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Designing LabVIEW Application for Impedance Measurement by using Differential Probe

Abstract. The paper purposed to design a LabVIEW application for measuring the S-parameters and impedance for high-frequency electronic devices such as RFID tag or antenna which cannot be connected to a connector by using a differential probe. A differential probe was fabricated from RG 402 semi-rigid coaxial cable for connecting to the impedance test point and to the vector network analyzer for S-parameter measurements. The LabVIEW Application was developed for data collection of S-parameter from the vector network analyzer and then the data used to calculate and determine the impedance of the device.

Streszczenie. Artykuł miał na celu zaprojektowanie aplikacji LabVIEW do pomiaru parametrów S i impedancji dla urządzeń elektronicznych o wysokiej częstotliwości, takich jak znacznik RFID lub antena, których nie można podłączyć do złącza za pomocą sondy różnicowej. Sonda różnicowa została wykonana z półsztywnego kabla koncentrycznego RG 402 do podłączenia do punktu pomiaru impedancji oraz do wektorowego analizatora sieci do pomiarów parametrów S. Aplikacja LabVIEW została stworzona do zbierania danych parametru S z wektorowego analizatora sieci, a następnie danych służących do obliczenia i określenia impedancji urządzenia. (Projektowanie aplikacji LabVIEW do pomiaru impedancji przy użyciu sondy różnicowej)

Keywords: Differential probe; Impedance; LabVIEW; S-parameter.

Słowa kluczowe: pomiar impedancji, LabView, sonda różnicowa.

Introduction

At present, impedance measurement in high-frequency electronic devices without connector cannot be done directly through a specifically designed instrument. The required numeric values need to be collected and the calculation must be done manually which can possibly and easily cause a lot of errors. In addition, to obtain those values, costly instrument and a calculation program are needed. The instrument required for impedance measurement is a vector network analyzer (VNA) for measuring S-parameters which, then, is used for impedance calculation with a probe connected to the VNA.

There have been several studies trying to seek for possible methods to measure impedance in high-frequency electronic devices without connector such as study [1]. In this study, an impedance of the RFID tag antenna in UHF frequency was measured using 3 types of probes: 1) single-ended probe, 2) balun connected probe, and 3) differential probe. The VNA was connected to each probe, and the impedance tag was measured. The impedance values were shown in the Smith chart on VNA display and they were compared to simulated results. It was found that the method which used the differential probe showed a better agreement with the simulated results than other methods. Moreover, it was also found that the method using balun connected probe to measure the impedance of loop antenna showed better agreement but produced greater noise than the one using a single-ended probe.

The differential probe was introduced by [2- 4]. They are fabricated from RG402 and RG405 semi-rigid coaxial cable or rigid coaxial cable. Because of its symmetric structure, the probe is applied to measure an antenna with a balanced structure. In a differential probe, two ports are soldered with coaxial cable ground. In research [5-7], a methodology that was able to characterize a balanced antenna impedance by using a two-port VNA and port-extension technique was proposed. The impedance of the antennas could be manually calculated from the measured S-parameters over broad frequency band.

On the other hand [8-11], proposed a control system of VNA based on LabVIEW. It was found that the automatic test system had the advantages of high reliability and practicality where the system connected a PC and VNA

through USB/GPIB bus. This motivated the make of a concept in the automatic instrument by using LabVIEW.

Therefore, this paper proposes the development of LabVIEW application connected to VNA to obtain S-parameter in full two-port for measuring impedance of antenna or other equipment. From the discussed research, impedance measurement using differential probe gives the most accurate results; this method is also appropriate for measuring the impedance of tag antenna. Therefore, this paper also proposes designing and fabrication of differential probe for impedance measurement. To prevent possible errors in the measurement, a semi-rigid coaxial cable was used in the proposed differential probe and connected to VNA to obtain S-parameters. The operating frequency was set in the UHF band (from 800 MHz to 1000 MHz). The overview of the system is shown in Figure 1.

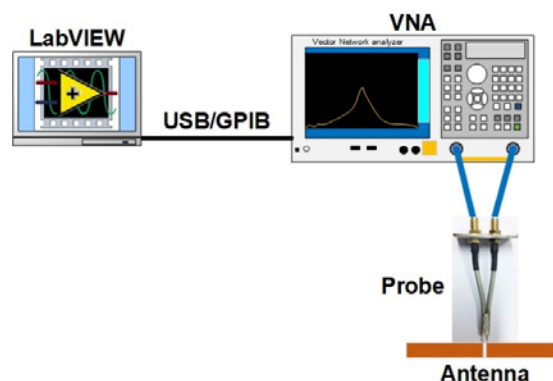


Fig.1. Overview of the proposed system.

Figure 1 shows the system overview for impedance measurement with differential probe via LabVIEW connected to VNA through USB/GPIB cable. The differential probe is connected to a two-port VNA for antenna S-parameters measurement. The LabVIEW application was designed for data collection of S-parameter from the VNA and then the data used to calculate and determine the impedance of the device and the computed results shown as a graph. Also, the results could be saved in an Excel (.xls) file.

This paper is organized as follows: Section II describes the process of differential probe fabrication and calibration setup. The equation for impedance calculation of differential probe is shown in Section III. The design of LabVIEW application is described in Section IV. Section V demonstrates the impedance calculation by LabVIEW application, compared with simulation. Finally, conclusions are given in Section VI.

Differential probe fabrication and calibration setup

Since impedance measurement needs the most accuracy, RG-402 semi-rigid coaxial cable was used in the proposed differential probe. This kind of cable is a low loss cable because the covering shield is made from copper which allows its maximum operating frequency to over 18 GHz [12]. The outer part of the cable was made from Teflon or PTFE (polytetrafluoroethylene). The diameter of the core conductor was 0.94 mm. The diameter of the PTFE insulator was 2.95 mm. The diameter of the shield covering the core conductor was 3.60 mm. The impedance was $50 \pm 1.0 \Omega$, the capacitance was 94 pF/m, and the working temperature range was -55°C to 125°C .

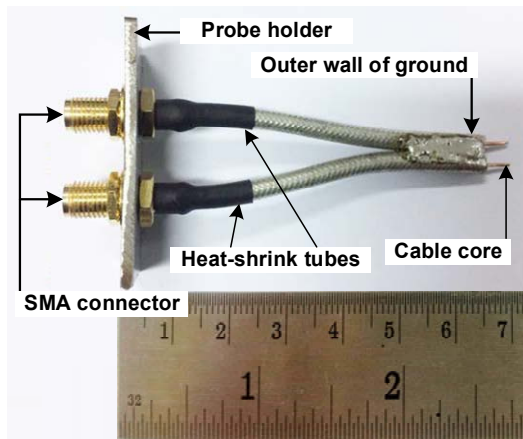


Fig.2. Differential probe prototype

To make a differential probe, an SMA female connector with the maximum operating frequency of 18 GHz was used to connect the RG-402 semi-rigid coaxial cable, and the connector were able to be fixed with another cable or a circuit board. The probe holder was made of stainless steel or steel with at least 10.5% of chromium alloy.

The length of the differential probe which was dependent on the operating frequency range of the measuring device was calculated from the quarter wavelength ($\lambda/4$). In this work, the operating frequency range was set between 800 -1000 MHz for the UHF band. Thus, the wavelength at 800 MHz was equal to 6.50 cm. At 1000 MHz frequency, the $\lambda/4$ of wavelength was equal to 5.21 cm which was shorter than the quarter wavelength at 800 MHz and could not support a lower frequency than 1000 MHz. Therefore, the coaxial cable with a length of quarter wavelength at 800 MHz was selected to support and cover the operating frequency range.

The following is the process of differential probe design and fabrication as shown in Figure 2:

- 1) Two coaxial cables with 6.5 cm length were prepared. For both cables, one end with a length of 0.35 cm was peeled off. The peeled conducting wires were used to calibrate and measure DUT (Device under test).
- 2) The 2 peeled conducting wires were firmly soldered to an SMA connector.
- 3) A probe holder (rectangular-shaped stainless-steel

plate) sized 2 cm x 4 cm was prepared. Two holes were made on the plate with 1.5 cm between the two holes.

4) The coaxial cables soldered to the SMA connector were fixed on the plate and firmly tightened with nuts. The soldered seams were then covered with heat-shrink tubes to maintain the soldering condition to be durable. The other end of both cables, at a 0.5 cm length, were then peeled off.

5) The end of the two coaxial cables were soldered together to keep the alignment of the cables like a case of the short circuit at the end of the $\lambda/4$ line.

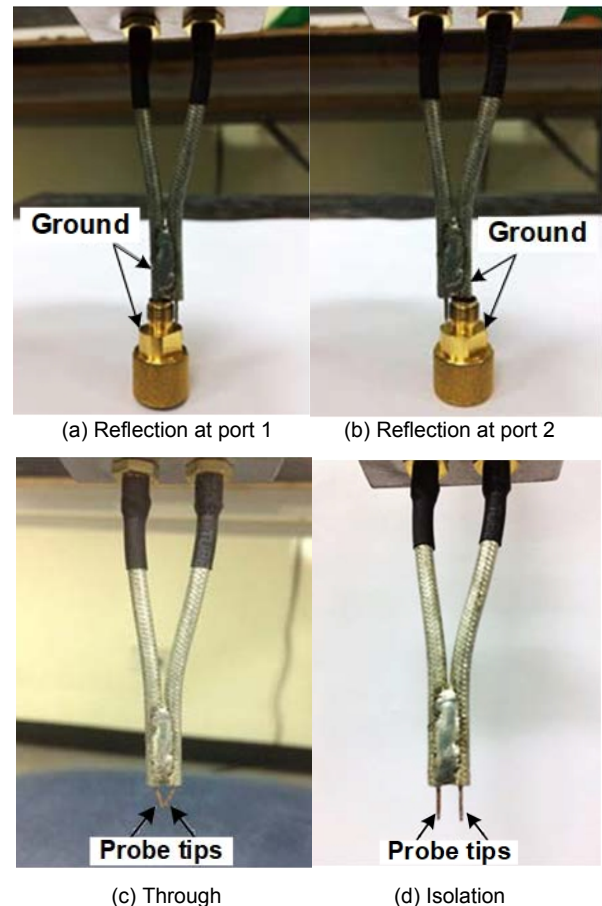


Fig.3. Differential probe calibration setup environment for impedance measurement

The calibration by using full two-port or short-open-load-through (SOLT) was the first step after the differential probe connection with the transmission line and VNA as shown in Figure 1. The calibration was done through the probe tips after peeling the ground of the cable as seen in Figure 2. The setup environment for the calibration is shown in Figure 3. Before calibration, the probe tips should be as short as possible but long enough to be inserted into the standard calibration kit, as shown in Figures 3 (a) and (b). In some cases, when the cable core is thicker than the hole of the calibration kit, resizing to the cable core is required. Thus, the contact between the probe tips and the inner hole of the calibration kit should not be of great concern, however, the contact between the ground of probe and the calibration kit should be certain. Mounting brackets were required in the measurement to ensure that the grounds of probe and calibration kit had contact [5]. On the other hand, the short circuit measurement by using a multi-meter is another way to verify that the grounds of probe and calibration kit had contact. The calibration is not possible until the short-circuit of grounds of probe and calibration kit is complete. The caution for the calibration are as follows:

1) Excessively thick and long cable core may allow a gap between the probe ground and the ground inside the calibration kit. If the gap occurs, slowly pull out the cable core of the probe and resize it to an appropriate one. Pushing the core into the kit can cause damage to the calibration kit especially the open calibration kit component which is very sensitive because of the inside dielectric material.

2) Excessively short or long cable core may cause inaccuracy when calibrating because the attached area is not properly fit.

Equations for impedance calculation of differential probe

From the literature review, it is seen that differential probe could accurately measure the impedance of both balanced and unbalanced antennas. Because the probe structure is symmetric in two-port π -networks, the currents at both ends of the probe were equal. The measured value was the actual impedance of the antenna produced by excitation.

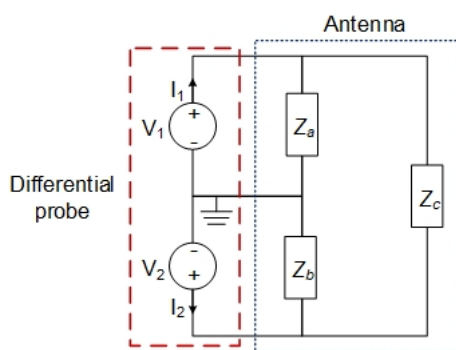


Fig.4. equivalent circuit for differential probe [1]

In Figure 4, the impedance of the differential probe is Z_{Ant} . The Z_{Ant} is the input impedance of the differential probe or the impedance of the antenna. Z_a and Z_b are the impedances between the input port and antenna ground ($Z_a = Z_b$) and Z_c is the impedance between each end of the antenna. The equation of impedance Z_{Ant} is:

$$(1) \quad Z_{Ant} = \frac{Z_c (Z_a + Z_b)}{(Z_a + Z_b + Z_c)}$$

When it is analyzed using Y-parameter and when $Z_a = Z_b$, the equation becomes:

$$(2) \quad Z_{Ant} = \frac{-2}{Y_{21} - Y_{11}}$$

Then, equation 2 is converted to S-parameter based on the parameter conversion table for two-port network parameters [13]. The derived equation is:

$$(3) \quad Z_{Ant} = \frac{2Z_0 \left((1 + S_{11})^2 - S_{12}^2 \right)}{(1 + S_{12})^2 - S_{11}^2}$$

When the results of the S-parameter measurement from VNA are achieved, the obtained S-parameter values are substituted in equation 3. Therefore, the calculation for antenna impedance from the differential probe is performed.

Designing LabVIEW Application

LabVIEW is a graphical programming or G language that uses icons instead of lines of text to create applications that need neither code nor command function [14]. The designed modules in LabVIEW are called virtual instruments or VI which imitate physical instruments. In one VI, there are 3 components: 1) front panel, 2) block diagrams, and 3) icon with a connector.

The front panel (see Figure 5) is a user interface that the user can build by using a set of tools and objects. In general, it looks like the front panel of physical instruments which consist of 1) Controls which are knobs, push buttons, dials, and other input mechanisms, and 2) Indicators which are graphs, LEDs, and other output displays. Users can add codes using G code or block diagram code of functions to control the front panel objects. The block diagram (see Figure 6) is the source code of the LabVIEW application and is the executable program. The objects on the block diagram include terminals and nodes. Users can build block diagrams by connecting the objects to wires. Constants are terminals on the block diagram that supply fixed data values to the block diagram. LabVIEW uses data flow programming, the flow of data through the nodes on the block diagram determines the execution order of the VIs and functions. The icons and the connector are similar to the subroutines in common programs. An icon is a block diagram with data passing through the connector. In the LabVIEW application, the subroutine is called Sub VI.

The advantage of using G language in programming is that each part of the VI can automatically and independently process, and if any additional program is later required, the previously built VI will then become a Sub VI. This way of programming is called a module.

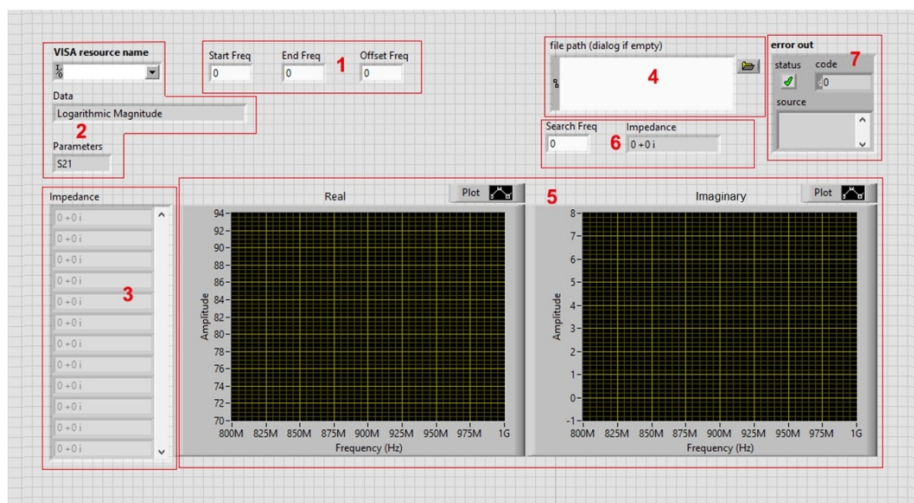


Fig.5. Front panel of developed LabVIEW Application

The development of the LabVIEW application for impedance measurement by using differential probe began with designing the front panel of the LabVIEW, especially the Control for VNA connection to read the S-parameter data through USB port and then calculate the impedance of the device. The designed front panel, see Figure 5, could perform 2 main tasks: 1) collecting the S-parameter data from VNA and 2) calculating the impedance, plotting the graph, and exporting to an Excel file. Figure 5 shows the front panel of the developed LabVIEW application. Task 1 consisted of No. 1 (the frequency range setting), No. 2 (the VNA connection), and No. 7 (the error out). On the other hand, Task 2 consisted of No.3 (the calculated impedance results), No. 4 (the exported Excel file path), No. 5 (the graph of calculated impedance versus frequency), and No. 6 (find calculated impedance by the specified frequency)

The procedure of the LabVIEW application had the following steps:

- 1) Defining the start frequency, the end frequency, and the step frequency for the frequency range setting (No. 1).
- 2) Selecting the type of VNA connection with the VISA resource name through a USB port. Then, selecting S₁₁ or S₁₂ parameters in a logarithmic magnitude or a phase format, this is a type of data that is read from VNA, (No. 2).
- 3) After running a VI, if any error is detected, it is shown in No. 7
- 4) After the LabVIEW connection with VNA, the calculated impedance from S-parameter data was shown in No.3 and the impedance vs frequency graphs plotted in No. 5.
- 5) Finally, the Excel file was exported on location as the specified path in No.4

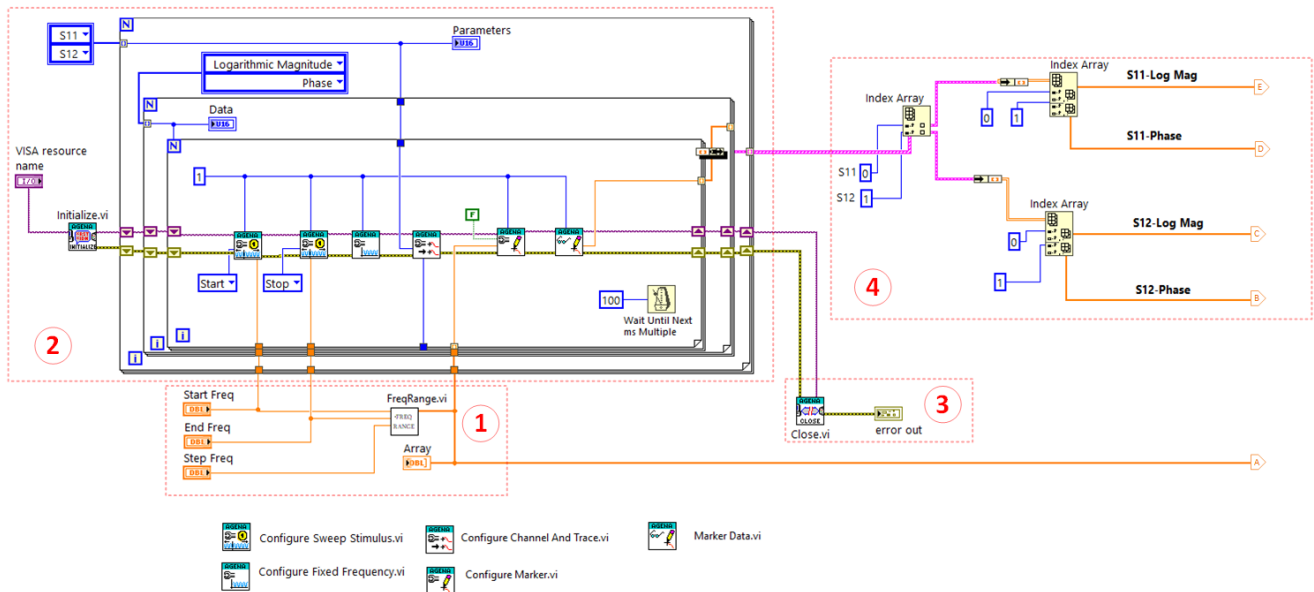


Fig.6. Block diagram for VNA connection and defined operation frequency

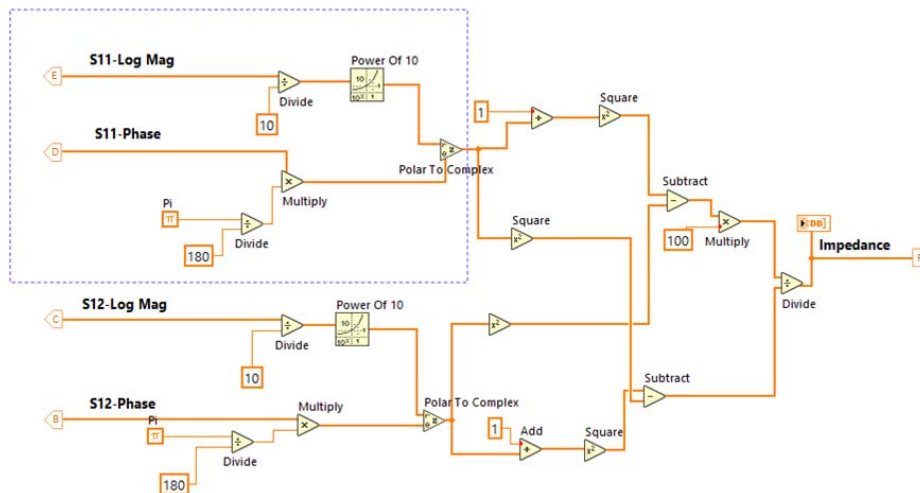


Fig.7. Block diagram for impedance calculation

Figure 6 shows the block diagram which is related to the front panel of the VNA connection in Figure 5. No. 1 shows the block diagrams of fixed-point data consisting of the start frequency, the end frequency, and the step frequency to set the frequency range and the number of working loops. The number of frequencies in the range and working loops were determined by subtracting the end frequency from the start frequency, then dividing the difference by the step frequency. All the frequencies were defined and kept in an

array. No. 2 shows the block diagrams and Sub VI that were used for VNA connection where 7 Sub VIs were used to initialize, configure setting and collect data from VNA, created and provided by [15]. No. 3 shows the errors, both connection error and operation error. After the LabVIEW connection with VNA and reading the S-parameter data, the data was extracted to the logarithmic magnitude and phase formats for both S₁₁ and S₁₂ (No. 4). The data from each parameter were converted into a 2D array which were used

for the impedance calculation. Figure 7 shows the block diagram for impedance calculation. Before the calculation, the data were converted into complex numbers (see the blue box) because the S-parameter data from the VNA of each frequency consisted of both magnitude and phase. Before impedance calculation, the magnitude of S-parameters was converted from dB into unitless by calculating an antilogarithm of the magnitude value divided by 10, while the phase of S-parameters was multiplied by $\pi/180^\circ$. Then, the magnitude and phase were converted from the polar form to complex form. The output of the "Divide" block diagram is computed by the above input divided by the below input. After calculating the impedance using equation 3, the results were saved in an array and displayed as shown in the front panel (No. 3) in Figure 5. Also, the calculated impedances were plotted as graph versus frequency. The graph can be separately shown for real and imaginary values. The impedance values were then exported to an Excel file (.xls) by plotting the graph and exporting it to an Excel file. The block diagrams of plotting the graph and exporting it to an Excel file are shown in Figure 8. Moreover, the loop box in Figure 8 shows the

process of searching the calculated impedance by the specified frequency (No. 6 in Figure 5). This process starts with the subtraction of the searching frequency from the frequencies in array and calculating their absolute value. Next step, the minimum values with the index for each value was found in array of the subtraction result. Finally, the calculated impedance matching with the index array of the specified frequency is shown on the front panel (No. 6 in Figure 5).

Test of Impedance Calculation by LabVIEW Application

This section describes the comparison between the simulated and measured results to validate the accuracy of the differential probe. The S-parameter measurement was performed by using a two-port VNA (Agilent E5071C [16]) and a test antenna. The measurement setup was followed as in Figure 1. First, the differential probe was connected to the VNA; then, a computer was connected to the VNA through a USB port. After that, the LabVIEW application was commanded to connect VNA and read the S-parameter in the operating frequency range for the impedance calculation.

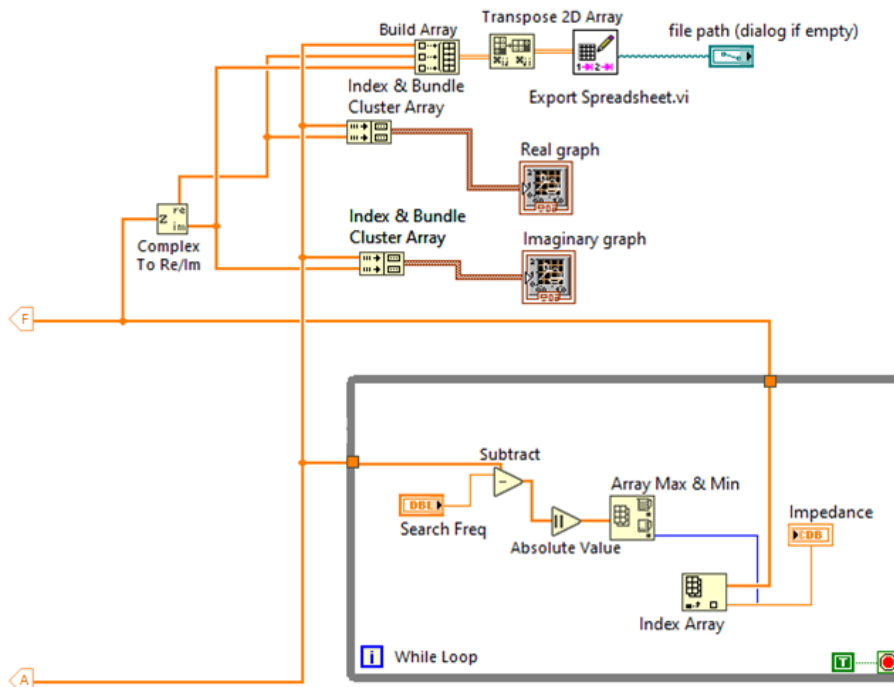


Fig.8. Block diagrams for plotting the graph and exporting to an Excel file

Three types of antennas were used in this measurement. They were printed dipole antenna, a copper wire dipole antenna, and a monopole antenna (see Figure 9).

The printed dipole antenna, Figure 9 (a), was made of a flexible one-side printed circuit board (PCB) with a 1.6 mm thick FR-4 substrate and a dimension of 16.5 cm x 1 cm. The antenna operated at the frequency of 900 MHz. The copper wire dipole antenna, Figure 9 (b), was made of copper wire with a diameter of 1 mm and a length of about 16.5 mm (half-wavelength). Its operating frequency was also at 900 MHz. Like the copper wire dipole antenna, the monopole antenna (see Figure 9 (c)), was made of copper wire with a diameter of 1 mm but the length of the monopole antenna was quarter wavelength with the operating frequency of 900 MHz.

The steps of impedance measurement by using the LabVIEW application were as follows.

- 1) Switching on the VNA and setting parameter for calibration
- 2) Connecting the differential probe to the VNA through port 1 and 2. Starting the calibration (see Figure 3).
- 3) Connecting the test antenna to the probe and measuring the S-parameters.
- 4) Connecting the computer to VNA via USB port and starting the LabVIEW application and setting up the parameter as shown in Figure 10, with the setting as follows.

No.1: Selected the VISA resource name as the model of VNA and connection, E5071CUSB was selected for this work.

No.2: Set the Start frequency at 800M (MHz).

No.3: Set the end frequency at 1G (GHz). No.4: Set the step of the frequency to increase by 1M (MHz).

No.5: Select the folder path for saving the Excel file.

5) After pressing the run button, the execution order to calculate the impedance followed as the block diagram in Figure 6-9.
 6) Finally, the impedances of the test antenna were calculated from the S-parameter data that were separately plotted as real and imaginary graphs.

Also, it was exported to an Excel file that saved on location as the specified path. Moreover, it could specify the frequency related to step frequency for searching the calculated impedance at this frequency (see the red box in Figure 10).

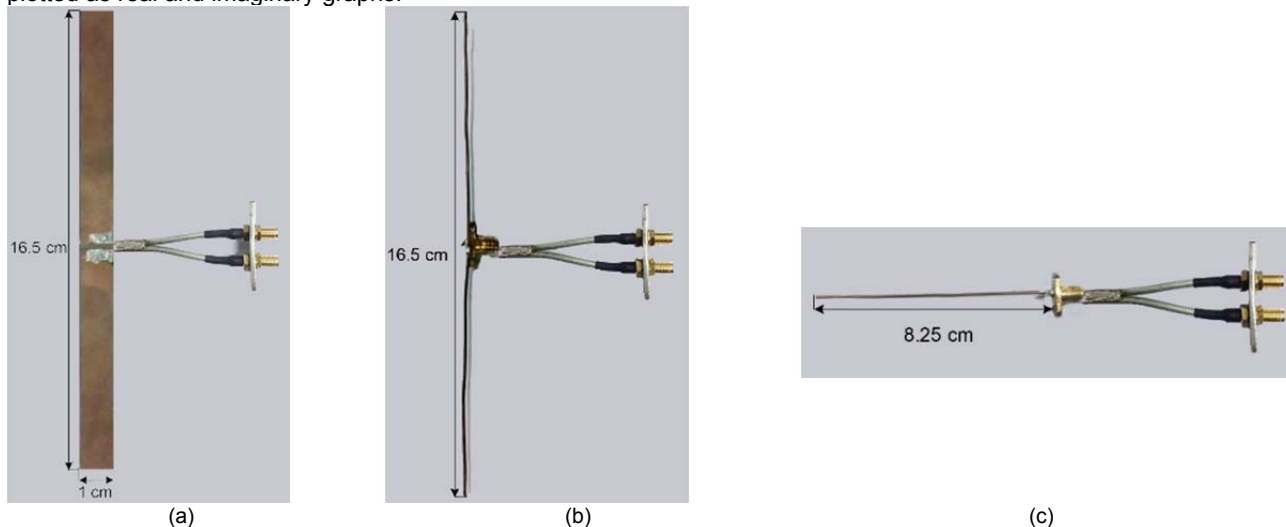


Fig.9. (a) printed dipole antenna, (b) wired dipole antenna, and (c) monopole antenna.

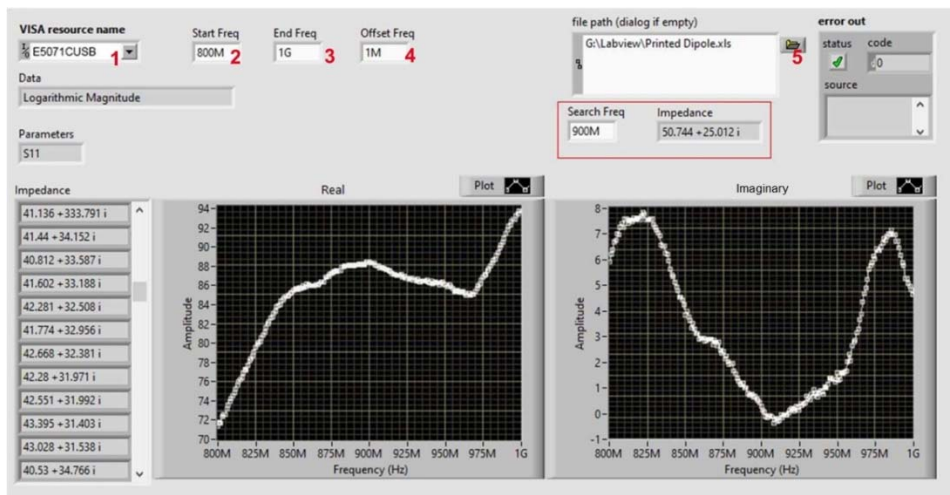


Fig.10. LabVIEW window for impedance measurement during the calculation

The comparisons of simulated results and the impedance measurement by using differential probe of the 3 test antennas as shown in Figure 9 are shown in Tables 1-3. Table 1 shows the results of impedance measurement for the printed dipole antenna at 900 MHz with the simulated impedance at $50.21+22.22i \Omega$ and the results of impedance calculation using the LabVIEW application. Five randomized impedance were compared to the simulated results with 0.96% error. Table 2 shows the results of impedance measurement for the copper wire dipole antenna at 900 MHz with the simulated impedance at $50.54-24.28i \Omega$. Five randomized impedance were compared to the simulated results with 0.90% error. Table 3 shows the results of impedance measurement for the monopole antenna at 900 MHz with the simulated impedance at $50.78+10.02i \Omega$. Five randomized impedance were compared to the simulated results with 0.97% error. Summarily, both the measured real and imaginary values of the calculated impedance showed good agreement with the simulation at 900 MHz for all test antennas

Table 1: The comparisons of simulated and calculated results of the impedance measurement of the printed dipole antenna

No	Simulated Results (Ω)	Calculated Results by using LabVIEW (Ω)	Magnitude (Ω)	Phase (degree)	Error (%)
1	50.21-22.22i	50.74+25.01i	56.57	26.24	1.03
2		49.94-0.18i	49.96	-0.21	0.91
3		49.19-8.35i	49.90	-9.64	0.91
4		50.48+22.67i	55.34	24.18	1.01
5		50.26+13.79i	52.13	15.34	0.95
Average		50.12+10.59i	50.78	11.182	0.96

Table 2: The comparisons of simulated and calculated results of the impedance measurement of the copper wire dipole antenna

No	Simulated Results (Ω)	Calculated Results by using LabVIEW (Ω)	Magnitude (Ω)	Phase (degree)	Error (%)
1	50.54-24.28i	50.58+3.75i	50.72	4.24	0.90
2		49.36+3.34i	49.47	3.87	0.88
3		50.99+1.65i	51.02	1.85	0.91
4		50.42+0.50i	50.42	0.57	0.90
5		49.93-0.189i	49.93	-0.22	0.89
Average		50.26+1.81i	50.31	2.06	0.90

Table 3: The comparisons of simulated and calculated results of the impedance measurement of the monopole antenna

No.	Simulated Results (Ω)	Calculated Results by using LabVIEW (Ω)	Magnitude (Ω)	Phase (degree)	Error (%)
1	50.78+10.02i	47.65+5.79i	48.00	6.93	0.93
2		52.71+0.90i	52.72	0.98	1.02
3		50.3+0.531i	50.30	0.60	0.97
4		51.61+5.98i	51.96	6.61	1.00
5		48.74 -1.73i	48.77	-2.03	0.94
Average		50.20+2.29i	50.35	2.62	0.97

Conclusions

This paper proposes the development of a differential probe for impedance measurement using LabVIEW to facilitate the calculation. An RG-402 semi-rigid coaxial cable was used to make the differential probe, and the probe was connected to a VNA. The LabVIEW application was programmed to collect S-parameters data from a VNA which were used for the impedance calculation. The results were exported to an Excel file and shown in a graph.

The proposed system consisted of 2 main parts: 1) the differential probe set at the frequency range of 800 MHz – 1000 MHz and 2) the LabVIEW application for automatically calculating impedance.

The impedance measurement via the developed LabVIEW application was done using 3 types of test antennas: printed dipole antenna, copper wire dipole antenna, and monopole antenna. The calculation by using the LabVIEW application was satisfactory. In addition, the application could provide the results in the graph showing the impedance tendency, and the impedances at all frequencies were exported in to Excel file (.xls) for future use.

The results showed that the developed differential probe could effectively be used to measure the impedance; with the use of LabVIEW to automatically calculate the impedance. The results obtained from using the developed LabVIEW system were in good agreement with the simulation. Therefore, it can be concluded that the developed system can be effectively used for impedance measurement.

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