core units responsible for creating and performing laboratory work and for displaying user interface are enclosed in the following modules [4]:

- laboratory workshop linker;
- laboratory workshop visualizer;
- database module.

The linker and the visualizer store and communicate the laboratory workshop data through the database. A linker is one of the packaged core modules responsible for creating and editing the laboratory work (fig. 2).

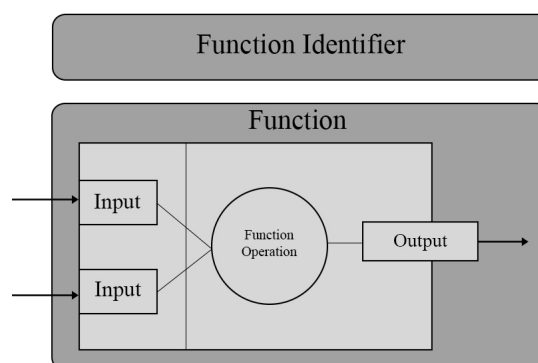


Fig. 1. Signals and functions organization

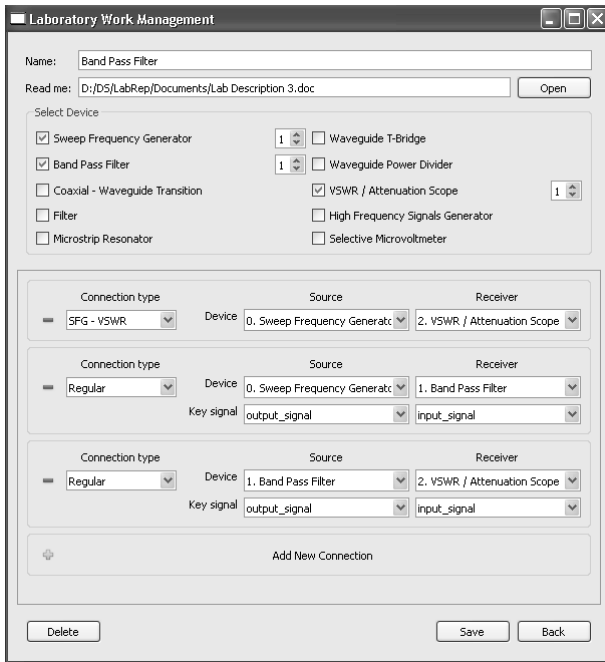


Fig. 2. Laboratory workshop linker interface

The linker receives the data from the user and then transfers it to the database module for storing. In fact, by using the linker, the user defines the rules according to which visualizer will carry out the laboratory work. The linker stores a list of available devices and checks for updates.

As a result, the linker enables arrangement of the laboratory work on the basis of the available devices. A visualizer is one of the package core modules responsible for assembling and displaying the created laboratory work. Visualizer allows the user to choose a laboratory work from among those already created. The laboratory workshop process is defined by the working principles of the comprised devices and the way they are connected with each other (fig. 3).

### III. SOFTWARE PACKAGE DESCRIPTION

The software package for the microwave device simulations and the connection of the microwave device modules is developed using the high-level programming language C++ on Microsoft Visual Studio IDE. A cross-platform toolkit for applications and user interface development Qt was chosen. Because of the small volume of stored information, the database SQLite was used.

The laboratory workshop linker and the visualizer form the basis of the package user interface. The linker allows users to define the way to combine the available devices in a single installation. The received data are transferred to a database module for storage. The visualizer allows not only choosing of the laboratory work but also reviewing of a methodological recommendation or switching among the loaded devices. According to the settings stored in the database, the visualizer loads modules, and creates the desired amount of samples of the devices, combines them into a single installation, and displays the user interface.

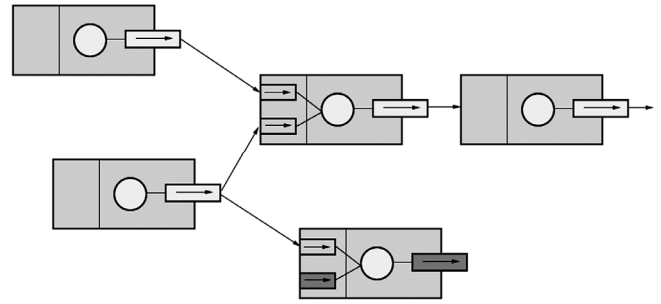


Fig. 3. Function interaction and signal transmission

There are several operating modes available for users [5]. At the "basic" operating mode, the constructed laboratory work is performed according to its application note. A skilled user can design new laboratory work. A professional level user can create devices and study their behavior in different configurations.

Signals are made as functors with the public programming interface, i.e. abstract signals. In general, a signal receives output values of the related signals, the current state of the whole system, and converts the received data to the output values according to the mathematical model of the device's working principles. There is a possibility of confluence cases. In those cases, the signal does not require other signal data to form the output value (e.g. working principles of generator signal mean only excitation of a system).

A device function is made as a particular method of a signal-functor that implements the mathematical model of the device working principles. Test device realizations also have a public programming interface, i.e. an abstract device. This interface only implements the possibility of connecting the signals of the source device to the signals of the receiving device. All working principles are described in the complete test device. Additionally, the abstract device is an inheritor of the QWidget class, which on the one hand allows creation of the device user interface and on the other hand enables use of the Qt system of meta-objects, since the QWidget by the same token is an inheritor of the QObject class.

To make the main package core linker and visualizer independent of a set of available test devices, they are compiled in the dynamic link libraries with a common public interface. To make such an approach possible, the QtPlugin principle is used. The module public interface is an abstract "factory" that creates the required number of samples of a device. This way was chosen due to the fact that the QtPlugin principle enables receipt of only a single instance of public class. The database module does not have any graphic interface and is used by other core modules for communication. To avoid possible interface delays during a database query, the module is always performed under a separate thread.

The module provided interface contains the following functionality: recording new laboratory work parameters; erasing existing laboratory work; acquiring a list of laboratory works; acquiring a list of devices of certain workshop; acquiring a set of device connections; acquiring an application note path.

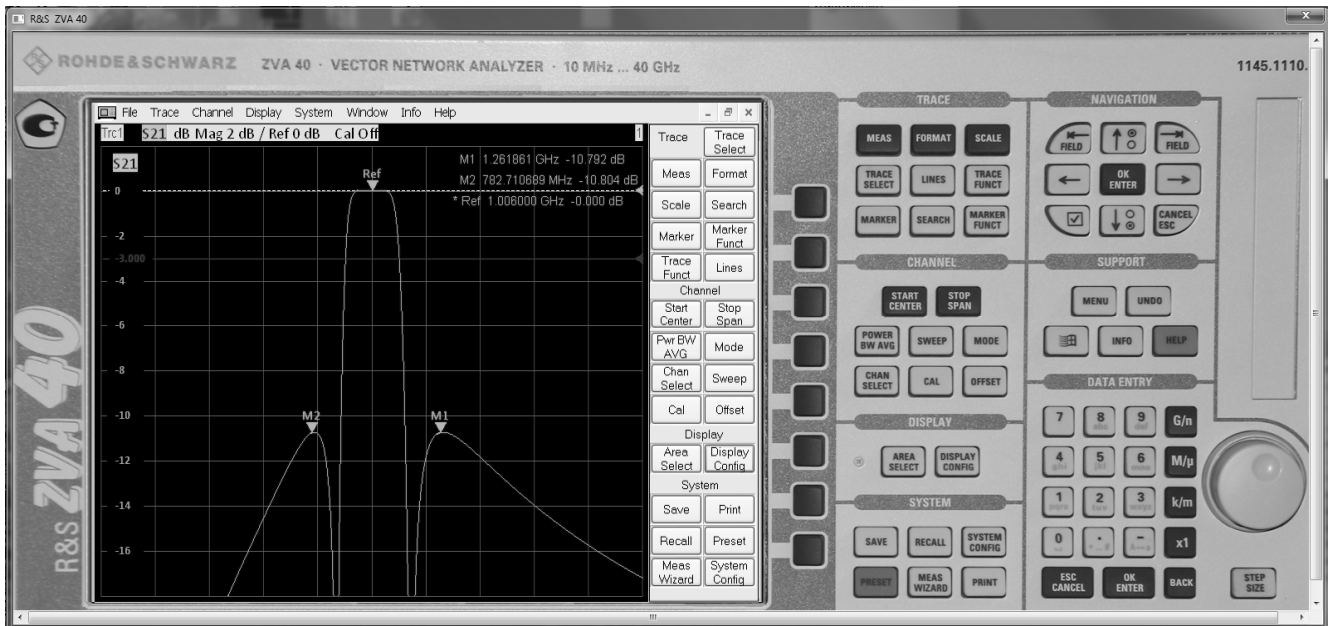


Fig. 4. Virtual laboratory workshop example with Rohde&Schwarz Vector Network Analyzer

#### IV. LABORATORY WORK EXAMPLE

As an example, the virtual laboratory work for studying the transmission characteristics of a microwave device is constructed. The computer model of the Rohde&Schwarz vector network analyzer ZVA 40 is used (fig. 4). As a device under investigation an analog band-pass filter (fig. 5) is applied. The ZVA 40 computer model has an interface with the interactive photo of the real device. All buttons could be pressed by the PC mouse with the same effect as on the real unit. The vector network analyzer provides the program interface to manage the initial and final frequencies and the frequency markers, the amplitude of frequency markers, the position of the measuring line, the frequency range of measurements and so on. All this allows the operator to investigate the amplitude-frequency characteristic of the device and to carry out all necessary measurements displayed on the screen.

Of particular interest is the simulation of the studied device, which is considered in the work as a certain “Blackbox.” This abstract device with the work logic is included in its output signals, whose behavior depends on the input signals and the physical characteristics of the device. The operation function of the studied microwave devices can be described by a mathematical model, by a data set received with specialized simulation programs, or by a set of experimental data.

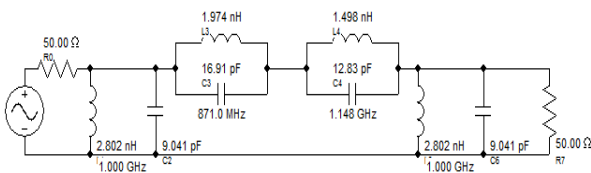


Fig. 5. The band-pass analog filter model

Such an approach allows modeling and studying almost all microwave devices in virtual laboratories.

The transmission characteristic of the “Blackbox” example (fig. 5) displayed on the screen (fig. 4) of the virtual laboratory is calculated analytically. The user can change the values of the capacitance and inductance of all elements of the circuit and investigate the amplitude-frequency characteristic of the filter.

The virtual laboratory allows studying also the real complicated microwave devices for example the modern SIW-filter on L-ridged rectangular waveguide [6] which transmission characteristics could be simulated by the well-known software package CST Microwave Studio (fig. 6). The received simulation data were processed and converted to the binary form to accelerate searching for and displaying devices.

The user can vary the filter dimensions including the length of resonators and impedance inverters and perform the measurements of pass-band, attenuation value, etc.

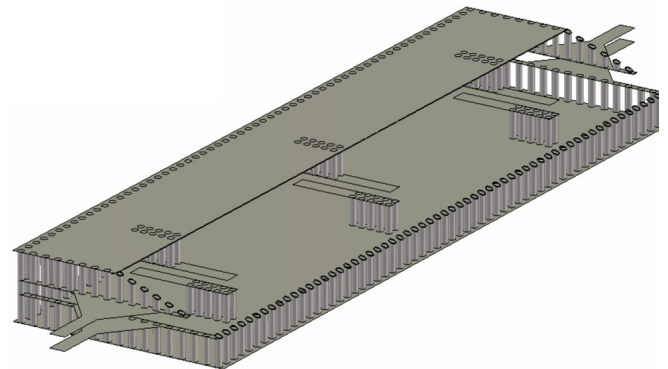


Fig. 6. The band-pass SIW-filter model

## V. CONCLUSIONS

As a result of the current investigation, the software package for constructing a virtual laboratory workshop was designed. It could be used in the education process as an interactive tutorial. The designed virtual laboratory is based on independent component modules that allow users to expand and edit the set of devices used for simulations without interactions with the package core.

The main feature of this realization is representing test devices as “Blackboxes” whose behavior depends on a mathematical model or on output values of external applications for microwave device simulations or on real experimental data.

All front panel views and manipulations of the components included in the presented laboratory workshop are identical to real devices.

It is necessary to note that a designed software package could be expanded to create remote laboratory workshops with internet access.

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