Technique for measurement of UHF RFID balanced antennas

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A balun designed on laminated epoxy PCB to measure inductive ultra-high-frequency-balanced antennas is presented. Its objective is to minimise the reflection coefficient at its unbalanced input when the antenna is connected to its balanced output. This improves the accuracy in the posterior extraction of the antenna parameters from the measurement of its reflection coefficient. Theoretical considerations, design parameters and experimental results with an evaluation antenna are shown.

Introduction: Balanced antennas, with impedance values far from those of reference impedance of instruments, are frequent, among other applications, in RFID systems that use passive tags. These tags are composed of an antenna and an integrated circuit that carries information that identifies the object, without external power. The reader emits an electromagnetic wave that powers up the passive tag. The harvesting process is later completed by capacitors performing the voltage multiplying; therefore, generating the chip capacitive input impedance.

The matching between antenna and chip impedances is a key aspect to improve the operating distance of a tag with this technology. The capacitive characteristics of the ultra-high-frequency (UHF) RFID chips establish that the impedance of the tag antenna has to be inductive, with low resistance and high reactance (typically a 10:1 ratio). Direct measurement of antennas with those characteristics represents a challenge since the usual input ports of network analysers are based on unbalanced coaxial connectors, which cannot be directly connected to the balanced antenna inputs. Besides, these impedances are far from the typical 50 or 75 Ω of the instruments that establish reflection coefficients close to 1. As a result, the voltage standing wave ratio (VSWR) at the load input is by far larger than 10:1 which leads to inaccurate results for the input impedance [1, 2]. In addition, the effect of the surface currents generated by the balanced antenna in the external mesh of the coaxial, alter both the impedance and the radiated field. Several methods have been reported for the measurement of balanced antennas. For example, direct measurements [3], ground planes to measure the equivalent monopole [4]. Measurements with a test fixture based on two coaxials have also been reported [5, 6]. In [7], a coaxial balun scheme has been used to measure the radiated field of small antennas.

In this Letter, we present the design of a balun to measure the input impedance and the radiation pattern of an UHF RFID tag antenna in the frequency of 915 MHz. It is built with low-cost epoxy laminate Flame Retardant 4 (FR4), with easy prototyping and design parameters. Owing to its features, it can be used with single-port microwave instrumentation [vector network analyser (VNA), spectrum analysers, signal generators], with measurement accuracy equivalent to those obtained from a combination of the fixture and two ports. It overcomes either restrictions of balanced port and high VSWR, common among RFID radiant elements.

Proposed balun: To reduce the complexity and manufacturing cost of the coax balun [7], the proposed design is implemented on a PCB board. The design consists of a microstrip line (unbalanced), which is connected to the instrument coaxial input, and a coplanar strip line connecting to the antenna. On the ground plane of the microstrip line, a high-impedance path is inserted, which blocks the currents on the outer mesh. Fig. 1 shows a schematic diagram of the proposed balun. The elements corresponding to the unbalanced line were located on the left-hand side. The main conductor of the microstrip line (black in the diagram) was located on the top face and the ground plane on the bottom face (grey in the diagram).

The balanced line feeding the antenna was located on the bottom face, on the right-hand side of this figure. The transition between both lines was made through a vertical pin electrically connecting both microstrip ends to the ground plane. A quarter wavelength slot ($\lambda_g/4$), which spreads out toward the left-hand side of the assembly, was added to the ground plane at the junction. In this way, the microstrip line became the L conductor of the balanced line (joined by the pin, see Fig. 1); moreover, both conductors of the balanced line turn into microstrip ground plane, isolated among them by the high impedance of the slot that operates as a short-circuited stub of $\lambda_g/4$.

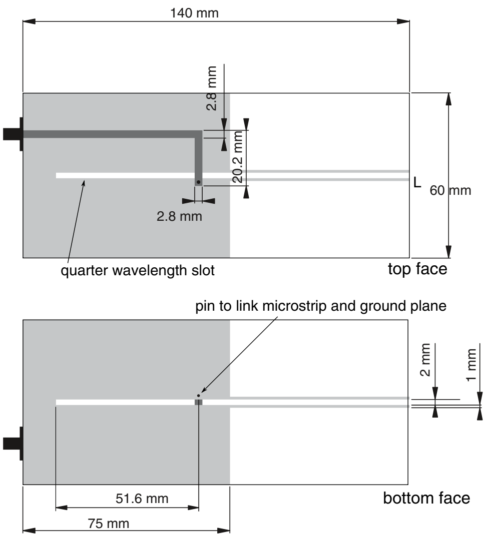

Fig. 1 *Schematic diagram of balun. Top face corresponds to microstrip line track; moreover, bottom face to ground plane, stub of* $\lambda_g/4$ *and coplanar line*

Fig. 2 shows a simplified electric model of the balun, composed of an unbalanced line segment with characteristic impedance Z_{0u} and length l_u; a stub of $\lambda_g/4$ terminated in short circuit, whose impedance Z_s is in parallel with the balanced line of impedance Z_{0b} and length l_b.

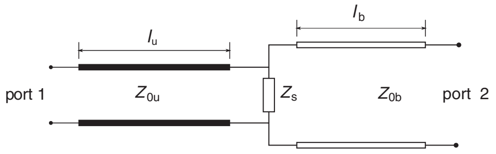

Fig. 2 *Balun model consisting of unbalanced line of* Z_{0u} *impedance,* Z_{0b} *balanced line with stub of* $\lambda_g/4$ *in parallel*

The *S*-parameters of the balun can be derived by neglecting the losses and the effect of the lumped elements modelling the transition between lines. If the stub is considered an open circuit, the equations are

$$S_{11} = \Gamma_{ub} e^{-2j\theta_u}, \tag{1}$$

$$S_{22} = -\Gamma_{ub} e^{-2j\theta_b}, \tag{2}$$

$$S_{12} = \sqrt{(1+\Gamma_{ub})(1-\Gamma_{ub})} e^{-j(\theta_u+\theta_b)}, \tag{3}$$

$$S_{21} = S_{12}. \tag{4}$$

where θ_u and θ_b are phase delays of both lines and Γ_{ub} is the reflection coefficient between the unbalanced and balanced lines given by

$$\Gamma_{ub} = \frac{Z_{0b} - Z_{0u}}{Z_{0b} + Z_{0u}}, \tag{5}$$

where Z_{0u} and Z_{0b} are the characteristic impedances of both lines.

Balun design: One of the design goals of the balun is improving the capability to extract the antenna impedance from the measurement of the reflection coefficient at the input of both balun and antenna. On the basis of this, the balun dimensions were fixed to minimise the reflection coefficient at the input. To do this, an expression for the reflection coefficient at the input of balun, Γ_e, was found, according to its *S*-parameters [(1)–(5)] and the reflection coefficient of the antenna Γ_a

$$\Gamma_e = \Gamma_{ub} e^{-2j\theta_u} + \frac{(1-\Gamma_{ub})(1+\Gamma_{ub}) e^{-2j(\theta_b+\theta_u)} \Gamma_a}{1 + \Gamma_{ub}\Gamma_a e^{-2j\theta_b}}. \tag{6}$$

Then, the term $e^{-2j\theta_u}$ was extracted as a common factor and algebraically operated to obtain an expression of the reflection coefficient module at the input of the balun

$$|\Gamma_e| = \left| \frac{\Gamma_{ub} + \Gamma_a e^{-2j\theta_b}}{1 + \Gamma_{ub}\Gamma_a e^{-2j\theta_b}} \right|. \tag{7}$$

Equation (7) shows that the ideal condition ($\Gamma_e = 0$) is verified when the module of both terms of the numerator ($|\Gamma_a|$ and $|\Gamma_{ub}|$) are equal, and their phases differ by 180°. Such a condition occurs when Γ_{ub} is positive and the difference between the phase of the coefficient Γ_a and the electric length of the balanced line $-2j\theta_b$ is $180°$ or when such difference is $0°$ and the reflection coefficient Γ_{ub} is negative. The condition $\Gamma_e = 0$ is hard to obtain since it means that the impedances of the lines must be very different, as well as the differences between the impedance of the antenna and of the balanced line of the balun.

However, an analysis of (7) shows that it is possible to improve the values of the reflection coefficient relative to those obtained by differential measurement. With unbalanced line impedances between 30 and 60 Ω, it is possible to reach reflection coefficients between 0.5 and 0.8, below those obtained with differential measurement (test fixture [5]). These conclusions served as a guide to complete the balun design. The final dimensions of the balun were obtained through simulations with the Computer Simulation Technology program (Fig. 1).

Experimental results: Various tests were carried out to evaluate the performance of the proposed design. First, the scattering parameters of a prototype of the balun fabricated using 1.5 mm FR4 substrate were measured. Its performance was then verified as a measurement tool. For this, a balanced and inductive test antenna was used, whose impedance was previously obtained with a test fixture [5]. These results were contrasted with those obtained by de-embedding the measurements with the balun. The impedance results are shown in Figs. 3 and 4.

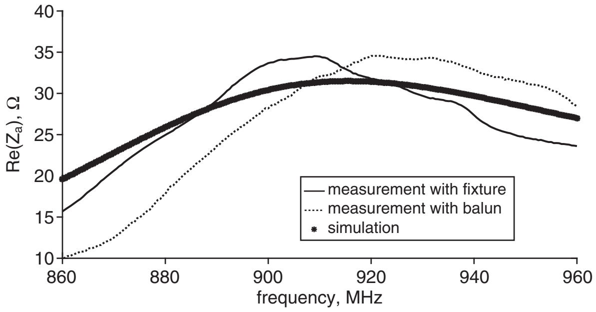

Fig. 3 *Antenna input resistance, measured with balun, measured differentially and simulated*

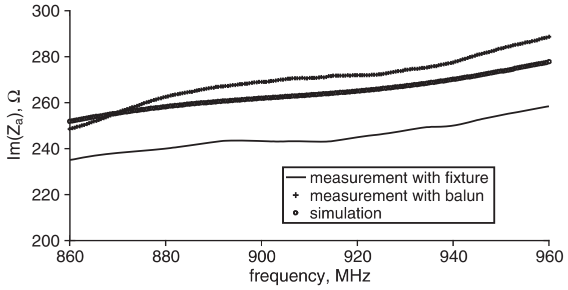

Fig. 4 *Antenna input reactance, measured with balun, measured differentially and simulated*

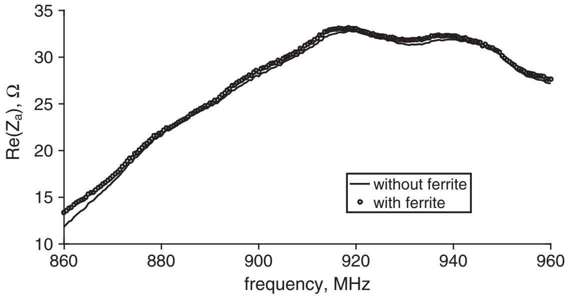

Fig. 5 *Antenna input resistance without ferrite and with ferrite core*

Finally, the balun effectiveness on blocking common mode currents on the coaxial cable external mesh is checked. To detect the presence of these currents, an indirect procedure was used; ferrite cores were placed in different positions on the coaxial cable. Samples of the reflection coefficient were taken at the input of the balun, with the test antenna at its balanced port, and the ferrite core static on different lengths surrounding the coaxial cable of the instrument. Then, the variations that the presence of the ferrite core produced in the antenna impedance are analysed (the measured impedance does not change by the action of the core if the surface currents are negligible). Fig. 5 shows the graph of the input resistance (obtained by de-embedding) for those ferrite positions that produced the most significant change.

The antenna resistance in the absence of the core is shown in full line. The dotted line corresponds to positions of the ferrite that produces more significant changes. As can be seen in this figure, at the working frequency of 915 MHz, the presence of the ferrite core does not change the resistance values significantly. At other frequencies, the maximum difference observed between the input resistance with or without a core is <500 mΩ. For reactances, the observed differences are even smaller.

Conclusion: In this Letter, a balun was proposed to measure the impedance and the radiation pattern of a balanced antenna. The balun was designed to be built with PCBs on a low-cost material (FR4). Its dimensions were established to achieve a good 'conditioning' of the reflection coefficient measurement at the input, which allows the subsequent de-embedding of the antenna impedance. A prototype of the balun was manufactured and used to measure the input impedance of an inductive dipole antenna. The balun was also tested by placing a ferrite core on the coax of the VNA to indirectly verify the existence of mesh currents. Taking into account the margins allowed by the magnitude to be measured and the precision of the instruments, the obtained results proved to be consistent with measurements taken by alternative procedures and numerical simulations. In addition, the balun was very useful as a tool for radiated field measurements or measurements taken with instruments lacking differential feed (signal generators or spectral analysers), since it does not require the use of two feed cables between instrument and antenna, as and when these measurements are taken by a differential procedure.

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One or more of the Figures in this Letter are available in colour online.

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