Comparison of Two Measurement Techniques of Electrical Equipment Impedances in Operating Conditions

Internship report

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ABSTRACT

Power line communication (PLC) or networking (PLN) is a communication method that uses electrical wiring to simultaneously carry both data (internet) and electric power. Power line networking uses existing electrical wiring, whether in a building or in the utility grid, as network cables, meaning they also carry data signals. It can be a means of extending an existing network into new places without adding new wires. Such technology depends mainly on the power grid topology but also on the connected household electrical appliances which impedances have a great impact on the PLC systems. The objective of the current contribution is to study the electromagnetic environment of the indoor power line grid. For this, two impedance measurement techniques seems to give better results and allow to characterize loads under its operating condition. It is about the two probes method on one hand and the capacitive coupler method on the other hand. With a proper pre-measurement calibration process, the proposed methods allow extraction of both the common mode (CM) and the differential mode (DM) noise source impedances with very good accuracy. The aim of the work is to study these two different approaches and compare them. The limits of each of the two methods will be determined, as well as their advantages and disadvantages.

Introduction

Nowadays the number of subscribers in the high-speed internet market is steadily increasing. The deployment of high-speed transmission technologies is mainly provided by DSL (Digital Subscriber Line) and FTTH (Fiber To The Home) links. Access providers use the existing telephone network and a fiber optic network as a transmission medium. The bit rates can then reach a hundred megabytes per second.

Services offered to customers include high-speed Internet, IP telephony (Internet Protocol) or high-definition digital television. The customer must have a DSL or FTTH modem to benefit from these services. Downstream of the client modem, one or more terminals must be assigned to each service. These terminals are often installed away from the DSL or FTTH modem. The connection between them can be achieved by using several communication technologies, Ethernet, Wi-Fi or very recently the transmission by online carrier currents (called CPL).

The technique of transmission by carrier currents consists in using the electrical network to transmit the digital data at high bit rate. It has the advantage of using an existing network and does not require additional cabling while offering rates for transmitting a data. Such a technique has made it possible to extend the high-speed network into the habitat.

Unfortunately, the quality of service using this technique varies enormously depending in one hand on the network and in the other hand the devices connected to it. This network is not sized for the transmission of a high-frequency signal. The electric cables therefore have a selective character in the CPL band. In addition to the attenuations caused by the electrical cables, electrical appliances create strong mismatches of the transmission and generate electromagnetic disturbances which will affect the transmission between the different PLC adapters [1]**.**

The study presented here concerns the modeling of the electrical network for the characterization of the CPL propagation channel. The parameters of the model are extracted from the measurement of the household electrical equipment impedances.

By this way, electric appliances impedances measurement is at the heart of many research programs; and the use of non-invasive tools to characterize these household equipment is quite attractive.

The performance of this such technology (PLC) depends on the noise source impedance of the circuit and the noise load impedance at the test site. The knowledge of the electrical home environment and the noise load impedance is essential in the design of the PLC **[2].**

For this, as all the measurement should be done in operating state, two methods seem to give better results, but have never been compared on an identical active load (LED TV...). These two experimental methods are on the first hand, the two probes approach and on the other hand the capacitive coupler technique.

The proposed internship subject consists to study these two methods and compare their measurement results.

The project is divided into two parts. The first one is realized in the electrotechnique and power electronic laboratory of Lille (L2EP) where I spend three mouths to learn the two probes method. And the second part of the project is done in the research group for materials, microelectronics, acoustics and nanotechnologies (GREMAN) at Tours where I passed three weeks in order to understand the capacitive coupler method.

This internship has been carried out within the framework of GT-SEEDS thematic group between three labs: L2EP, GREMAN and IETER (Institute of Electronics and Telecommunications of Rennes).

The rest of this report is organized as follow:

- The first chapter consists to studying the two probes method. We will determine its principle. Then some loads will be characterized in non-operating and operating state by applying the measurement protocol of this approach. Simulation results to test the two probes method are given lastly.
- The second chapter is dedicated to the analysis of the capacitive coupler method. Its principle of work is presented first. Then we will use this technique to measure some passive and active loads in off and on state
- The third chapter addresses the comparison of the studied methods on the same load. The limits of each method will be determined, as well as the advantages and disadvantages.

Chapter I:

The two probes method

I- Characterization of electrical equipment impedances with the two probes method

The aim of this introductory part is to present the two probes method in power electronic. Thus we shall first try to understand the principle of this measurement technique. We will then discuss its operating points. We will recall briefly the way, the measurement is done with one port system (In this case we do not need any probe). At last we will use this proposed method (two probes) to characterize some impedance of electrical equipment without, and under voltage.

1. Principle of the current probes method

1.1 Measurement with one port system

We consider a vectorial network analyzer (VNA) on one hand. On the other hand we have a device we want to characterize. The device is connected to the source by a length of transmission line of characteristic impedance Z_0 =50 Ω as shown in Figure I.1 below.

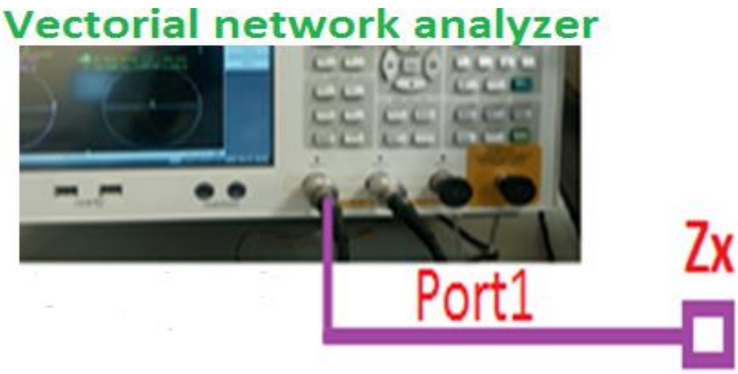


Figure I-1 experimental apparatus of the one port system

From this experimental test bench, we can determine the electrical equivalent circuit which is presented in Figure I.2.

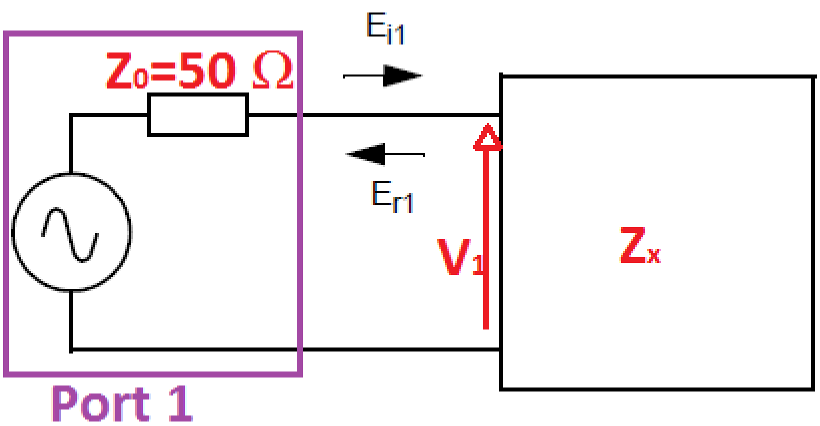


Figure I-2 Electrical equivalent circuit of the one port system

We know that a network analyzer supplies a sinusoidal signal to a device under test (Unknown impedance), measures its incident and reflection waves called E_{i1} and E_{r1} respectively and displays the results as ratios of the input signal over the signal source. In clear terms the voltage V1 is characterized by E_{i1} and E_{r1} **[3]**.

$$V_1 = E_{i1} + E_{r1} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(1)$$

We can define these following normalized notation:

$$a_1 = \frac{E_{i1}}{Z_0} \qquad\qquad b_1 = \frac{E_{r1}}{Z_0} \dots\dots\dots\dots\dots\dots\dots\dots \ (2)$$

Where a_1 and b_1 become the square root of the forward and reflected powers. Thus the square of a_1 and b_1 have the dimension of power. We can write a function S_{11} such that:

$$b_1 = S_{11} * a_1 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.(3)$$

$$S_{11} = \frac{b_1}{a_1} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.(4)$$

This new parameter S_{11} is given directly by the vectorial network analyzer. The unknown impedance can be expressed as a rectangular value ($Zx = R + jX$) with R being the real part of Zx and X the imaginary part of Zx thanks to the following formula;

$$Z_x = \frac{1 + S_{11}}{1 - S_{11}} * Z_0 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(5)$$

The equation (5) allows thus to determine the magnitude and the phase of the impedance we want to characterize.

1.2 The two probes method principle

The two probe method is an accurate measurement technique to measure the common mode (CM) and the differential mode (DM) noise source impedances of any electrical equipment under its operating conditions **[4]** as well as in off state. There is no direct electrical contact to the power line wires. The main advantage of the proposed method is that it can isolate the measurement equipment from the high voltage. Therefor it reduces the risks in practical use. Hence, no isolating chokes are needed, which makes the measurement setup very simple to implement. The proposed method is also highly accurate as it has the capability to eliminate the error introduced by the measurement setup.

The basic test bench of this method to measure an unknown impedance Z_x is illustrated in Figure I.3.

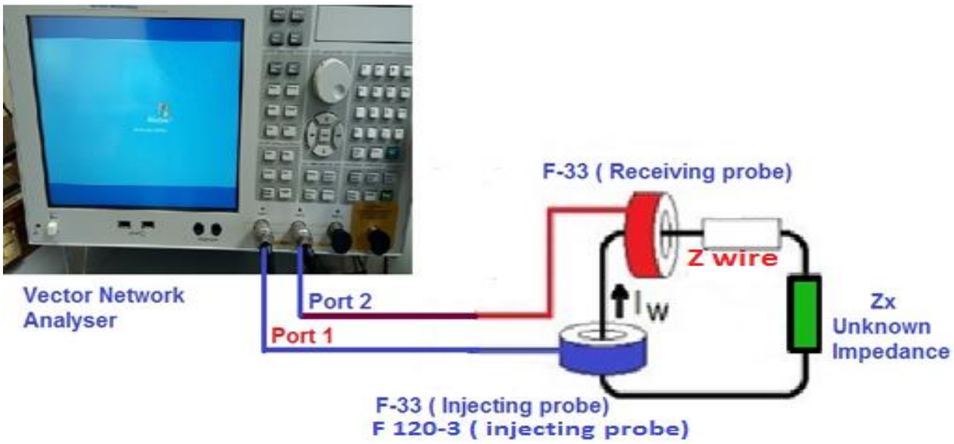


Figure I-3 Basic setup of the two-probe measurement. with the network analyzer

The experimental design is constituted of a vector network analyzer, a current injection probe (F-33-3 or F120-3) and a current receiving probe (F-33-3).

The port 1 of the VNA provides AC signal into the closed loop through the injecting probe in the measurement circuit and the resulting signal current in the loop is measured at port 2 of the VNA through the receiving probe. With the calculation on S parameters, the unknown Zx can be characterized. The current probes are modeled as equivalent transformers as shown in the Figure I.4.

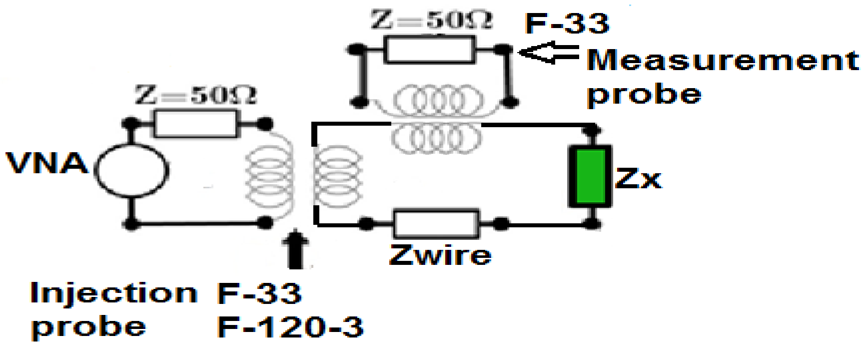


Figure I-4 circuit of the two-probe measurement setup

The complete equivalent circuit of the measurement setup is presented in the Figure I.5. V_1 is the signal source voltage of port 1 connected to the injecting probe and Vp2 is the resultant signal voltage measured at port 2 with the receiving probe. The output impedance of port 1 and the input impedance of port 2 of the VNA are both 50 Ω. L_1 and L_2 are the primary inductances of the injecting and the receiving probes, respectively. L_W and r_W are the inductance and the resistance of the wiring connections that formed the circuit loop, respectively. M1 is the mutual inductance between the injecting probe and the circuit loop and M2 is the mutual inductance between the receiving probe and the circuit loop. Zp1 and Zp2 are the input impedances of the injecting and the receiving probes, respectively **[4]**.

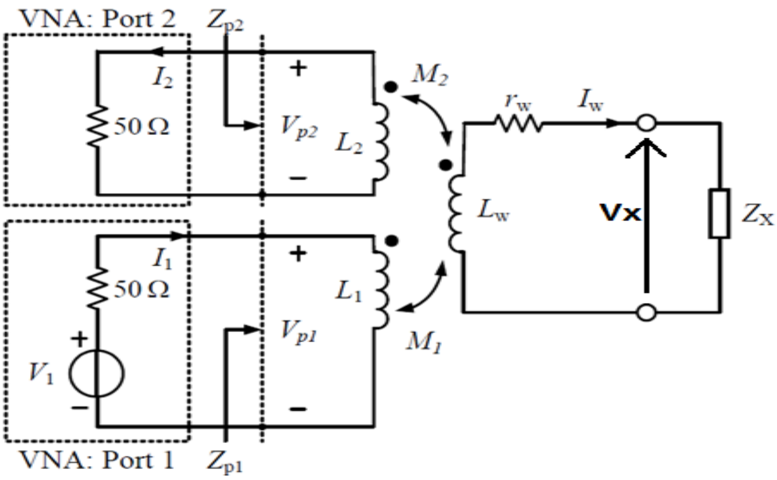


Figure I-5 Electric equivalent circuit of the two probes method

Referring to the figure, one system of three equations are resulted.

$$\begin{bmatrix} V_1 \\ 0 \\ -V_x \end{bmatrix} = \begin{bmatrix} 50\,\Omega + Z_{p1} & 0 & -jwM_1 \\ 0 & 50\,\Omega + Z_{p2} & +jwM_2 \\ -jwM_1 & +jwM_2 & r_w + jwL_w \end{bmatrix} * \begin{bmatrix} I_1 \\ I_2 \\ I_w \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

We determine the expression of I_1 and I_2 from the first and second line of the matrix.

$$V_1 = (50\,\Omega + Z_{p1}) * I_1 - jwM_1 * I_w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

$$0 = (50\,\Omega + Z_{p2}) * I_2 + jwM_2 * I_w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

$$-V_x = -jwM_1 * I_1 + jwM_2 * I_2 + (r_w + jwL_w) * I_w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

$$I_1 = \frac{V_1 + jwM_1 * I_w}{50\,\Omega + Z_{p1}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

$$I_2 = \frac{-jwM_1 * I_w}{50\,\Omega + Z_{p2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

Then we replace equation (10) and (11) in (9). We obtained this global equation.

$$-V_x = \frac{-jwM_1 * V_1}{50\,\Omega + Z_{p1}} + \frac{wM_1^{\,2} * I_w}{50\,\Omega + Z_{p1}} + \frac{wM_2^{\,2} * I_w}{50\,\Omega + Z_{p2}} + (r_w + jwL_w) * I_w \ldots\ldots\ldots\ldots\ldots(12)$$

We define

$$V_{M1} = \frac{-jwM_1}{50\,\Omega + Z_{p1}} * V_1, \quad Z_{M1} = \frac{wM_1^{\,2}}{50\,\Omega + Z_{p1}}, \quad Z_{M2} = \frac{wM_2^{\,2}}{50\,\Omega + Z_{p2}}$$

Now we put in equation (12) these previous expressions. At last we have this new equation.

$$V_{M1} = V_x + I_w * (Z_{M1} + Z_{M2} + Z_w) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(13)$$

According to the expression in (13), the injecting probe can be reflected in the closed circuit loop as an equivalent voltage source V_{M1} in series with a reflected impedance Z_{M1} and the receiving probe can be reflected in the same loop as another impedance Z_{M2}, as shown in Figure below.

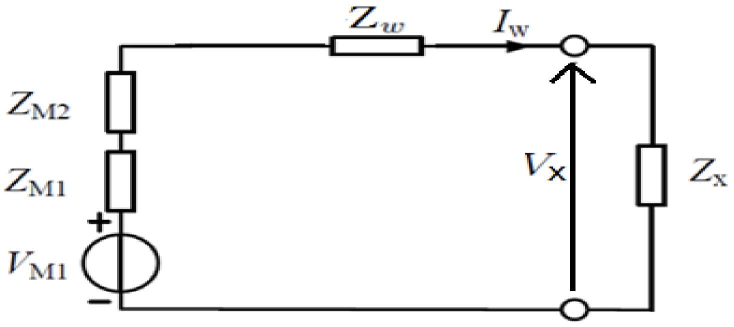


Figure I-6 Final electrical equivalent circuit of the measurement setup

With

- $Zp1$ input impedances of the injecting probe
- $Zp2$ input impedances of the receiving
- $V_{M1}$is the electromotive force generated at the secondary of the probe
- V_1 the voltage of the VNA
- Z_{M1} and Z_{M2} are insertion impedances of the probes

Thanks to Ohm's law, we know that $V_x = Z_x * I_w$

We substitute the expression of V_x in equation (13)

$$V_{M1} = I_w * (Z_{M1} + Z_{M2} + Z_w + Z_x) \dots\dots (14)$$

We can rewrite

$$V_{M1} = I_w * (Z_{setup} + Z_x)$$

$$Z_x = \frac{V_{M1}}{I_w} - Z_{setup} \dots\dots (15)$$

The current I_w measured by the receiving probe is

$$I_w = \frac{V_{p2}}{Z_{T2}} \dots\dots (16)$$

Where V_{p2} is the signal voltage measured at port 2 of the VNA and Z_{T2} is the calibrated transfer impedance of the receiving probe provided by the probe manufacturer. Substituting VM1 and (16) into (15) yields.

$$Z_x = \left(\frac{jwM_1 * V_1}{50\ \Omega + Z_{p1}}\right) * \left(\frac{Z_{T2}}{V_{p2}}\right) - Z_{setup} \dots\dots (17)$$

The excitation source V1 of port 1 of the VNA and the resultant voltage at the injecting probe Vp1 is related by:

$$V_1 = \left(\frac{50\ \Omega + Z_{p1}}{Z_{p1}}\right) * V_{p1} \dots\dots (18)$$

By substituting (18) into (17), the unknown impedance can finally be expressed as **[5]**.

$$Z_x = K * \left(\frac{V_{p1}}{V_{p2}}\right) - Z_{setup} \quad \text{(19)}$$

Where K is a frequency dependent coefficient. The ratio $\frac{Vp1}{Vp2}$ can be obtained through the S-parameters measurement using the VNA.

$$K = \left(\frac{jwM_1 * Z_{T2}}{Z_{p1}}\right), \qquad \frac{V_{p1}}{V_{p2}} = D_{p1p2} = \left(\frac{1 + S_{11}}{S_{21}}\right)$$

At last we have

$$Z_x = K * D_{p1p2} - Z_{setup} \quad \text{(20)}$$

Now, we have obtained the general formula of the unknown impedance. The next step will consist in determining the coefficient K and the impedance of the setup $Zsetup$ by following two indispensable stages.

Firstly, we replace the impedance we want to characterize (Zx) by a short circuit ($Z_{x=0\,\Omega}$) and we measure the $D_{p1p2\,sc}$ with the S-parameter given by the VNA. Secondly we repeat the same measurement but we use an impedance of 50 Ω instead of the short circuit ($Z_{x=50\,\Omega}$). Thus we can determine the $D_{p1p2\;50\,\Omega}$.

Knowing these two values of D_{p1p2}, we determine the value of K and Z_{setup} through these following formula.

$$K = \frac{(Z_{x=50\,\Omega} - Z_{x=0\,\Omega})}{D_{p1p2\;50\,\Omega} - D_{p1p2\;0\,\Omega}} \quad \text{(21)}$$

$$Z_{setup} = K * D_{p1p2\;50\,\Omega} - Z_{x=50\,\Omega} \quad \text{(22)}$$

Noting that the short circuit and the 50 Ω impedances must keep a constant value even in high frequency. It is also necessary to minimize Z_{setup} value in order to reduce the measurement error if a small Z_x is to be characterized.

2. Characterization of the measurement probes

The concepts of transfer impedance functions is essential for a clear understanding of any experimental measurement. It would be important to notice the operating point of the probes we used during the study. Thus we can notify the frequency bandwidth where the measurements are accurate.

We use two types of probes. The first is called F-120-3. It has been designed to extend the use of conducted immunity testing over the bandwidth 10 KHz -100 MHz. The F-120-3 is a high efficiency injection probe used primarily for low frequency conducted susceptibility testing. The input power rating is 100 watts for 30 minutes.

The second probe we use is the F-33-3. This probe is for laboratory and field testing. The useable frequency range of the F-33-3 is 1 kHz – 200 MHz. It has a small outer diameter, approximately 71 mm with an internal diameter of 32 mm. The Figure I-7 represents the two probes.

(a) F-120-3 (b) F-33-3

Figure I-7 Measurement probes

Their characteristic curves are presented in the following Figure I.8

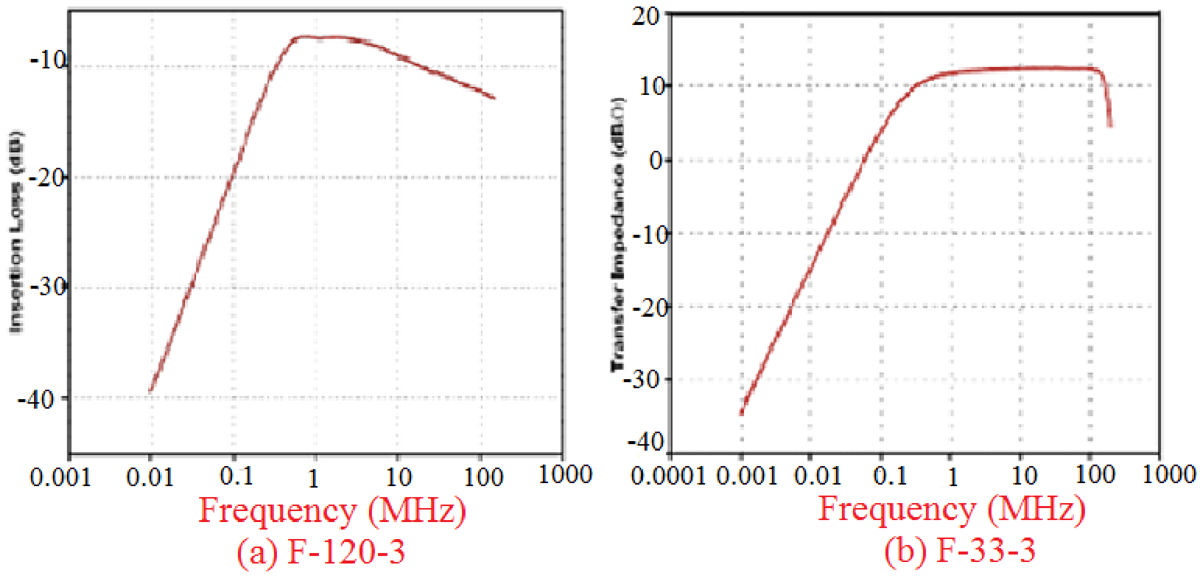


Figure I-8 characterization of the two probes[5]

We can notice that the F-120-3 is more attenuate than the F-33-3 at low frequencies. However at high frequencies we remark that the F-33-3 is strongly attenuate. Thanks to these characteristic, we can expect a good precision during measurement for the F-120-3 from 0.3 MHz to 100 MHz and for the F-33-3 from 0.1 MHz to 100 MHz.

3. Measurement of passive components by probes method

Before any measurement, we should calibrate all ports of the network analyzer we are going to use. Calibration data are measured by connecting an OPEN standard, a SHORT standard and a LOAD standard to the desired test ports. This calibration effectively eliminates the directivity error, crosstalk, source match error, frequency response reflection tracking error, and frequency response transmission tracking error from the test setup in a transmission or reflection test using those ports. This calibration makes it possible to perform measurements with the highest possible accuracy **[6].**

During the study, whenever we characterize an unknown impedance with the two probes method, we compare the results obtained to those of the impedance analyzer to validate the technique. All the measurements are done in the frequency range of 100 kHz-100 MHz.

3.1 Capacitor impedance characterization

A known capacitor of 4.4 nF is measured by applying the two probes method principle on one hand and on the other hand the measurement with one port system is presented. We use a setup of one turn and 0.293 mm^2 of section. The results are compared to the impedance analyzer one as shown in the Figure. I.9.

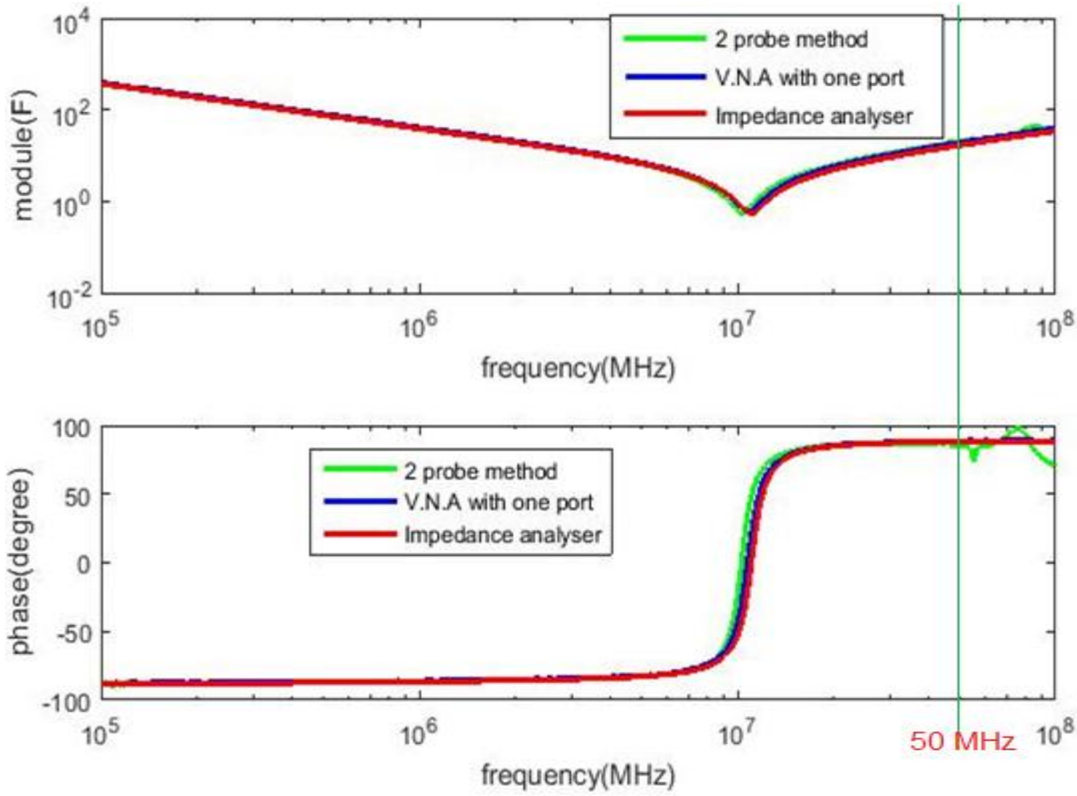


Figure I-9 Characterization of a capacitor

As we observe the two methods are similar to the impedance analyzer result except the two probe method which present some imprecisions from 50 MHz. The slightest variation of the setup may induce these perturbations.

From the figure I.9 we plot above, we determine the different parameters such as the value of the capacitance, the parasitical resistance and inductance of the capacitor. We determine also the rate of error of each method as presented in the table I.1.

	C	Rp	Lp
Imp. Analyser	4.15 nF	547.2 mΩ	518.8pH
V.N.A one port	4.03nF (2,89%)	619.6 mΩ (13,23%)	554,6 pH (6,90%)
2 probe methode	4.07 nF (1,93%)	553.3 mΩ (1,11%)	588.2 pH (13,38%)

Table I.1: Parameters of the capacitor

In terms of precision the two probes method is more adequate.

3.2 Impedance measurement with the variation on number of turns of the setup

In this time also, we keep the same experimental test bench. We replace the previous capacitor by another type of impedance. We use a coil instead of the capacitor. We still compare the result to the impedance analyzer one as presented in the Figure I.10 below.

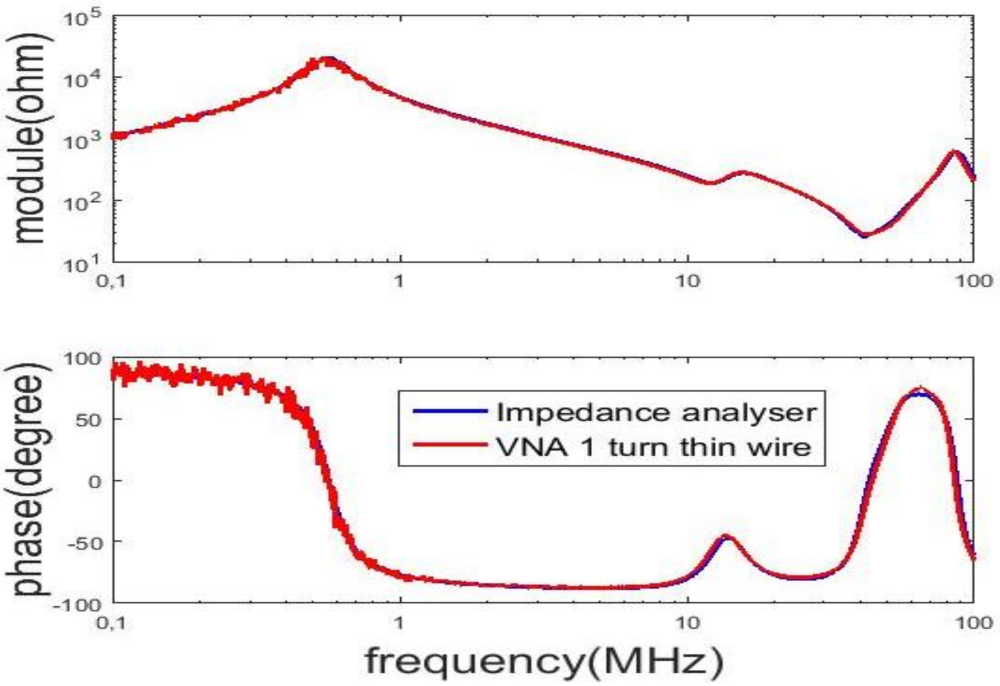


Figure I-10 Charaterization of a coil

We notice that the two probes method matches perfectly with impedance analyzer one despite of some noise at low frequencies. This is due to the fact that the impedance of the coil we characterized presents a high impedance value. We can remediate it by increasing the number on turn of the setup.

For this, we did now three turns of the setup and the result is impressive. All the noise we have seen in low frequency, have disappeared. The main drawback is the loss of precision in high frequency. We can see it in the following Figure I.11. The measure is accurate until 40 MHz.

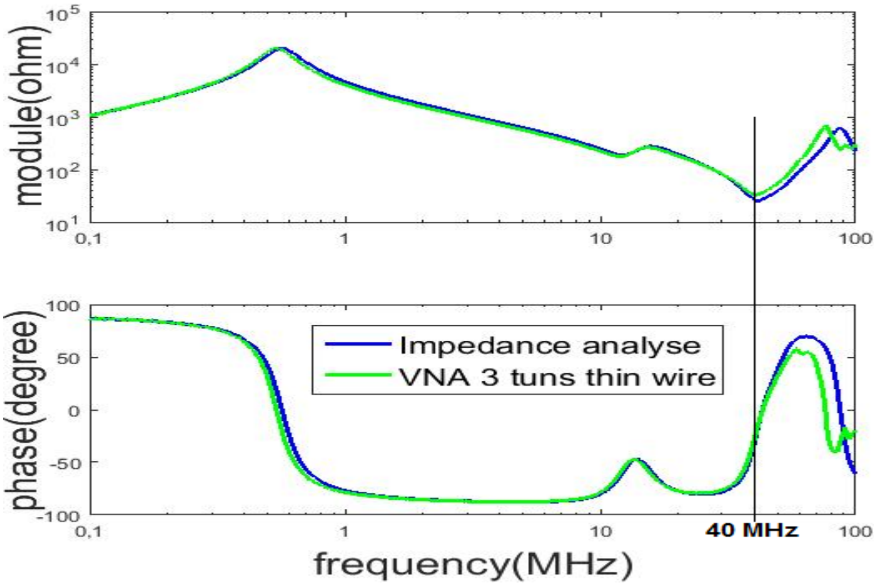


Figure I-11 impedance of the coil with three turns of the setup

After that, we determine the different parameters of our coil. We summarize them in the table I.2.

	L	Rp	Cp
Impe Analyser	1.70 mH	19.77 KΩ	47.52 pF
VNA 1 turn thin wire	1.68 mH (1,17%)	19,46 KΩ (1,57%)	47.91 pF (0,82%)
VNA 3 turns thin wire	1.70 mH (0,2%)	20.29 KΩ (2,63%)	49.53 pF (4,23%)

Table I.2 : Parameter of the coil

When the number of turn increases, the parasitical effects increase also as demonstrated by the calculation of error. It is the reason why the measurement are less accurate at high frequencies.

So according to the application we want to use, we can choose either only one turn for high frequencies utilization or more than one turn for low frequencies usage.

3.2 Impedance measurement with the variation of the section of the cable of the setup

In this part, we increase the section of our measurement setup. We use a thick wire of 1.767 mm^2. We keep the same test bench. And we compare the result to the measurement we have done for the thin wire (section= 0.293 mm^2) as presented in the figure below.

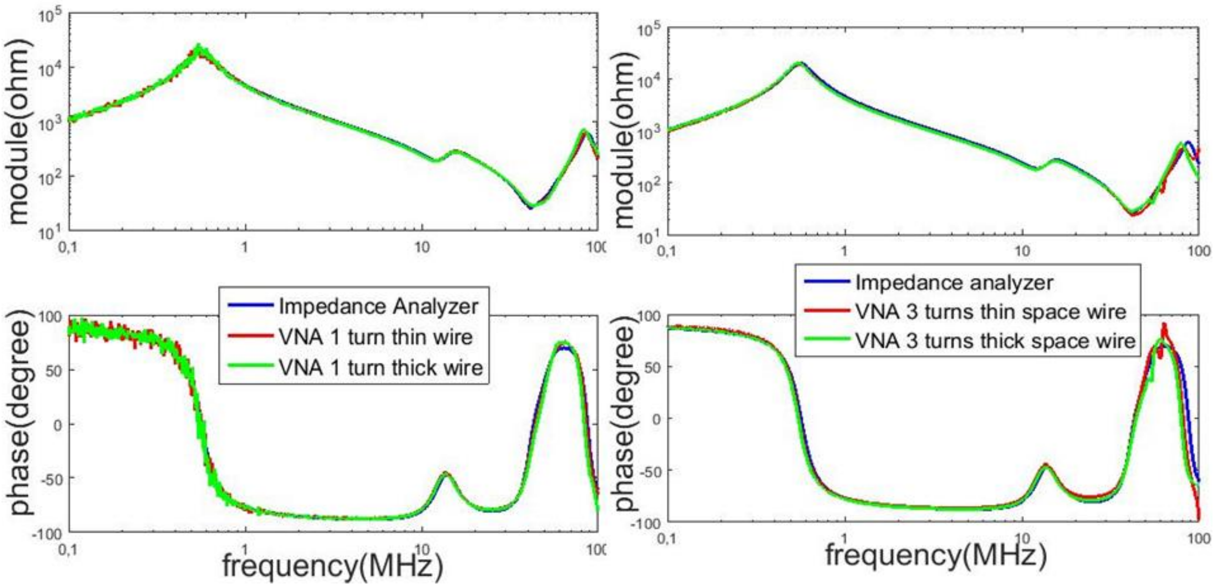


Figure I-12 Coil characterization with the increasing of the section of the cable

Through these result, we assert that the cable section does not have any influence on the measurement but the number of turns does.

4. Measurement of active loads impedance by the two probes method

We have seen that this measurement technique (two probes method) was applied to characterize some passive components and validated thanks to the impedance analyzer. If the two measured impedance are close, this will confirm that we measured the right appliance impedance.

From that moment, by using this measurement protocol, various and widely used electrical devices in the home environment will be characterized.

4.1 Influence of the line impedance stabilization network (LISN) on the test bench

Measurement of electrical equipment impedances shall be carried out by connecting the equipment under test to a LISN (Line Impedance Stabilization Network). The LISN behaves as a filter that is inserted between the device under test and the network supplying the energy. It must isolate the network, which may have common mode and differential mode disturbances, from the equipment under test.

In this part we are going to see if adding the LISN may impact our measurements. For this, we consider the following test bench as presented in the Figure I.13.

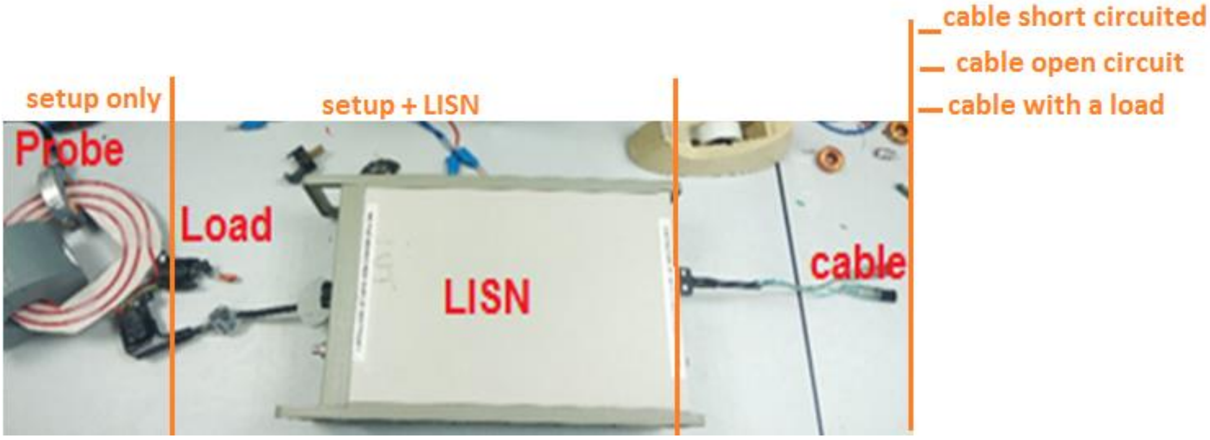
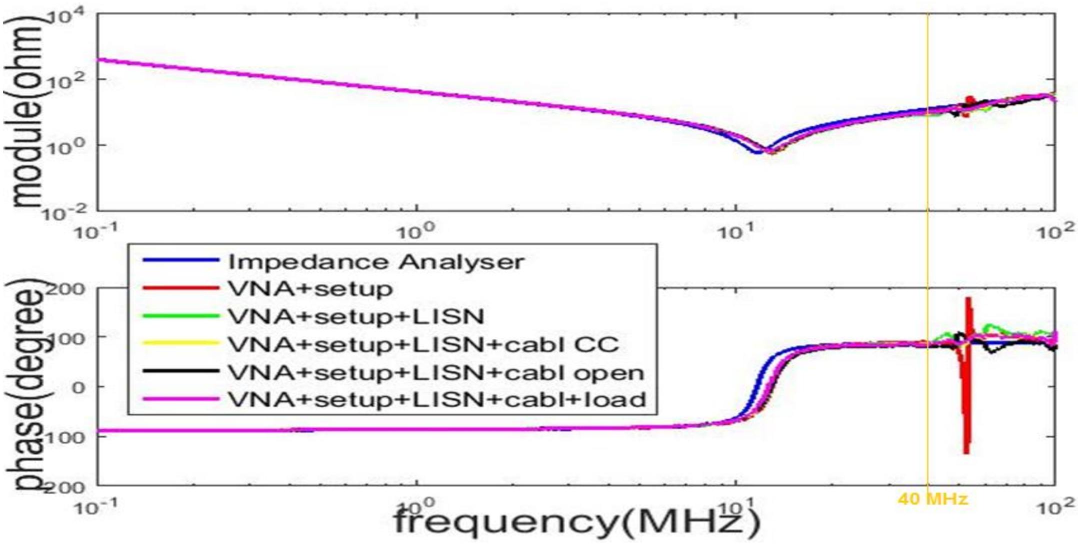


Figure I-13 different measurement setup with the LISN

We consider a capacitor as a load. Firstly we characterized it by using the setup only, then we added a LISN without its alimentation cable. After that we plugged the cable by short circuiting it, afterward we left the cable open. And lastly we used the cable with 50 Ω impedance. We obtained the following results.



We can notice that up to 40 MHz, all the measurement are close to the impedance analyzer result. And it is normal because the LISN we used operates only up to 30 MHz. From this frequency the measurement is not guaranteed.

4.2 Impedance characterization in operating state

We consider in this section some household appliance to characterize. We measured their impedance in off and on state by using the complete test bench as presented previously with the LISN. For the measurement under voltage, we plugged the alimentation cable of the LISN to the power grid.

The Figure I.14 present the magnitude and the phase as function of the frequency in the [100 kHz-100 MHz] frequency range for class 1 appliance such as a capacitor, a TV screen. We obtained the waveforms shown in Figure I.14.

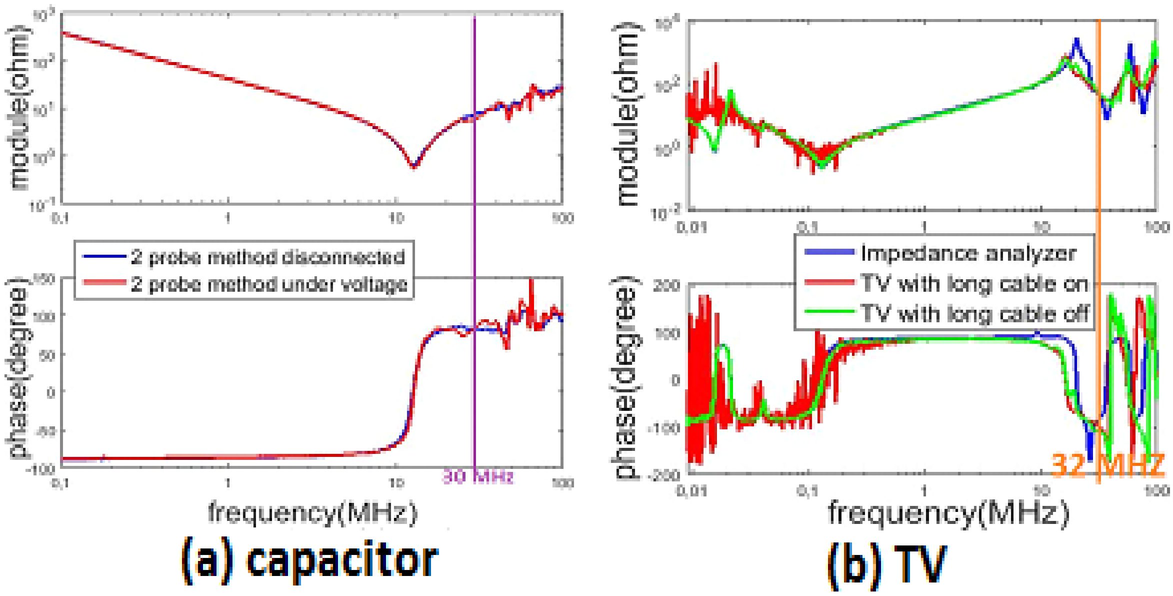


Figure I-14 impedance measurement under voltage

We can remark that the measurement in off and on state of these two impedances are close. For the TV, the shift observed in high frequency is normal. This is due to the fact that the alimentation cable cannot be plugged entirely in the impedance analyzer.

5. Simulation of the two probes method

This part consists in simulating the two probes technique on LTSPICE software. We choose a capacitor as a load. And we compare the results to the experimental one. The results are satisfactory. The Figure I.15 and I.16 show us respectively the electrical equivalent circuit of the two probes method and the comparison of the two results (experimental and simulation).

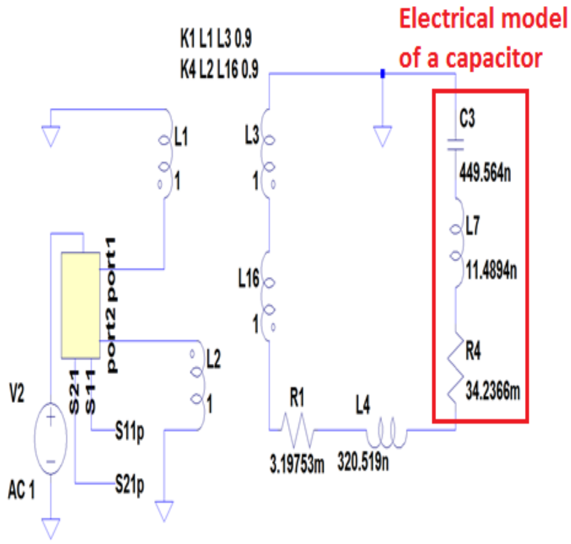


Figure I-15 equivalent electrical circuit of the two probes method

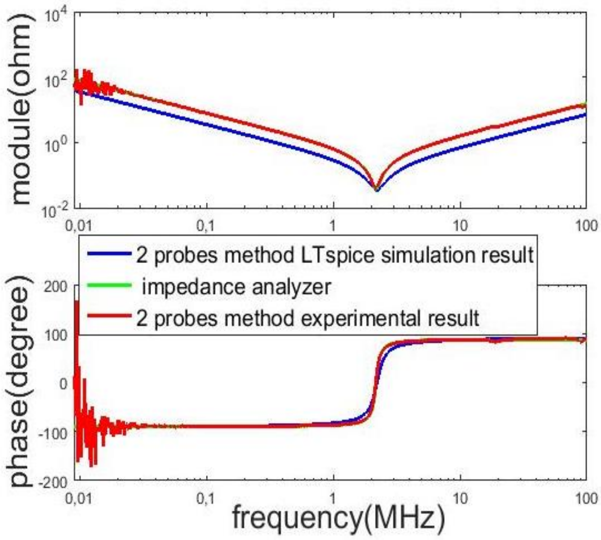
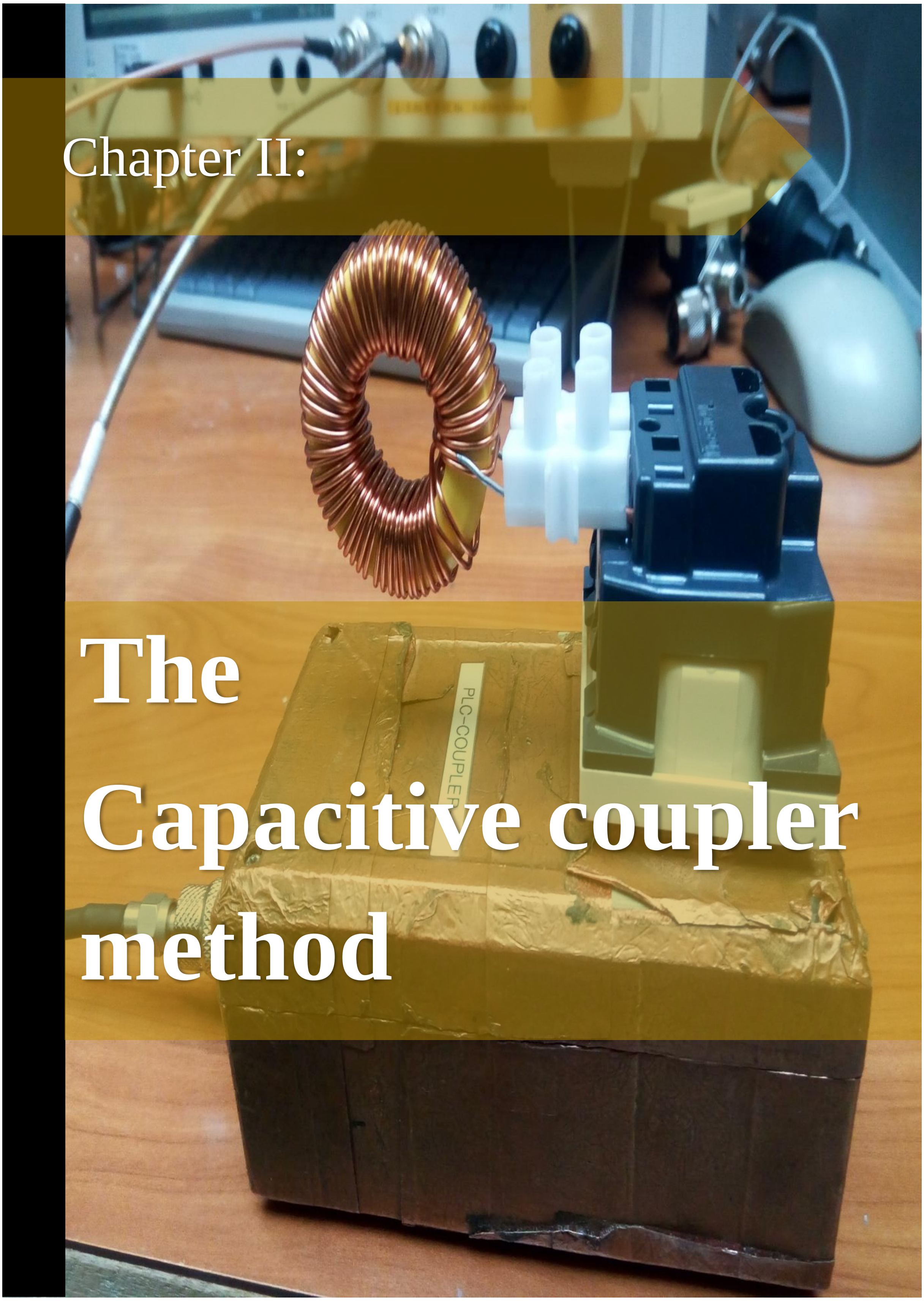


Figure I-16 Comparison between simulation and experimental result

The simulation result can be improved by determining properly the coupling coefficient of the two probes (transformer L1L3 and transformer L2L16).



Chapter II:

The Capacitive coupler method

II- Characterization of the electrical equipment impedance with the capacitive coupler method

Through this second sections, we will define first the protocol of the impedance measurement with the capacitive coupler method. Then we will describe the coupler itself followed by the determination of its frequency operating points. After that we will use this technique to characterize some impedances in off state on one hand and in operating state on the other hand.

1. Principle of operation of the capacitive coupler method

1.1. Measurement test bench

Here also this technique requires the vectorial network analyzer in addition to the capacitive coupler. We use also a line impedance stabilization network (LISN) in order to make normative measurements. The protocol consists of two steps. First we do the measurement without the device we want to test. Secondly we add to the test bench, the impedance we want to characterize **[8].** The two Figure II.1 and II.2 describe the two cases.

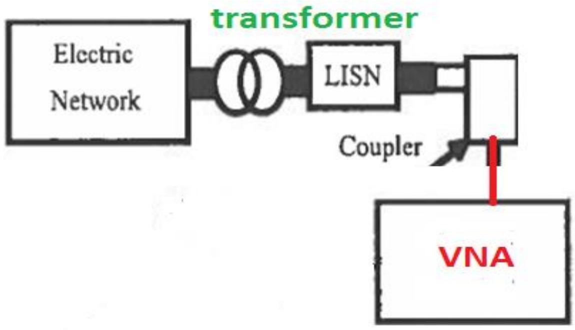


Figure II-1 Measurement test bench without the device to characterize

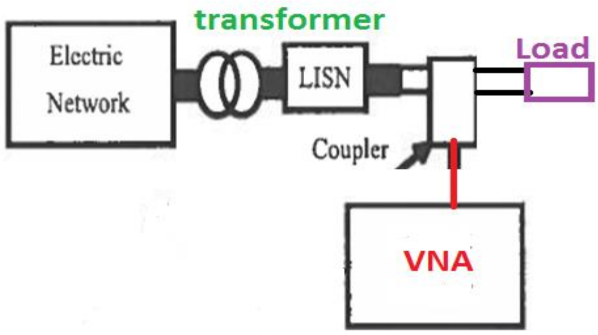


Figure II-2 Measurement test bench with the device to characterize

1.2. Measurement process of the capacitive method

As presented previously, we must do two tests to achieve the measurement of the load. First we measure only the network impedance as presented in the Figure II.1 above. We obtain a reference impedance. We call it Z_{ref}.

The second manipulation consists in plugging the device (load), we want to determine in parallel to the LISN, to the coupler. We obtained a new impedance called Z_t.

Thus, the impedance of the load named Z_{load} is deduced from Z_{ref} and Z_t by means of the equation 23.

$$Z_{load} = \frac{Z_{ref} * Z_t}{Z_{ref} - Z_t} \dots \dots (23)$$

2. Characterization of the coupler

In this subsection we will present the coupler we used during the study on one hand. It consists of high voltage capacitor to filter out the 50/60 Hz high voltage waveform, a broadband transformer, a couple of two diodes to protect against over voltage. The Figure II.3 below gives us better presentation of the capacitive coupler.

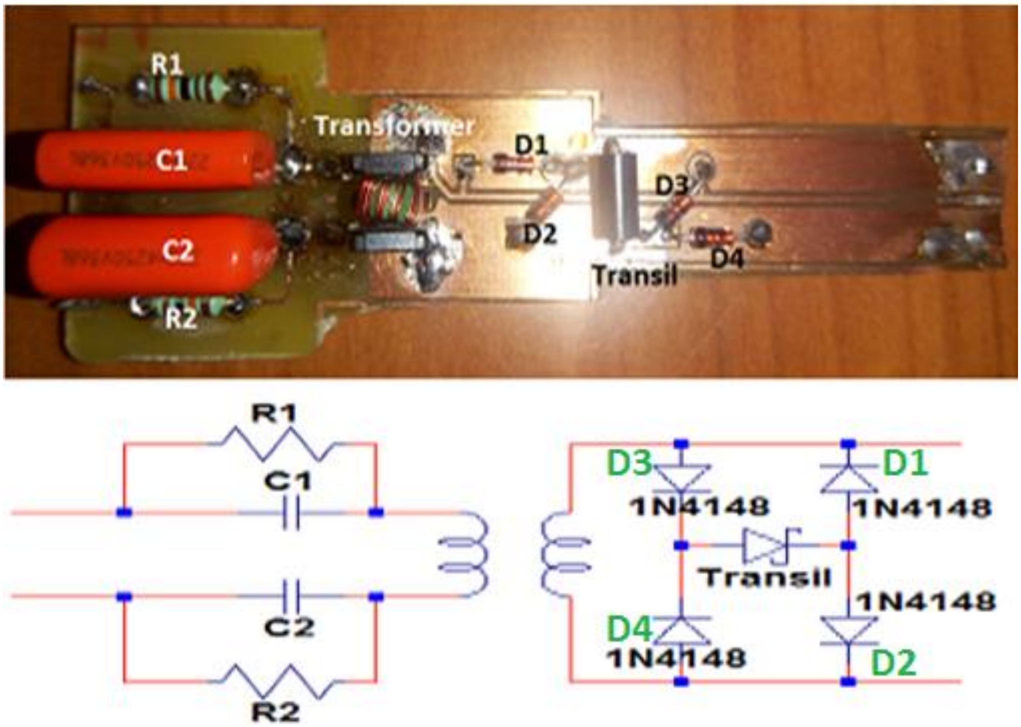


Figure II-3 Capacitive coupler electrical circuit

In the other hand, in order to predict the frequency bandwidth where this technique (capacitive coupler method) seems to provide better results, we determine its transfer function by plotting the parameters S_{11} and S_{21}. These parameters are obtained thanks to the vectorial network analyzer through this following test bench as shown by the Figure II.4.

We define S_{11} as the coefficient of reflection of the signal in port 1 of the VNA and S_{21} the signal transmission coefficient from port 1 to port 2.

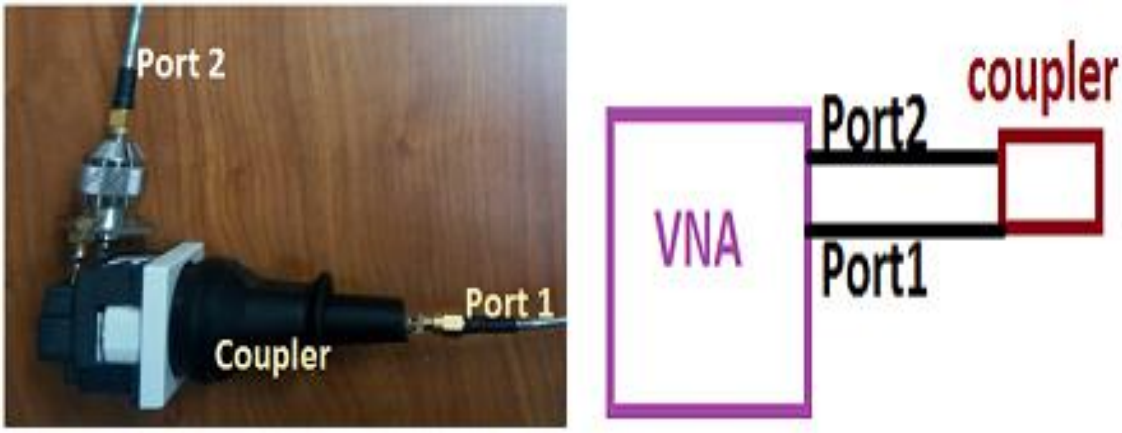


Figure II-4 Transfer function measurement setup

Thus, the frequency bandwidth is found by subtracting 6 dB to the maximum amplitude of S_{21}.

We use two types of coupler during this work. We present the transfer function of the two used coupler in the Figure II.5.

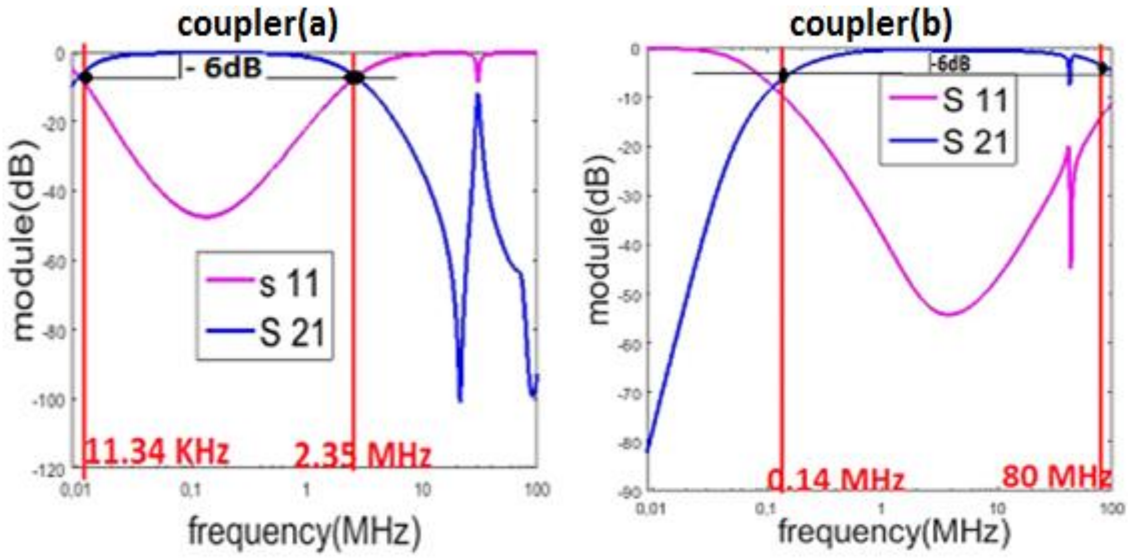


Figure II-5 Transfer function of the two couplers

By applying a tolerance of - 6 dB, we can notice that the coupler **(a)** operates only at low frequencies. We can expect to obtain better results in the frequency range from 11.34 kHz to 2.35 MHz.

However for the coupler **(b)** we observe the opposite reaction. It is done specially for high frequency usage. We can see that this coupler operates from 0.14 MHz to 80 MHz.

These analysis allow us to say that there is no coupler which can operate at the same time at low and high frequencies.

3. Measurement of device in off state with the capacitive method

3.1. Measurement without the LISN

In order to achieve this part of work, we consider the basic experimental setup as indicated in the Figure II.6. We do not plug the LISN. The test bench consists only of the vectorial network analyzer, the coupler and the load. The measurement can be done with only one port of the VNA. Here we do not need to calculate preliminary the reference impedance (Z_{ref}) and the total impedance (Z_t) as said previously in the method principle. We determine the impedance of the load directly from the VNA by considering the S-parameter S_{11} only. Hence we can use the equation (5) to determine the module and the phase of the load. We do not plug the load into the power grid (off state)

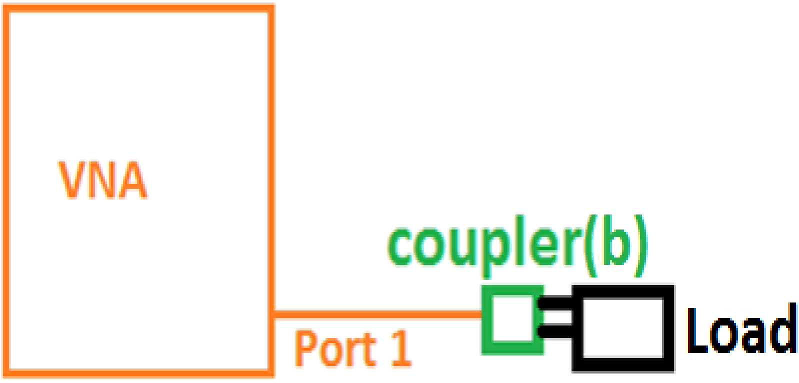


Figure II-6 Capacitive coupler test bench without the LISN

We characterize then a capacitor and an inductor. We determine their magnitude and phase. We use also the coupler (b) which frequency operating point start from 0.14 MHz to 80 MHz (Figure II.5). We present the two results in the following figures.

We consider the impedance analyzer as a reference. Every time we characterize a load, we compare the result to the reference. Thus we can validate the technique and the test bench. We did the measurement in the frequency range 9 kHz - 100 MHz.

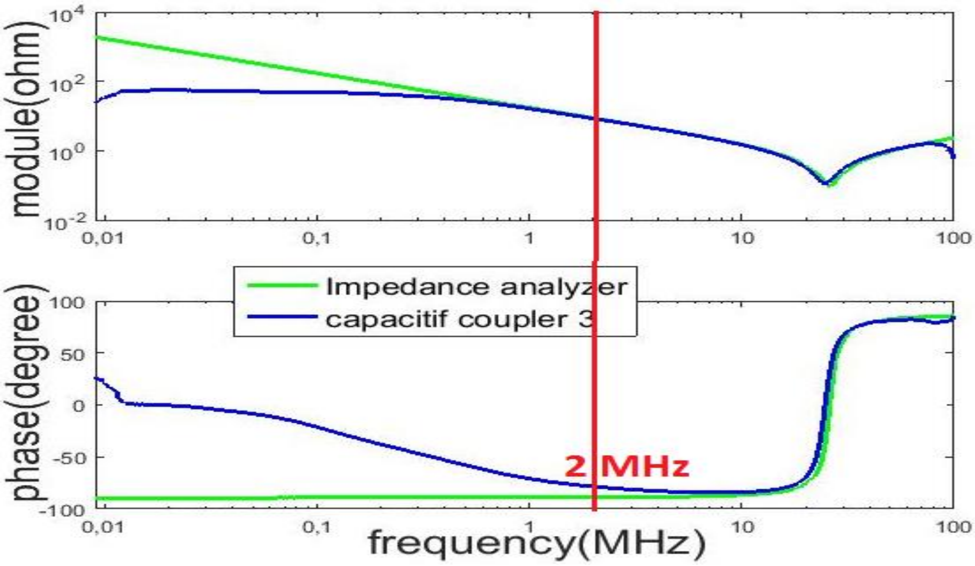


Figure II-7 Capacitor impedance characterization

As we know the coupler we used here in this case is made for high frequency usage (coupler b). So it is normal that the result we obtained at low frequencies does not match with the impedance analyzer one.

However, we can notice that from 2 MHz until 100 MHz, The two results match perfectly. And the small shift we see at high frequencies is due to the fact that the connections of the capacitor are not plugged symmetrically during the two measurement (impedance analyzer and coupler method).

In the same setup configuration, we replace the capacitor by an inductor. The result we obtained is shown in the Figure II.8

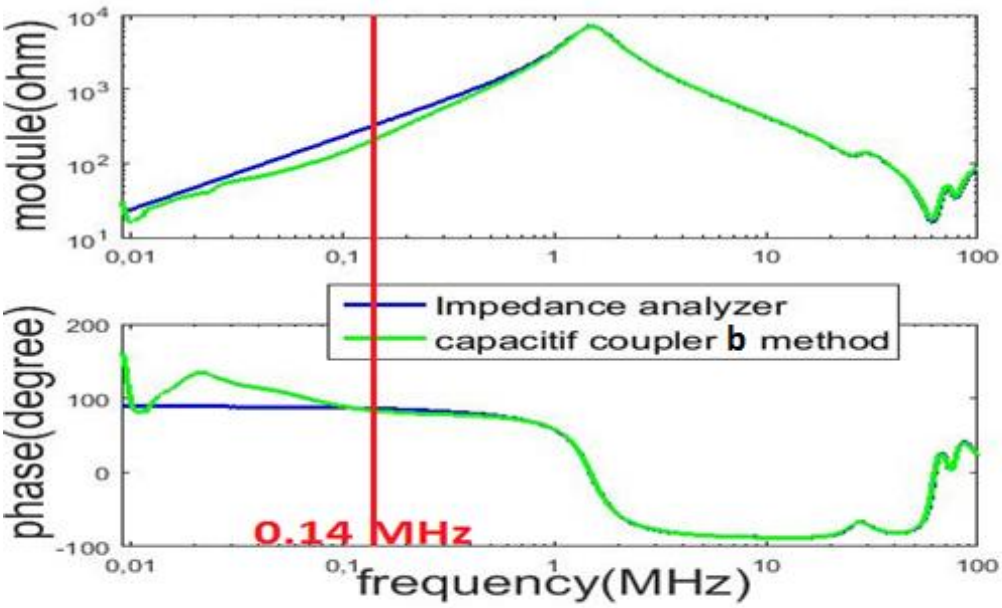


Figure II-8 Inductor measurement with the coupler method

Here we remark that the measurement is similar in the whole frequency operating point of the coupler. From 0.14 MHz to 100 MHz, we have a good accuracy. At low frequencies, as the coupler does not operate in this zone, we do not have any accuracy there.

From these two measurements, we can conclude that the capacitive coupler method is precise when the load we want to characterize has a high impedance value.

4. Impedance measurement under voltage with the capacitive coupler method

4.1. Measurement Test bench

We characterize some device under voltage in this part of the chapter. Unlike the previous test bench, here we add a LISN and a transformer. We did different tests. We varied the length of the cable between the LISN and the coupler. We choose first a short cable of 0.3 meter, then another medium cable of 0.6 meter and at last we use a long cable of 0.9 meter. The Figure II.9 presents the test bench.

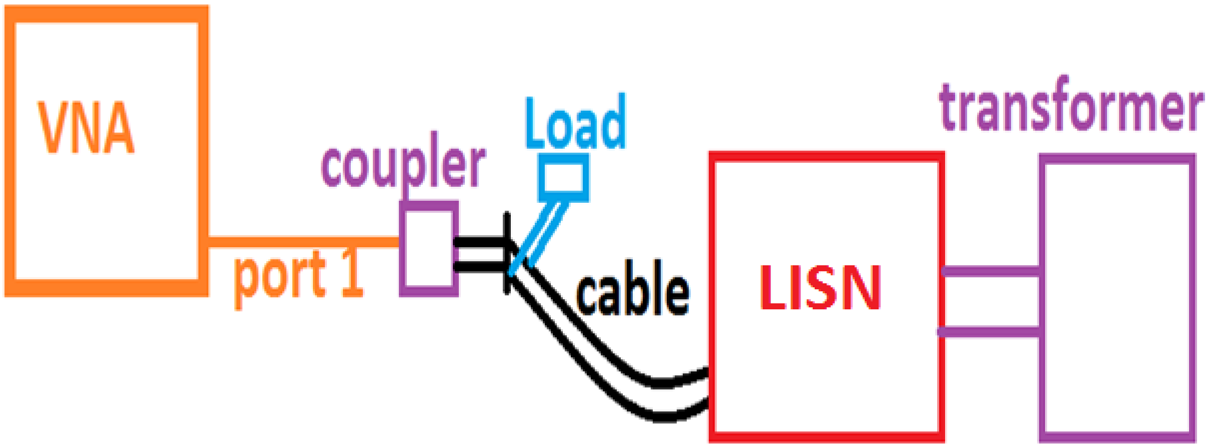


Figure II-9 Capacitive coupler method test bench

4.1. Impedance characterization

The measurements are performed in off and on state. We compared them to the impedance analyzer result. We consider first a capacitor.

Here also we use the coupler which is designed for high frequency utilization (Coupler b). We work in differential mode in the frequency bandwidth of 9 kHz to 100 MHz

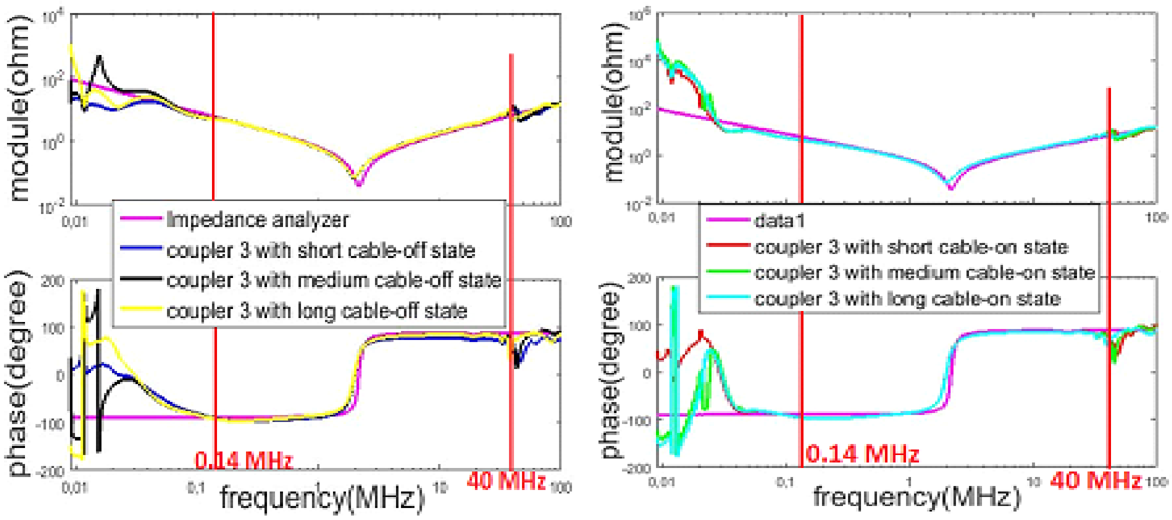


Figure II-10 Capacitor measurement with variation of the cable between the coupler and LISN in off and on state

As indicated by the border (in red) in the figure above, the measurement is accurate from 0.14 MHz to 40 MHz.

We can see that when the load is close to 100 Ω (impedance of the LISN in differential mode), the method presents some precision. It is due to the fact that the load is placed in parallel to the LISN. By this way the method is limited. If the load we are going to characterize is too high or too small, the capacitive coupler method cannot give good precision.

We can notice also that the length of the cable between the LISN and the coupler influences the measurement. In fact we have some drawbacks in high frequency which are caused the cable. The more this cable is long, the more it becomes difficult to measure the impedance.

This time, we change the load. At the place of the capacitor, we use a TV screen. The alimentation cable of this TV is about 1m70. We applied the same protocol as the previous load. The Figure II.10 below shows the measurement results.

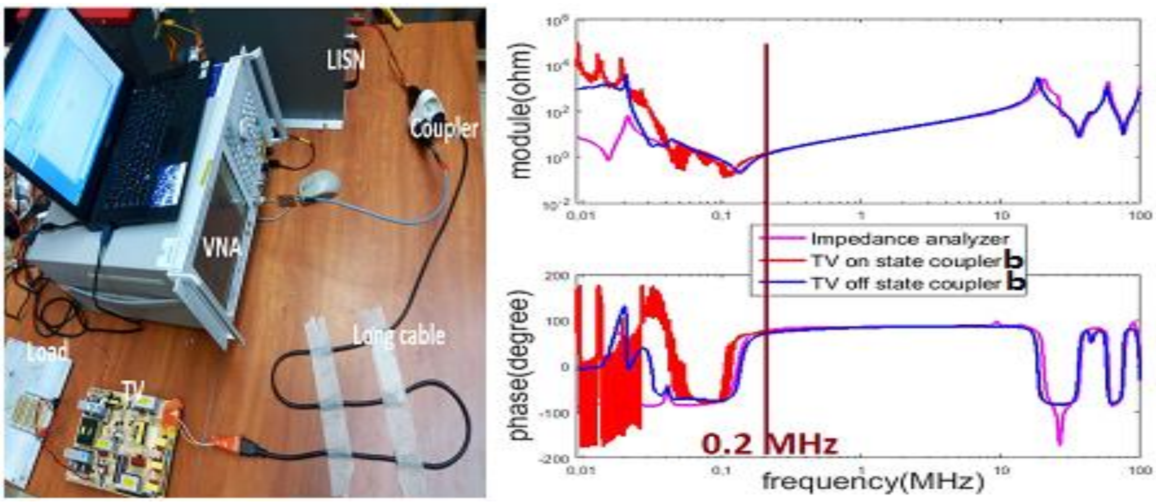


Figure II-11 TV screen characterization with the capacitive method

At low frequencies, we don't have any precision. This is due to the coupler. The measurement is accurated from 0.2 MHz to 100 MHz as indicated in the figure II.11 above despite the length of the alimentation cable of the screen effect.

Now, we change the type of the load. We use a class 2 impedance. The particularity of this kind of load is the fact that each time, its impedance varies between two states (on and off). It exists several class 2 load such as internet box, TV box charger, mobile charger, fluorescent lamp…. In our case we will study only the fluorescent lamp. We applied the capacitive coupler protocol to characterize its impedance.

Here, we must be careful during the setting of the vectorial network analyzer. The sweep time of the VNA should be much higher than the temporal variation of the measured impedance in order to detect the two states of the fluorescent.

The Figure II.12 below represents a photos of the considered lamp. The alimentation cable of the lamp, we plugged to the coupler has a length of 1m50.

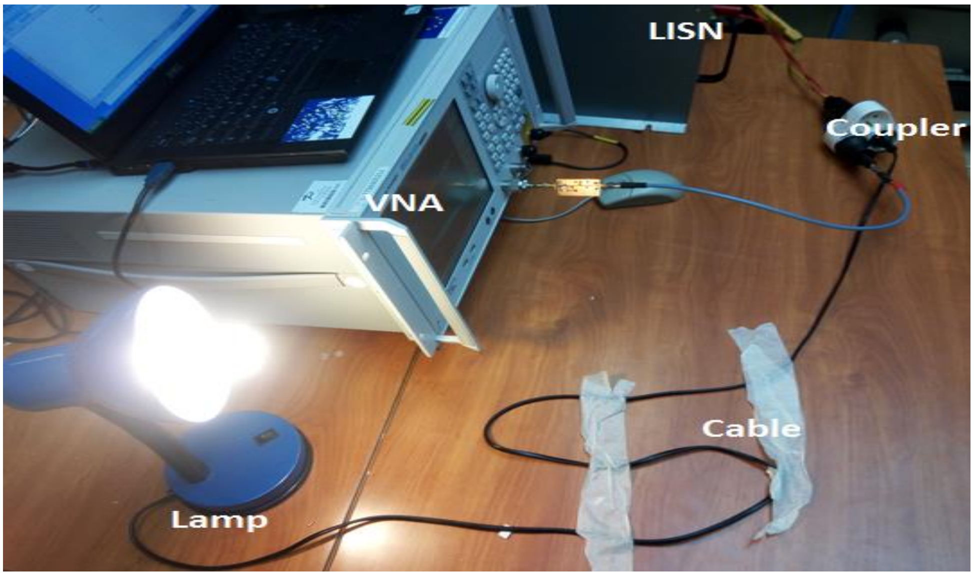


Figure II-12 Measured lamp with the capacitive coupler method

The Figure II.13 show the result we obtained in non-operating state is compared to the impedance analyzer one on one hand. On the other hand we present also the result in operating state.

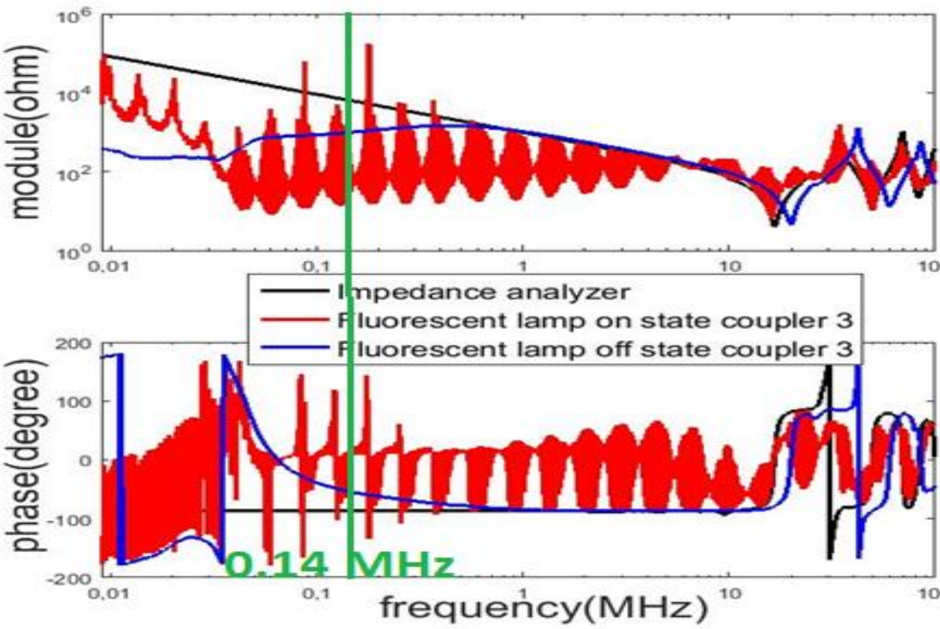
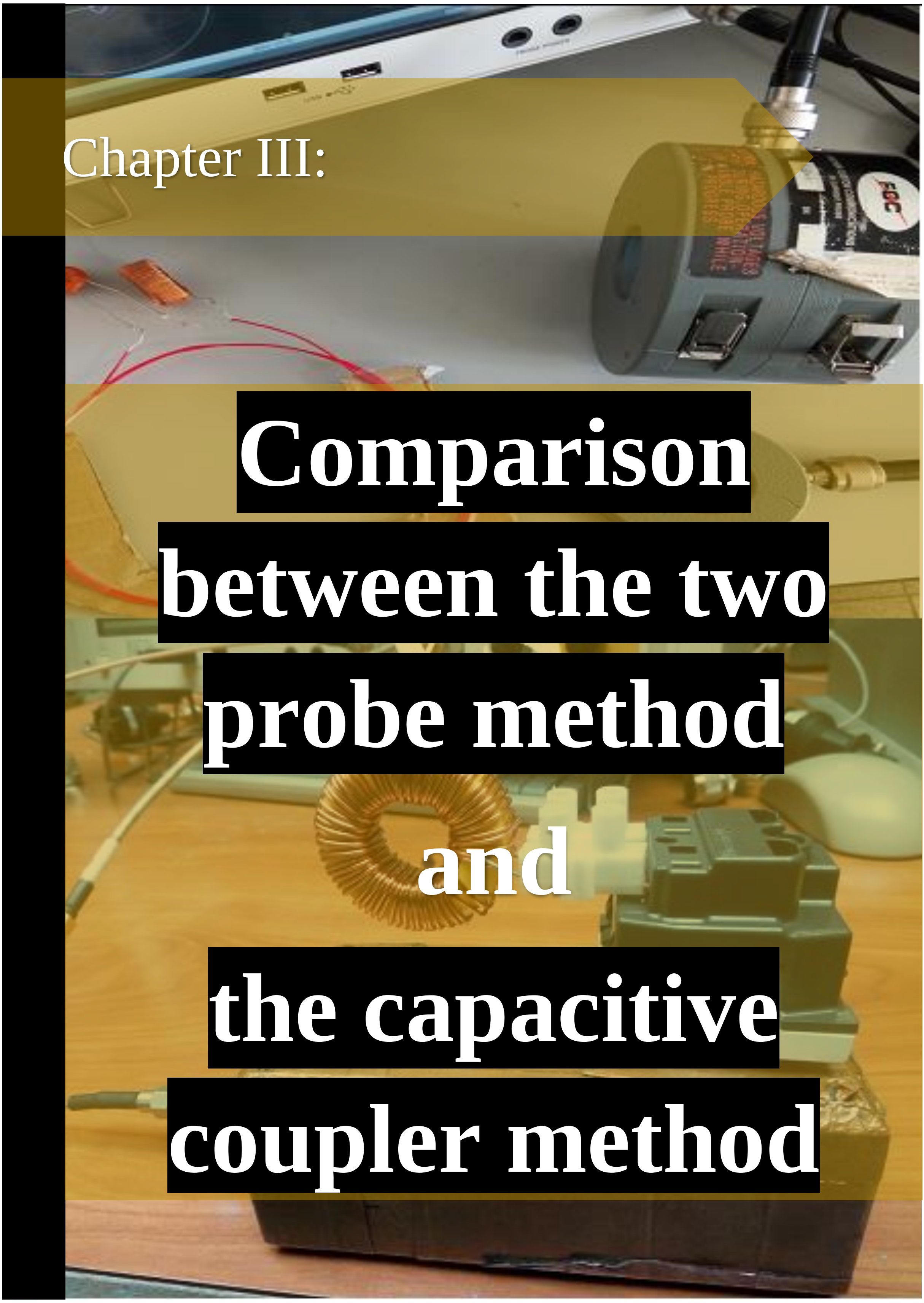


Figure II-13 Impedance of the fluorescent lamp

The shift observed in high frequency is due to the inductance of the lamp's power cable outlet. The variations which are seen in on state are caused by the different switching state of the lamp.

The class 2 household appliances play an important role in the performance and reliability of the PLC system. The time variation of these kind of load induces a cyclic time variation of indoor power line channel [**5**].



Chapter III:

Comparison between the two probe method and the capacitive coupler method

III- Comparative study between the capacitive coupler method and the two probes method

We have seen previously the principle of work of the two proposal methods. We applied their measurement protocol to characterize some loads. We measure their impedances in non-operating state first, then in operating state.

Now in the remaining work we will compare these two measurement techniques on the same load.

After that we will go further; we will select one household electrical equipment to characterize. Thanks to the results we obtained, we will determine its equivalent electrical scheme. Then we will use this proposed equivalent circuit to simulate on LTSPICE software in order to see if we find again the total impedance of the chosen household electrical equipment.

1. Comparison result and analysis

1.1. Test on passive components

We start the measurements with some passive elements. First, we consider a capacitor. We characterize its impedance by applying the inductive and the capacitive method protocol. We did the measurement in the frequency bandwidth of 9 KHz up to 100 MHz. As the considered capacitor does not support high voltage (230 v), we stay in off state. We did not plug the LISN, and the test bench is as we have presented it in the two previous chapter. The result is presented in the Figure III.1 below.

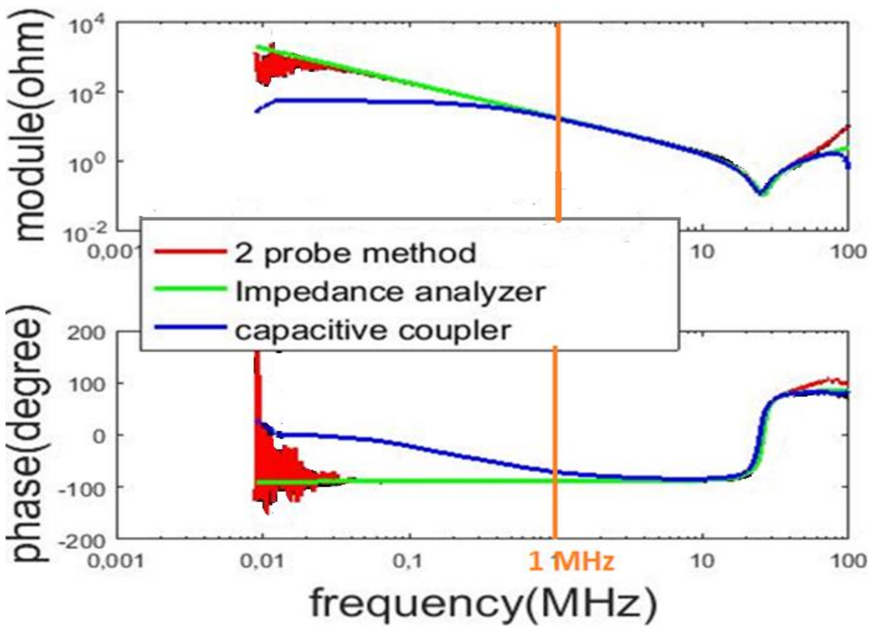


Figure III-1 Capacitor characterization with the two method

Here also we use the coupler (b) which is accommodated for high frequency (see chapter 2). We can notice in the figure above that from 1 MHz, the two method are similar compare to the impedance analyzer. Before 1 MHz, only the two probes method matches with the impedance analyzer.

Secondly we change the load; we measure an inductor. We stay always in the same condition. The following figure indicates the result we obtained.

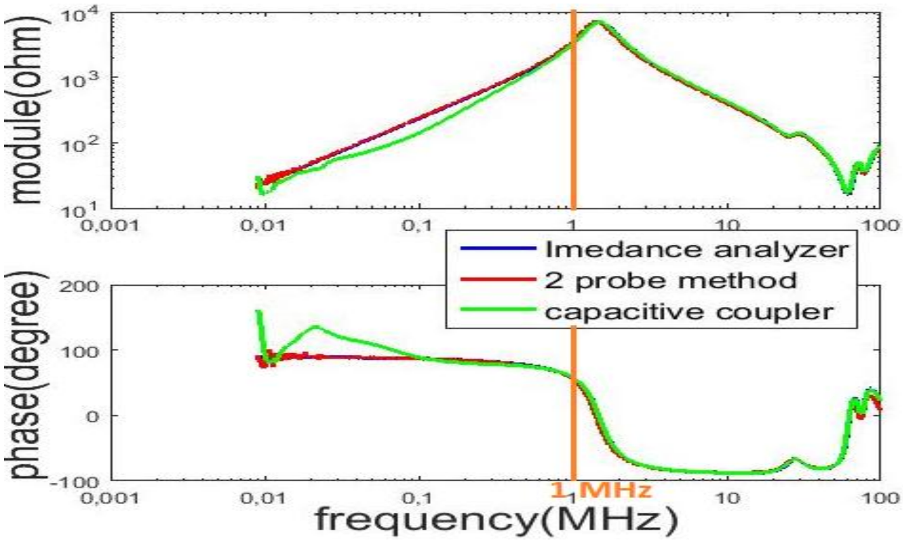


Figure III-2 Inductor measurement with the two method

The remark is the same here as the previous analysis. From 9 kHz to 1 MHz, only the two probes method gives better result. Nevertheless, in the remaining frequency band, the two techniques are very close.

1.2.Test on complex loads

The second step of our work consist to comparing the capacitive and the inductive method on some household equipment.

For this, we have at our disposal a TV screen in the firstly as presented in the figure III.3. We do not consider its alimentation cable. In this case, we used the coupler (a) which is adapted for low frequency utilizations in addition to the coupler (b).

The measurement test bench and protocol are the same as described in the previous studies.

The Figure III.4 shows the different measurements we found with these two methods in these conditions.

Figure III-3 TV screen input impedance

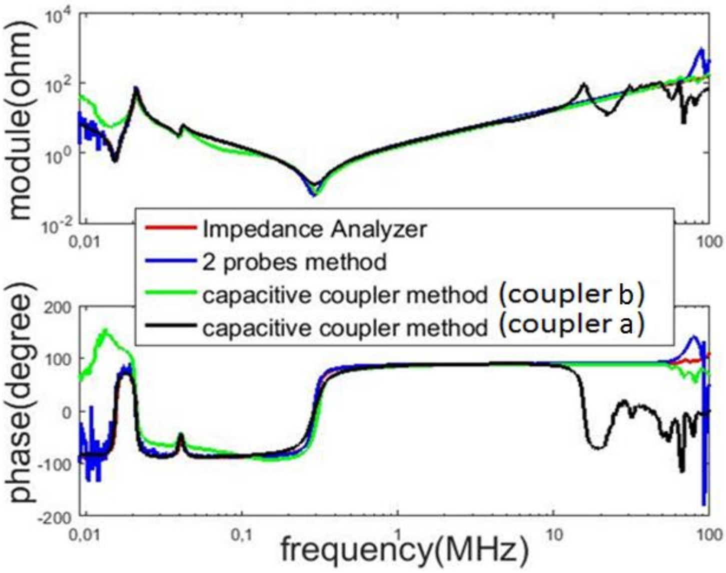


Figure III-4 TV characterization with the two techniques

We can say that the two probes method is more practical. We don't need to change the test bench and it provides better results.

For the coupler method, we can see that the coupler (a) allows to obtain a good precision at low frequency (9 kHz up to 9 MHz) contrary to the coupler (b) which present better precision at high frequency (0.14 MHz up to 80 MHz).

We need at least the coupler (a) and (b) to cover the whole frequency band.

Secondly a fluo-compact lamp is proposed to characterize with the presented two process. The test bench stay the same. We just change the load. Instead of the screen, we plug a lamp with its power cable.

For the capacitive method, only the coupler (b) is used. The results are indicated in the Figure III.5 below.

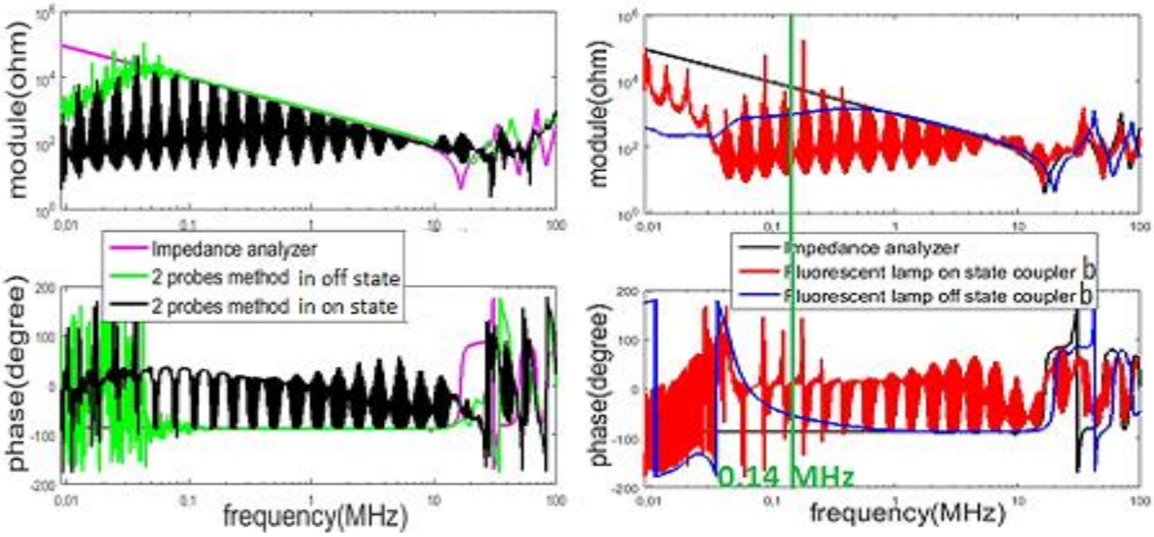


Figure III-5 Fluorescent lamp characterization with the inductive and capacitive method

We can notice that when we are in off state, we are able to determine the florescent lamp impedance from 0.14 MHz to 100 MHz for the coupler method and in whole frequency band for the two probes technique. The shift observed at high frequency is due to the inductance of the power outlet.

However, when we are in operating state, we observed a lot of variations caused by the different switching states of the lamp. The impedance of this kind of equipment is not measurable by the vectorial network analyzer (VNA). The VNA does not take into account the temporal variation of the impedance. Only the frequency variation is considered here.

2. Determination of equivalent electrical circuit of a household appliance

We consider the input impedance of a TV circuit. The goal of this part is to have an idea about the different components of the circuit which influence the whole TV impedance during the measurements. Hence the idea to unsold one by one all the components of the circuit as presented in the Figure III.6.

Every time we removed one component of the circuit, we measured the impedance of the remaining circuit by using only the impedance analyzer in the frequency band of 9 kHz-100 MHz. Thus we can identify which passive elements of the circuit constitute mainly the impedance of the TV. The result is presented in the Figure III.7.

We will propose then an electrical equivalent circuit.

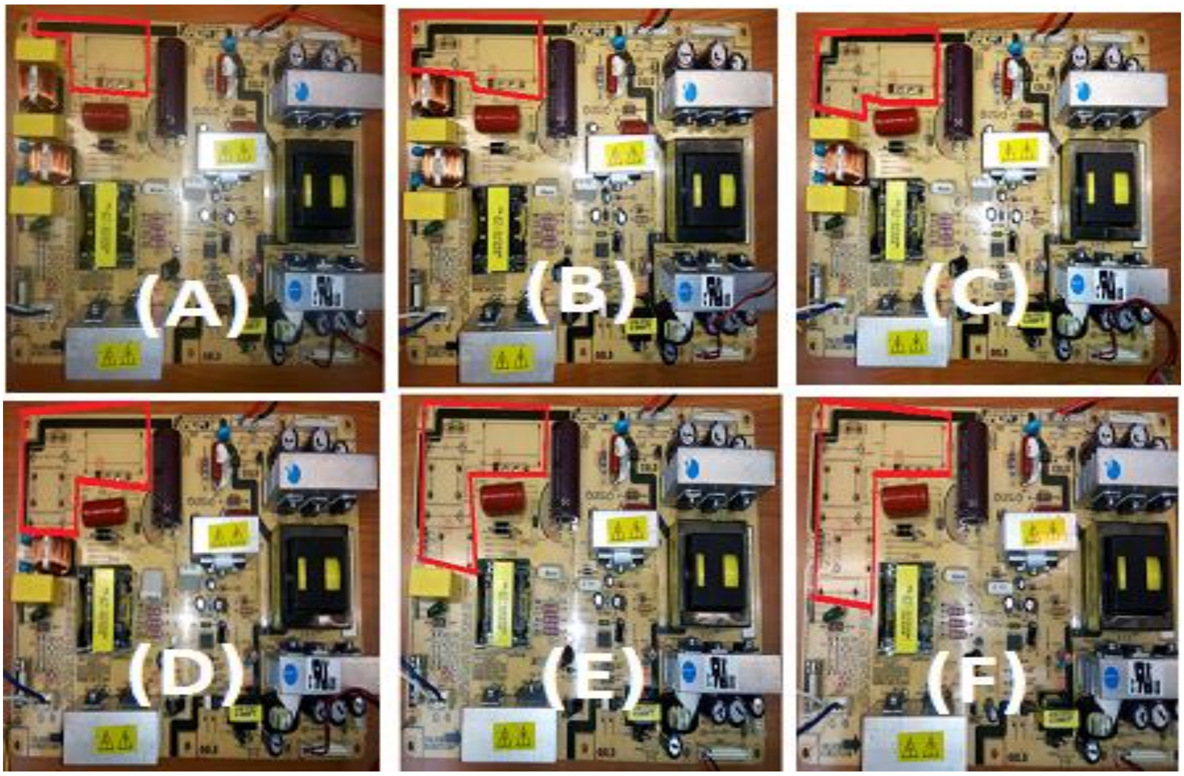


Figure III-6 Characterization of the TV

In each case which is presented in the figure above (A, B, C, D, E, F), we determine the impedance of the circuit and we present the result in the next figure.

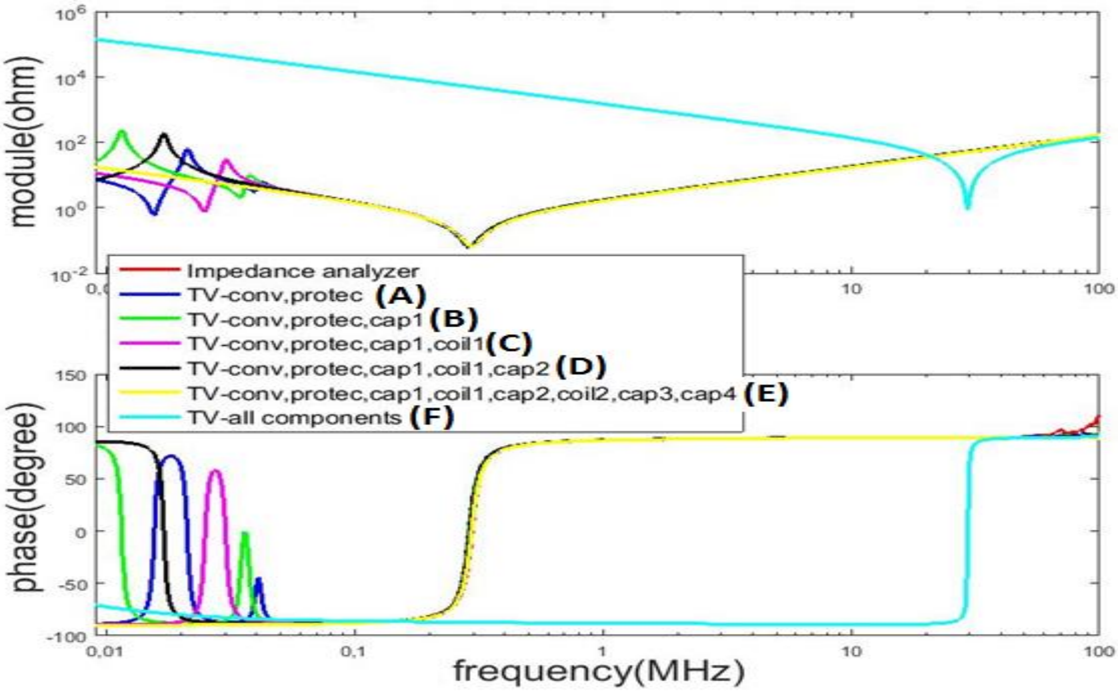


Figure III-7 TV characterization steps results

Thanks to this process, we are able to propose an equivalent electric model of the studied TV. It is presented in the Figure III.8 below. The circuit consists of three capacitors and two inductors.

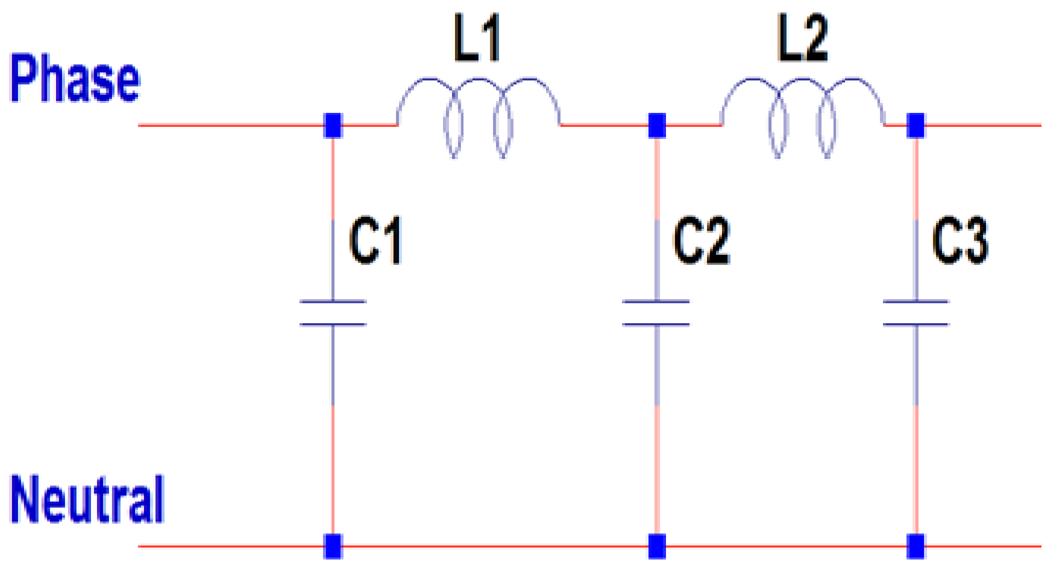


Figure III-8 Equivalent electrical model of the TV

3. Simulation with the two probes method of the proposal model of the TV

We have proposed previously an equivalent electrical model of our TV. In this part, we are going to see if the impedance of the model we determined looks like the impedance of the TV that we have already characterized.

In fact the aim is to validate our model. Thus, we will use LTSPICE software with one of the two techniques. Here we use the two probes method. The Figure III.9 shows the results.

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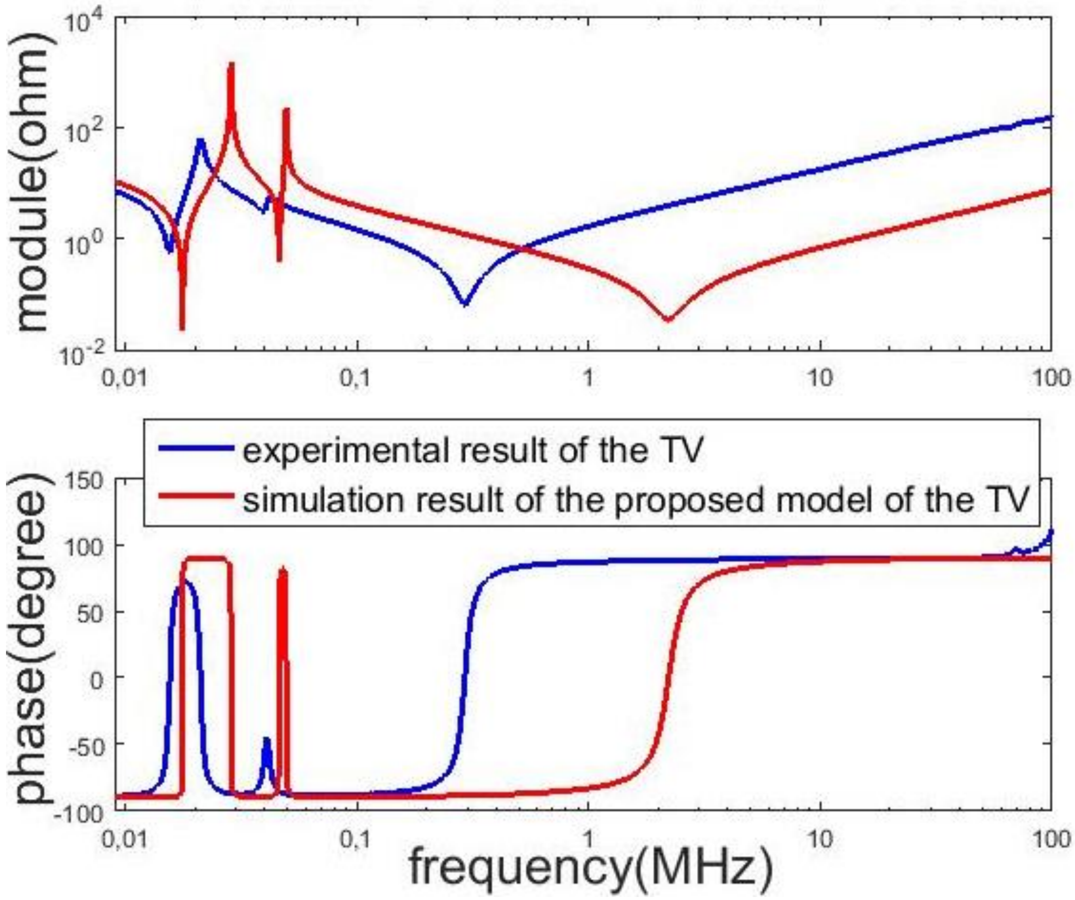


Figure III-9 Comparison between simulation result of the proposed model and the experimental result of the TV

We can see that the simulation result does not match with the experimental one. The resonant points present a shift. We can obtain better results by adding for instance some parasitic from connections and circuit track.

Conclusion

In definitive, the principal aim of this master's final internship is to contribute to the understanding and modeling of data transferring by using PLC signal. In fact, in order to implement an efficient communication signal, it is necessary to have a model of the indoor communication channel such as electrical equipment appliances. For this, two measurement techniques namely the two probes method and the capacitive coupler method, are studied.

On such a base, we investigated the methodology to determine impedances by the proposed methods. The first technique principle is based on a direct clamping two-probe measurement approach. The differential mode (DM) source impedances of some passive and active loads in off state and under their operating condition are extracted with good accuracy. The measurement setup is simple and it also allows both the magnitude and the phase of the DM source impedances of the loads to be extracted with ease. The major feature of the proposed method is its ability to eliminate the error due to the impedance of the measurement setup. The second techniques, however, is based on a capacitive coupling. Some electrical equipment devises have been characterized. This approach is simpler than the previous one to implement.

As measurements results, we learned that many appliances maintain the same their input impedance in operating state and non-operating. However a great difference can be observed regarding to some loads. For many device such as the fluorescent lamp, the input impedance is time varying in operating state which demonstrates the limit of the two methods. This kind of device perturbed the power line network and consequently the PLC signal. We notice also the alimentation power cable caused some troubles during the measurement and especially at high frequencies. The two probes method seems to give better results than the capacitive coupler method.

As perspective, we can add an oscilloscope in order to take into account the temporal variations of the loads.

In short, the results of this investigation are promising. Despite the fact that both techniques are limited at very high frequencies (from 100 MHz), these procedures of loads characterization still more practical in protecting yourself firstly, efficiency estimation during measurements. On the other hand, the study can help PLC technologies designers to transmit better digital convergence signal in the home environment. Deeper studies are carried out to improve the techniques results by decreasing for instance the parasitical effects when the earth is plugged (Common mode). These studies will undoubtedly lead to important and economically justifiable results for the various PLC technologies manufacturing companies.

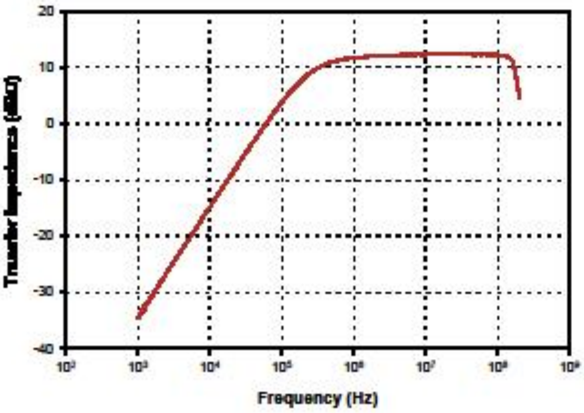
References

Appendix

CURRENT PROBE

F - 33-3

The F-33-3 is for laboratory and field testing. The useable frequency range of this probe is 1 kHz – 200 MHz. A typical calibration curve is shown below. This probe has a small outer diameter, approximately 71 mm with an internal diameter of 32 mm.



Specifications

Frequency:	1 kHz – 200 MHz
Internal diameter:	32 mm
External diameter:	71 mm
Height:	19 mm
$Z_t\Omega$[1]:	4.5
$dB\Omega$[1]:	13
Connector:	Type-N
DC to 400 Hz:	100 amperes
RF(CW):	10 amperes
Peak Pulse Current[2]:	50 amperes

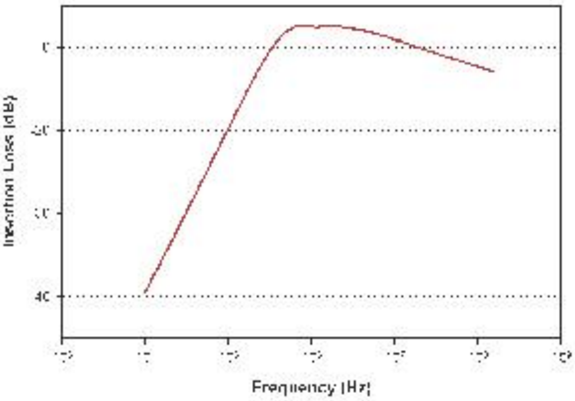
1: Probe calibrated with 50 Ω + j0Ω Load Impedance.
2: Depends upon the pulse width and pulse rep. rate.

Fischer Custom Communications, Inc.

20603 Earl St., Torrance, CA 90503
Phone: 310-303-3300
Fax: 310-371-6268
Email: sales@fischercc.com

BULK CURRENT INJECTION

The F-120-3 has been designed to extend the use of conducted immunity testing over the bandwidth of 10 kHz – 100 MHz. The F-120-3 is a high efficiency Injection Probe used primarily for low frequency conducted susceptibility testing. The input power rating is 100 watts for 30 minutes.



Specifications

Frequency:	10 kHz – 100 MHz
Inner diameter:	40 mm
Outer diameter:	127 mm
Height:	70 mm
Input Power rating:	100 watts (30 minutes)

Accessories

FCC-BCICF-1 • Calibration Fixture
Bandwidth: 10 kHz – 400 MHz
F-52 • Current Probe
Bandwidth: 10 kHz – 400 MHz

F - 120-3

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11-5 LCD23VFAX Schematic Diagram(23")