Measurements for Wireless Power Transfer by Using NanoVNA

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Abstract

This paper suggests the use of Nano VNAs (Vector Network Analyzers) as a practical and cost-effective alternative to standard VNAs for the characterization of WPT links operating at low frequencies. Experimental data for a link operating at 7 MHz are reported and compared with those obtained through a standard VNA, thus demonstrating the good accuracy achievable with Nano VNAs.

1 Introduction

Wireless Power Transfer is a technology gaining a great interest in wireless recharging of electronic devices [1], [2], etc. Depending on the specific application of interest, three different strategies that differ for the coupling mechanism between the transmitter and the receiver are available for WPT links: far-field based on electromagnetic coupling, near-field based on inductive coupling, near-field based on capacitive coupling.

The mostly used operating frequencies are the ISM (industrial, scientific, and educational) bands [3]. In more detail, the typical operating frequencies of near-field WPT links are 6.78 MHz, 13.56 MHz, 40MHz; while those usually adopted for far-field links are 433MHz, 900MHz, 2.4 GHz [4], [5].

For both far-field and near-field WPT, it is possible to model the link as a two-port electrical network represented by one of the possible matrix descriptions (i.e., scattering, impedance or admittance matrix). Consequently, the experimental characterization can be performed using a suitable setup for electrical networks measurements. In this regard, at high frequency, a good accuracy can be obtained by using Vector Network Analyzers which are very expensive. For links operating at low frequency, such as in the case of near-field links, a cost-effective alternative, the so-called NanoVNA [6], has recently been introduced to the market.

The use of a NanoVNA for the experimental characterization of an inductive WPT link is discussed and investigated for the first time in this paper.

It will be shown that by means of this inexpensive and handy instrument it is extremely easy to characterize a WPT link operating at low frequency. Comparisons with a standard VNA will also be provided to demonstrate the achievable accuracy.

2 Characterization of WPT

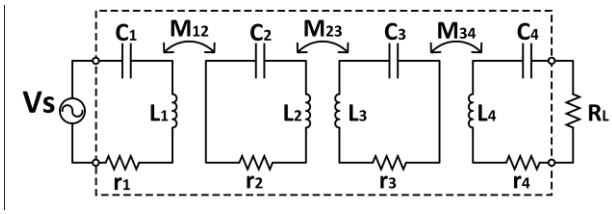


Figure 1. The equivalent circuit model of a 4-coil WPT link.

Measurements have been performed on a 4-coil link; the equivalent circuit is illustrated in Fig. 1. The four coils resonate at the same frequency, i.e., $\omega_0 = 1/\sqrt{L_i * C_i}$ (i=1,2,3,4). The coupling coefficients k_{ij} are defined as:

$$k_{ij} = \frac{M_{ij}}{\sqrt{L_i L_j}} \tag{1}$$

The power transfer efficiency is given by [7]:

$$\eta = \frac{P_L}{P_{in}} = \\ = \frac{(k_{12}^2 Q_1 Q_2)(k_{23}^2 Q_2 Q_3)(k_{34}^2 Q_3 Q_{4L})}{[(1 + k_{12}^2 Q_1 Q_2) \cdot (1 + k_{34}^2 Q_3 Q_{4L}) + k_{23}^2 Q_2 Q_3]} \\ \cdot \frac{Q_{4L}}{[1 + k_{23}^2 Q_2 Q_3 + k_{34}^2 Q_3 Q_{4L}] Q_L} \tag{2}$$

where
$Q_i = \omega_0 L_4/(R_L + r_4)$, ($i$=1,2,3,4),
$Q_L = R_L/\omega_0 L_4)$, $Q_{4L} = Q_L Q_4/(Q_L + Q_4)$.

The efficiency of the WPT system could be evaluated through measurements on the overall link and the resonators so to derive the equivalent parameters to be used in (2). More simply, by using a VNA the efficiency could be calculated directly from the measured scattering parameters [9], [10]:

$$\eta = \frac{|S_{21}|^2}{1 - |S_{11}|^2}. \tag{3}$$

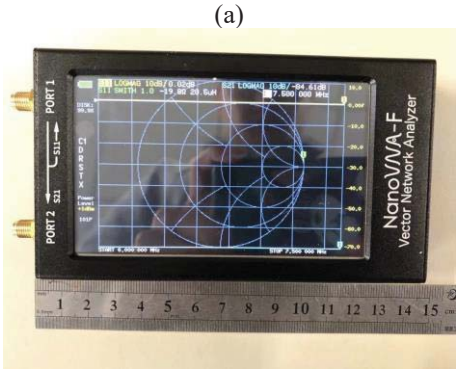
Equation (3) highlights the importance in the context of WPT as well as for generic two-port networks of a suitable

and versatile experimental setup for network parameters measurements.

3 VNA vs NanoVNA

In this section the experimental data obtained with a standard VNA are compared with those provided by a NanoVNA. The NanoVNA is available from Deepelec with about 15mm size, the operating frequency range is 10KHz ~1.5GHz, as shown in Fig. 2. The part number of the standard VNA is E5071C, Agilent ENA series. The analyzed WPT link is completely symmetrical as shown in Fig. 2. The transmitter and the receiver are identical, and both consist of 2 coils fabricated on the front and the back face of the same dielectric substrate (F4BM, ε_r=3.5, $tan\delta$=0.001, thickness=1mm). These two coils are shown in Fig. 3. In more detail, referring to Fig. 1, the first coil (driving coil), shown in Fig. 3(c), is one turn square coil with a diameter of 55 mm and the width of 3mm. The second coil, shown in Fig. 3(b), is a 3 turns square coil with diameter of 80mm and the width of 2mm. The fourth coil is identical to the first coil and the third coil is identical to the second coil.

(a)



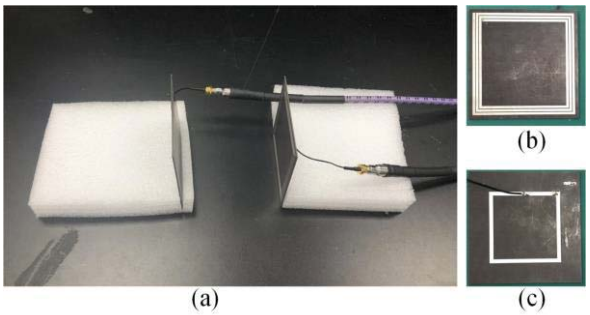
(b)

Figure 2. Photographs of the standard VNA (a) and the NanoVNA (b) used for measurements.

First of all, measurements were performed to derive the equivalent parameters of each coil (inductance and resistance/quality factor). The network analyzer was directly connected to the coils for measuring the S-parameter [7], [8], of each coil.
The measured S-parameter were used for calculating the Z-parameter. Then, the equivalent parameters of the coils were calculated by using the following formulas:

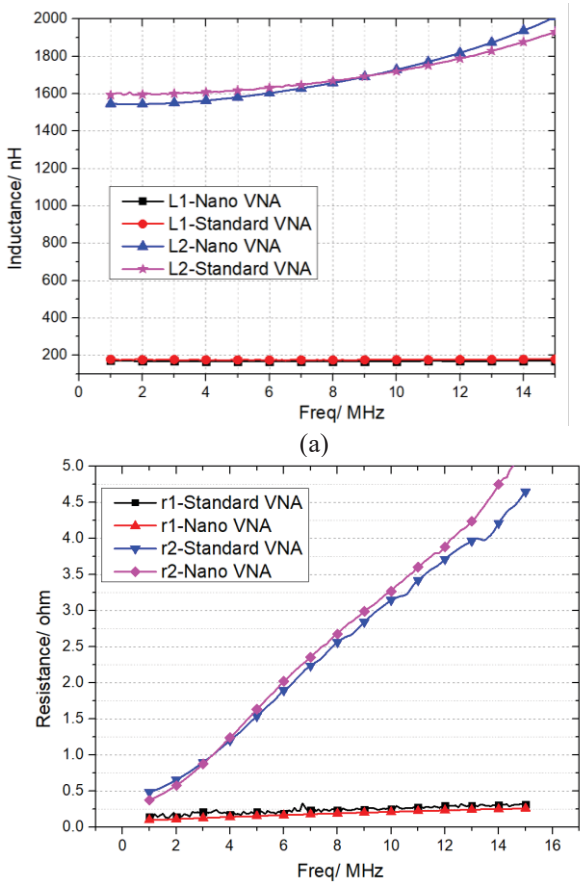
$$L = \frac{Im(Z)}{\omega}, \qquad r = Re(Z)$$

$$Q = \frac{Im(Z)}{Re(Z)}, \; k_{ij} = \frac{Im(Z_{12})}{\omega\sqrt{L_i L_j}}. \tag{4}$$



(a) (b) (c)

Figure 3. WPT link used for measurements. (a), (b): The two coils used for both the transmitter and the receiver: photos of the two coils fabricated on the front and the back face of the same substrate.



(a)

(b)

Figure 4. Equivalent parameters obtained for the transmitting coils: comparison of the meaured data obtained with the VNA and those obtaiend with NanoVNA. (a) Inductances L_1 and L_2, (b) resistances r_1 and r_2.

The obtained results are depicted in Fig. 4; considering that the WPT system is completely symmetrical, only the results obtained for the coils of the transmitter are reported.

The figure compares data obtained by using the measurements performed with a standard VNA with those obtained by using the NanoVNA. It can be noticed that in the analyzed frequency range a good agreement was obtained.
In particular, at the operating frequency of 7 MHz, the value calculated for L_1 is 175 nH from the VNA measured data, while it is 167 nH from the NanoVNA measured data. As per L_2, 1643 nH is the value obtained from the VNA measurements, while 1604 nH is that obtained from the NanoVNA. These values were used for determining the compensating capacitors to be used for making the coils resonating at 7 MHz.

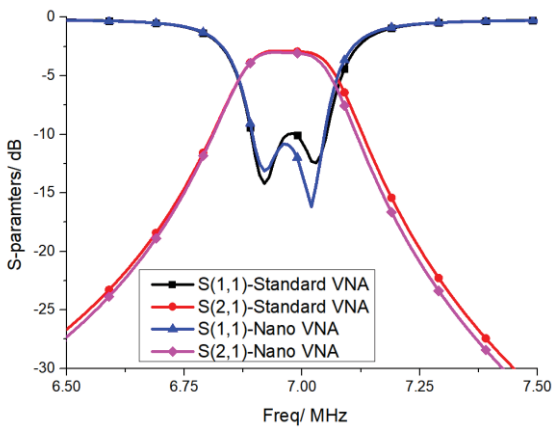


Figure 5. Measured S-parameters: comparison between data provided by the NanoVNA and those obtained with the standard VNA. The results refer to a transfer distance of 100 mm.

The compensating capacitors were added in series configuration with the coils and the scattering parameters of the link were measured by using both the standard VNA and the NanoVNA. Measurements refer to a transfer distance between the transmitting and the receiving coils of 100 mm. A comparison of the data obtained with the standard VNA and those provided by the NanoVNA is given in Fig. 5. As it can be seen, an excellent agreement has been obtained.

4 Conclusions

In this paper, the use of a NanoVNA for the experimental characterization of a near field WPT link is discussed. By analyzing an inductive resonant WPT link operating at 7 MHz, the good accuracy achievable with a NanoVNA is demonstrated through comparisons with a standard VNA. The reported results highlight that the NanoVNA represents a cost-effective and handy alternative to standard VNAs especially for links operating at low frequencies.

5 References

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