MEASUREMENT OF ELECTRICALLY SMALL ANTENNAS

Jaroslav Zechmeister

Doctoral Degree Programme (1), FEEC BUT

E-mail: xzechm02@stud.feec.vutbr.cz

Supervised by: Jaroslav Lacik

E-mail: lacik@feec.vutbr.cz

Abstract: Measurement of electrically small antennas is a great challenge due to the influence of a test cable and surrounding environment. For the elimination of an unbalanced current on non-symmetrical feed cable, two methods can be exploited. The first one uses a quarter wave sleeve balun placed between the test cable and antenna under test for the compensation of the unbalanced current. The second one is a two-port method which measures the input impedance with suppression of the unbalanced current. Both the methods are in this contribution studied in deep and compared on the measurement of a printed dipole antenna and printed inverted F-antenna. In addition, for the antenna efficiency measurement of those antennas, a generalized Wheeler cap method is exploited.

Keywords: Electrically small antenna measurement, two-port measurement, Wheeler cap method

1 INTRODUCTION

Electrically small antennas are widely used in portable devices like mobile phones, communicators ect. Their importance has growth due to Internet of Things (IoT) which is fast-growing wireless communication technology. Billions of devices for IoT networks are expected in few years. That brings challenges pushing to antenna cost and miniaturization.

High challenge is a measurement of electrically small antennas, due to their sensitivity to surrounding environment and especially due to unbalanced currents induced on non-symmetrical measurement cables. The suppression of the unbalanced currents is very important for their precious characterization. The presence of the unbalanced currents can be confirmed by a “hand effect” or varying of the test cable length with subsequent fluctuating of the measurement results.

The compensation of the unbalanced currents can be achieved by various techniques. For example, ferrite rings located on the test cable imposes high impedance to the current. Baluns can be also used for the minimalization of the current [1]. A two-port method enables measurement of the input impedance by synthetizing the balanced mode from the measurements of S-parameters of two ports [2].

In this contribution, two methods for the measurement of the input impedance of electrically small antennas are studied and compared in deep. The first one exploits the sleeve “bazooka” balun and the second one is the two-port method. For the antenna efficiency measurement, a generalized Wheeler cap method is exploited [3].

2 MEASUREMENT METHODS

2.1 SLEEVE BALUN

The suppression of unbalanced currents can be achieved by baluns. A quarter-wave sleeve balun is an appropriate choice. The influence of the sleeve balun dimensions on the insulation of unbalanced current were investigated in [1]. The points of the interest were the outer diameter of the coaxial cable, the diameter of the balun and its length. These results were used to design a balun used in this contribution. The length of the balun (*l_BALUN*) is 76.6 mm and the diameter of the sleeve is 28 mm (Figure 1b).

A comparison of the simulated reflection coefficient responses for a simple planar dipole antenna without (Figure 1a) and with (Figure 1b) the quarter-wave sleeve balun for different lengths of the test cable is shown in Figures 1c and 1d, respectively. Obviously, the variance of the results of the reflection coefficient for the operating frequency (marked points) is reduced when the sleeve balun is placed on the test cable.

Unfortunately, the quarter-wave sleeve balun is a narrowband structure, therefore its characteristics has to be considered in the measurement.

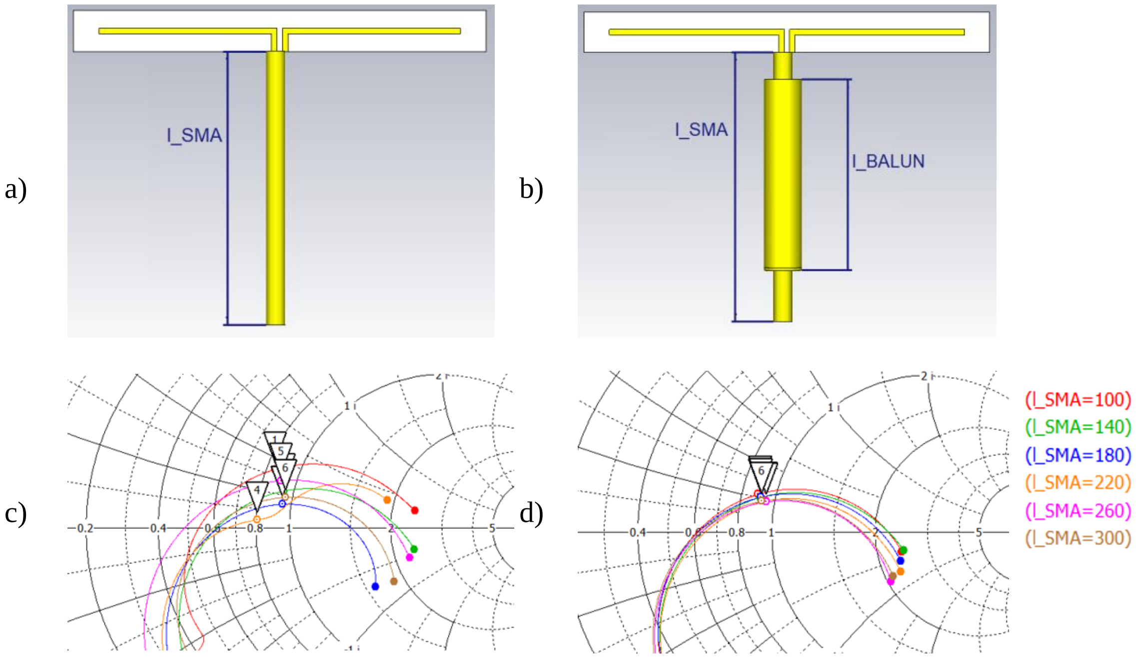

Figure 1: Printed dipole antenna fed by coaxial line without sleeve balun a) with sleeve balun b) and corresponding reflection coefficient for different lengths of feed cable of dipole antenna without sleeve balun c) with sleeve balun d).

2.2 Two-port method

The two-port S-parameter method is broadband method for the input impedance measurement without the influence of the unbalanced currents [2]. Two unbalanced lines are connected to each element of the symmetrically fed antenna. In case of the non-symmetrical antennas, one line is connected to a radiation element and the second one is connected to the ground plane. This method requires the full S-parameters measurement.

In Figure 2b, an equivalent diagram of the antenna with a measurement jig is shown. Obviously, the characteristic of the jig is included in the measured S-matrix. For the compensation of the jig, the ABCD-matrix is exploited.

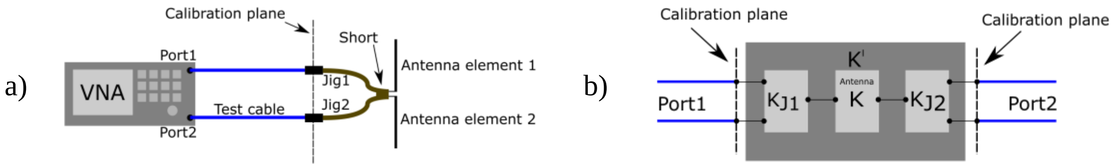

Figure 2: Measurement scheme for two-port method a), equivalent circuit diagram of antenna with jig b).

The measured S-matrix can be transformed to the ABCD-matrix as follows [2]

$$K' = \begin{bmatrix} \frac{(1+S_{11})(1-S_{22})+S_{12}S_{21}}{2S_{21}} & \frac{(1+S_{11})(1+S_{22})-S_{12}S_{21}}{2S_{21}} \\ \frac{(1-S_{11})(1-S_{22})-S_{12}S_{21}}{2S_{21}} & \frac{(1-S_{11})(1+S_{22})+S_{12}S_{21}}{2S_{21}} \end{bmatrix} \quad (1)$$

For removing of the influence of the jig, the following relation can be used

$$K = K_{j1}^{-1} K' K_{j2}^{-1}. \quad (2)$$

In (2), K_{J1} and K_{J2} are ABCD-matrixes of the jig. For the compensation of the jig, the open-short-correction method was employed which uses the input impedance of the open- and short- ended lines. Then the ABCD-matrixes of the jig can be obtained found

$$K_{jn} = \sqrt{\frac{Z_{n,open}}{Z_{n,open}-Z_{n,short}}} \begin{bmatrix} 1 & Z_{n,short} \\ 1/Z_{n,open} & 1 \end{bmatrix} \quad (3)$$

where $Z_{n,open}$ is the input impedance of the open-ended line and $Z_{n,short}$ is the input impedance of the short-ended line, respectively.

The input impedance of the measured antenna can be written

$$Z_{in} = \frac{1}{C}(A + D - AD + BC + 1) \quad (4)$$

where A,B,C and D are items of the ABCD-matrix of the antenna.

2.3 WHEELER CAP METHOD

The efficiency of an antenna can be estimated by employing the Wheeler cap method [3]. The method requires measurement of the antenna for two conditions. At first, the antenna is measured in free space. Then the measurement is performed in a metallic cap which shields the radiation of the antenna. The efficiency is obtained by derivation of a series resistance model of the antenna

$$\eta = \frac{R_{rad}}{R_{rad}+R_{loss}} = \frac{\Re\{Z_{fs}\}-\Re\{Z_{wc}\}}{\Re\{Z_{fs}\}} \quad (5)$$

where the R_{rad} and R_{loss} are the radiation and loss resistance, Z_{fs} and Z_{wc} are the input impedance of the antenna in free space and in the Wheeler cap, respectively. Note that the method has few conditions which have to be met. The first consis in a minimal distance between the antenna and walls of the radiation shield which has to be at least:

$$d = \frac{\lambda}{2\pi} \quad (6)$$

where λ is the wavelength at the operating frequency. The second condition requires that the operating frequency of the measured antenna is lower than first resonance of the cap.

In [3], the generalized Wheeler cap method is described. The main advantage of this method lies in the elimination of the deviation at the resonance frequency of the cap. This approach is based on the representation of the antenna as a two-port network. The first port of that structure is the input port of the antenna. The second one is a transition between the antenna and free space. So, the radiation efficiency can be evaluated by the following equation [3]

$$\eta = \frac{|S_{21}|^2}{1-|S_{11}|^2} \quad (7)$$

where S_{11} represents the reflection coefficient of the antenna and S_{21} is the transmission coefficient between the antenna input port and free space. For the term $|S_{21}|^2$, it can be written [3]

$$|S_{21}|^2 = \frac{2}{(\Delta S_{max})^2+(\Delta S_{min})^2} \quad (8)$$

where ΔS_{max} and ΔS_{min} are the maximum and minimum value of ΔS described in [3]

$$\Delta S = |S_{11wc} - S_{11fs}| \tag{9}$$

where S_{11fs} and S_{11wc} are the measured input reflection coefficient of the antenna in free space and enclosed in the radiation shield, respectively. A graphical solution of the generalized Wheeler cap method is shown in Figure 7b.

3 EXPERIMENTAL RESULTS

For the testing of the described measurement methods, two antennas operating at 868 MHz, were designed. A half-wave printed dipole (Figure 3a) and a printed inverted F-antenna (PIFA) (Figure 3b). The PIFA represents an example of the antenna typically used for IoT applications.

a) b)

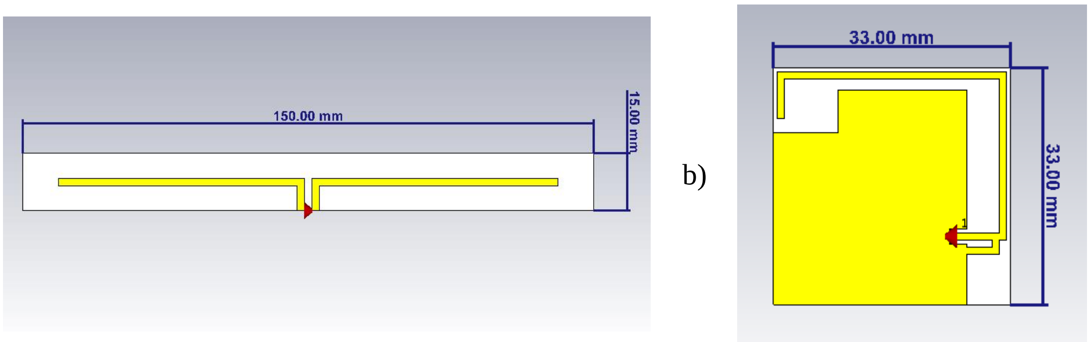

Figure 3: Printed half-wave dipole a), printed inverted F-antenna b).

3.1 INPUT REFLECTION MEASUREMENT

The sleeve balun and the measurement jig for the two-port measurement method were realized. The sleeve balun was made from a copper pipe of the diameter 15 mm and the length 75 mm (Figure 4a). The length of the balun was determined with respect to the results presented in [1]. The jig for the two-port measurement was made from two coaxial lines equipped by SMA connectors. The outer conductors of the lines were soldered together (Figure 4b). For the comparison, a coaxial line equipped by a SMA connector soldered to the antenna input was considered as the third measurement approach.

a) b)

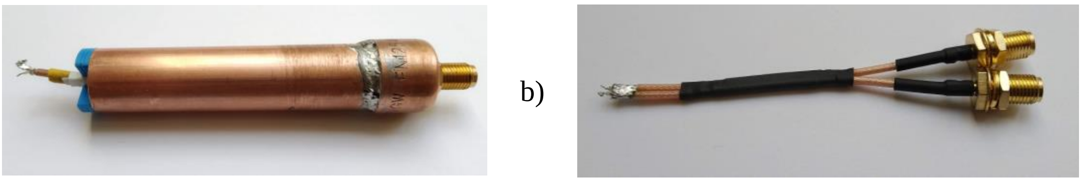

Figure 4: Sleeve „bazooka“ balun a), realized jig for two-port measurement b).

The comparison of the measured and simulated data for the printed dipole is depicted in Figure 5. Obviously, we can observe very similar responses. These results confirm that both methods can be used for the measurement of symmetrical fed antennas.

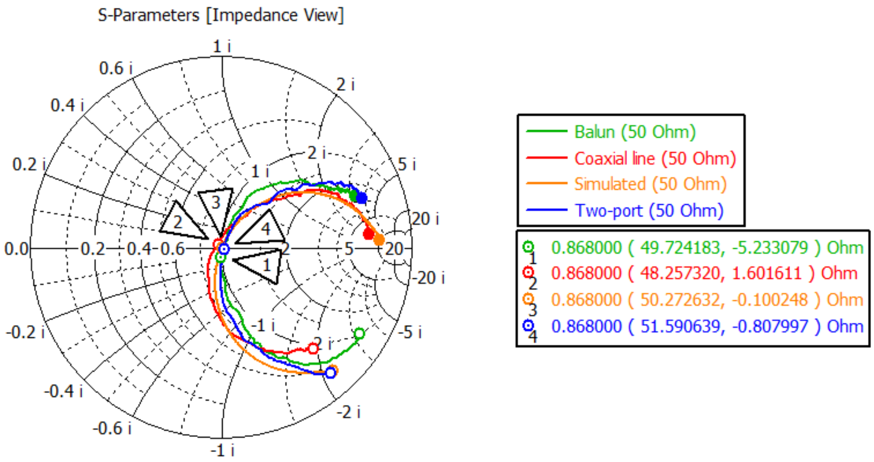

Figure 5: Comparison of measurement methods with simulated data – reflection coefficient of dipole antenna

The simulated and measured results of PIFA are depicted in Figure 6. Apparently, the differences between results are much more dramatic than for the dipole antenna. At the operating frequency (the marked points), the two-port method gives best agreement with the simulated data. The measurement with balun also gives a good result whereas the measurement with coaxial line directly soldered to the antenna input provides insufficient result.

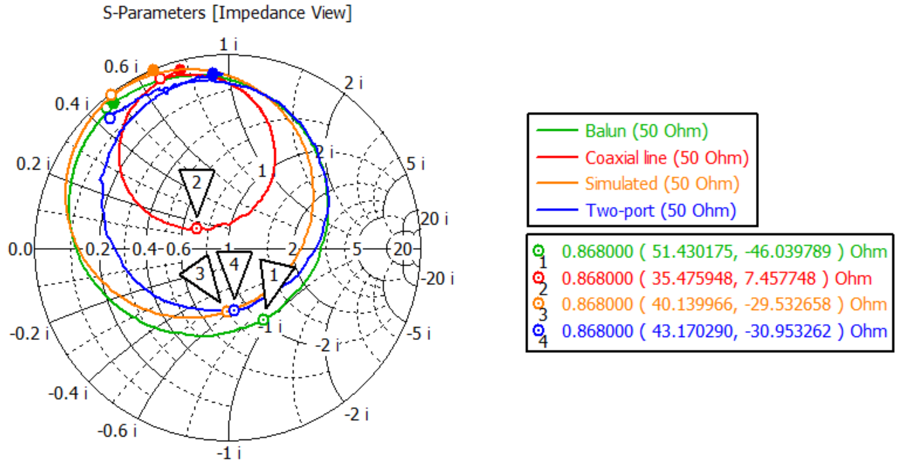

Figure 6: Comparison of measurement methods with simulated data – reflection coefficient of printed inverted F-antenna

3.2 Efficiency Measurement

The Wheeler cap was made from a metallic can of a cylindrical shape with the height of 210 mm and the diameter of 110 mm. The two-port method was used for the efficiency measurement based on the generalized Wheeler cap method.

The measured reflection coefficients for the dipole antenna in free space and enclosed in Wheeler cap are shown in Figure 7a. Note that the measured results of the reflection coefficient in the cap may cover only a fraction of the reflection circle. In this case, the reflection circle, which is crucial for valid results of efficiency, can be obtained by using an interpolation.

The PIFA was measured in three positions (Figure 7a-c). Different results were obtained for these positions (Table 1). The differences probably occurred due to the insufficient dimensions of the Wheeler cap. That was confirmed by the simulations. Two sets of simulations were made with two different Wheeler caps. The first set with the Wheeler cap and the same dimensions as the fabricated one, the second one with the same height of the can, but the diameter was increased to 160 mm. The simulated result for the bigger Wheeler cap provides more consistent results. The obtained results are summarized in a Table 1.

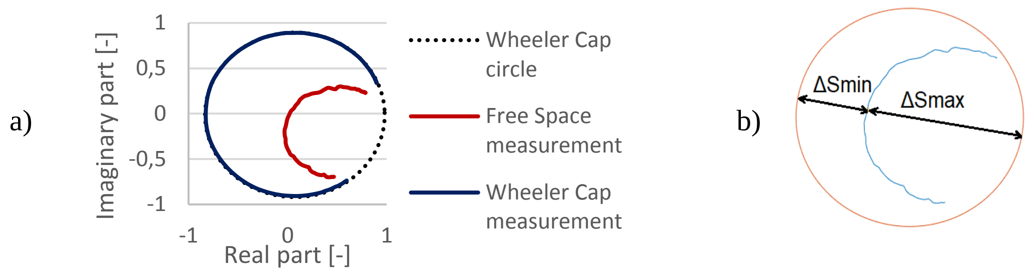

Figure 7: Reflection coefficients for dipole antenna and Wheeler cap reflection circle a), graphical solution of generalized Wheeler cap method b).

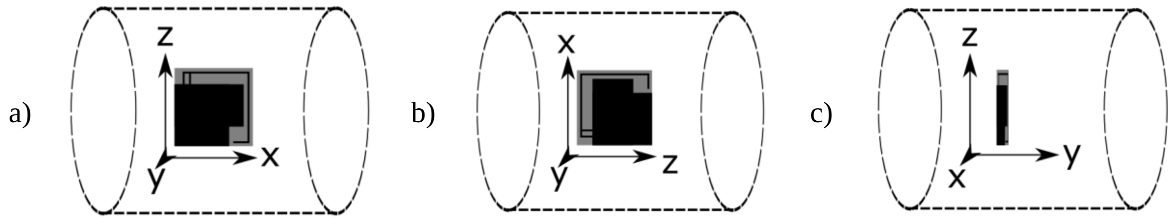

Figure 8: Visualization of position of PIFA in Wheeler cap

Antenna	Directly simulated	Extracted from simulated data 210x160mm	Extracted from simulated data 210x110mm	Measurement
Dipole	95.22 %	-	-	90.1 %
PIFA pos. a)	12.85 %	11.7 %	10.49 %	13.02 %
PIFA pos. b)	12.85 %	12.4 %	10.73 %	13.3%
PIFA pos c)	12.85 %	11.4 %	13.36 %	21.24%

Table 1: Comparison of measured and simulated values of antenna efficiency at 868 MHz

4 CONCLUSION

In this contribution, two methods for the measurement of electrically small antenna parameters were presented.

It was shown that the sleeve balun method can be used for the measurement of the reflection coefficient of electrically small antennas. The presented results have sufficient accuracy compared to the simulated data. There are two main disadvantages of this approach. The first one is that the balun itself as a piece of metal influences the measurement. The second one is that the balun is a narrowband structure.

The two-port method also provided sufficient results for the measurement of the reflection coefficient. The measurement jig is a tiny and can be easily soldered to the final device with all components enclosed in a casing. This method requires a full two-port measurement with postprocessing which is disadvantageous.

The generalized Wheeler cap method for the measurement of the antenna efficiency was studied. The measurement provided non-consistent results for different positions of the antenna in the cap. That was caused by using the Wheeler cap with insufficient dimensions which was confirmed by simulation. Nevertheless, the results showed that the method is applicable for the measurement of small antennas for IoT applications.

ACKNOWLEDGEMENT

The presented research was supported by the Internal Grant Agency of Brno University of Technology project no. FEKT-S-20-6526.

REFERENCES

[1] S. A. Saario, J. W. Lu and D. V. Thiel, "Full-wave analysis of choking characteristics of sleeve balun on coaxial cables", *Electronics Letters*, vol. 38, no. 7, pp. 304-305, 2002

[2] T. Sasamori and T. Fukusawa, "S-Parameter Method and Its Application for Antenna Measurements", *IEICE Transactions on Communications*, vol. E97.B, no 10., pp. 2011-2021, 2014.

[3] C. Mendes and C. Peixeiro, "Theoretical and experimental validation of a generalized wheeler cap method", *in IET Seminar Digest*, 2007, vol. 2007, no. 11961.