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ISAP07: Antenna Matching Network Design Methods for Estimating System Efficiency

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1. Introduction

At the present time, there is tremendous demand for antennas with high efficiencies and wide bandwidth in very small form factors that fit inside ever-shrinking wirless devices like handsets. However the gain-bandwidth limitation of electrically small antennas is a fundamental law of physics that limits the ability of the antenna engineer to simultaneously reduce the size of an antenna while increasing its bandwidth and efficiency [1]. Often matching networks are used in order to overcome the limited bandwidth of the antenna. However, the reactive components used for the matching network are lossy, and they tend to decrease the overall antenna system efficiency even though a desired bandwidth can be obtained. In order to design a proper matching network that can minimize the system loss, it is critical not only to observe the return loss of the antenna, but also evaluate the losses in the antenna matching network components and overall system efficiency.

In this paper we discuss a method that can be effectively used to estimate losses in the matching components for simple antenna systems and introduce a technique that models the antenna as a two-port device to account for the effect of its frequency response on the system.

2. Estimation of the Losses in the Antenna Matching Network Using Two-Port Power Gains

The section illustrates how the losses in the matching network can be obtained using the two-port *S*-parameter models for the matching network. With reference to Figure 1, the overall system loss L_{sys} introduced by the matching network can be express as

$$L_{sys} = 1 - \left|\Gamma_{in}\right|^2 - G_T .$$

where Γ_{in} is the reflection coefficient seen looking toward the matching network connected between the source and load (i.e., antenna input impedance) impedances Z_o and Z_a, respectively.

Using

$$\Gamma_L = \frac{Z_L - Z_o}{Z_L + Z_o},$$

We can write Γ_{in} as

$$\Gamma_{in} = \frac{Z_{in} - Z_o}{Z_{in} + Z_o} = \frac{S_{11} - \left(S_{11} \cdot S_{22} - S_{12} \cdot S_{21}\right) \cdot \Gamma_L}{1 - S_{22}\Gamma_L}.$$

Note that G_T is the transducer gain of the two-port network when the source is perfectly matched to the system characteristic impedance Z_o and can be expressed as [2]

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$$G_T = |S_{21}|^2 \cdot \frac{\left(1-|\Gamma_L|^2\right)}{|1-\Gamma_L \cdot S_{22}|^2}.$$

Therefore, the system loss L_{sys} can be explicitly calculated in terms of *S*-parameters of the matching network and antenna input impedance Z_a which can be either simulation results or real measurement data.

3. Two-Port Representation of an Antenna for the Matching Network

In this section we presents a procedure for deriving a rigorous two-port model for an antenna [3] from simulated and/or measured data, and demonstrates its use with a matching network. In many situations it is desirable to model an antenna as a two-port network. Such a model can be used in circuit simulations to compute the overall efficiency of the antenna with a lossy passive matching network. Furthermore, we anticipate that such a representation of the antenna could be quite useful in overall link simulations that include a channel model.

Given the input impedance and radiation efficiency of an antenna at a specified frequency from either simulation or measurements, a two-port representation of the antenna can be derived as follows. Let the complex input impedance of the antenna be denoted by Z_a, and the radiation efficiency be denoted by e_{cd}. Then, we can express the antenna impedance at that specific frequency as

$$\begin{aligned} Z_a &= R_a + jX_a = R_r + R_l + jX_a, \\ R_r &= e_{cd} \cdot R_a = \text{radiation resistance}, \\ R_l &= (1 - e_{cd}) \cdot R_a = \text{dissipative loss resistance}, \\ X_a &= \text{antenna reactance}. \end{aligned}$$

The radiation resistance R_r now can be replaced with a transformer to the impedance of free space, or more conveniently, to any port impedance that we wish (such as 50 Ω). The turns-ratio of the transformer is given by

$$N = \sqrt{\frac{R_r}{Z_0}},$$

where Z_o is the desired port impedance. The resulting two-port representation of the antenna is shown in Figure 2.

At each frequency, a two-port representation of the form shown in Figure 2 can be constructed, and the two-port scattering matrix evaluated and written into an appropriate file format (such as Touchstone) for use in a circuit simulator. Note that when port 2 of the two-port network shown in Figure2 is terminated by the proper port impedance, the antenna's input impedance is obtained as

$$Z_a = Z_0 \frac{1+S_{11}}{1-S_{11}},$$

and its total efficiency is obtained as

$$e_{tot} = |S21|^2 = (1-|S11|^2) \cdot e_{cd}.$$

4. Simulation and Measurement Results

This paper encompasses both the aforementioned methods to evaluate the losses in the matching circuit. In particular, it is demonstrated that the two approaches (i.e., two-port power gain and two-port representation of an antenna) are equivalent and yield the same results (see Figure 5 (b)). A test fixture, comprising a ground plane (90 × 50mm) and a simple inverted L antenna on a FR4 substrate (overall dimensions 100 × 50mm, $\varepsilon_r = 4.3$, see Figure 3) has been built and measured in a full 3D anechoic chamber, using a sleeve choke to prevent unwanted RF currents from flowing on the coaxial cable. The radiation efficiency e_{cd} of that antenna at 1.5GHz has been found to be 93.5%. The measured return loss and radiation efficiency of the antenna are used for designing the matching network shown in Figure 4, and the overall efficiency for the system has been evaluated using the two approaches. The matching network has been implemented on the test antenna, and the efficiency has been measured again and compared against the predicted system efficiency. Good agreement for both the return loss and the efficiency has been reported as shown in Figure 5.

5. Conclusion

In this paper, two simple methods for designing a low-loss antenna matching network are discussed. One of the methods describes how the overall system loss can be computed by using the two-port *S*-matrix of a matching network and the return loss of an antenna. And then we discussed a rigorous two-port representation of an antenna which can be readily obtained on a frequency-by-frequency basis from simulated or measured data. The usefulness of these methods for use in circuit simulations has been verified and compared with the measured response of an example involving a *T*-matching network and inverted L antenna.

6. Figures and Tables

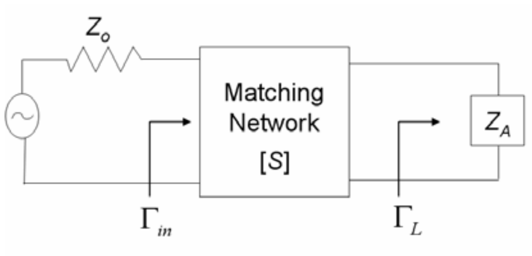


Figure 1: Two-port matching network with the antenna input impedance

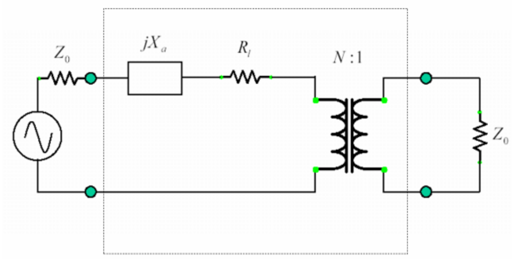


Figure 2: Two-port representation of the antenna (valid at a single frequency)

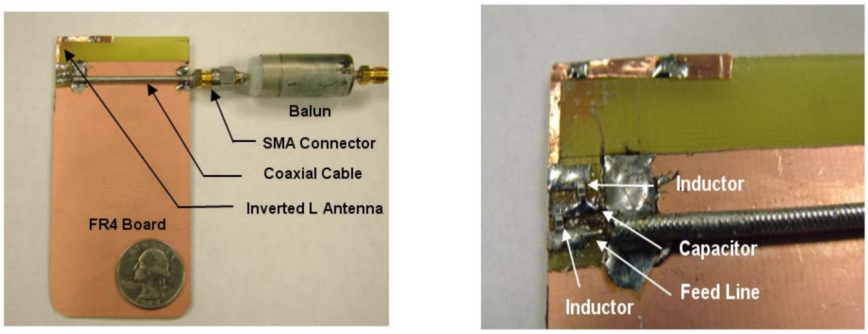


Figure 3: Photo of the fabricated antenna and its matching network

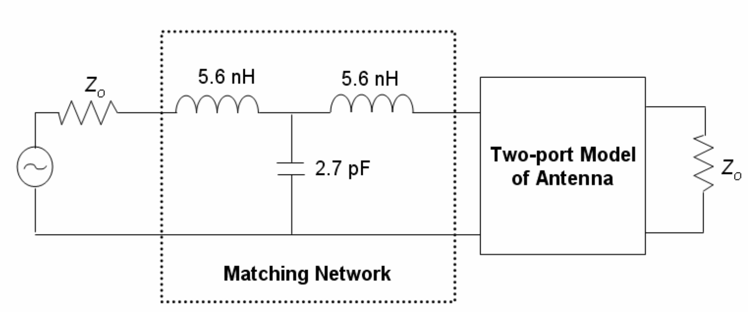
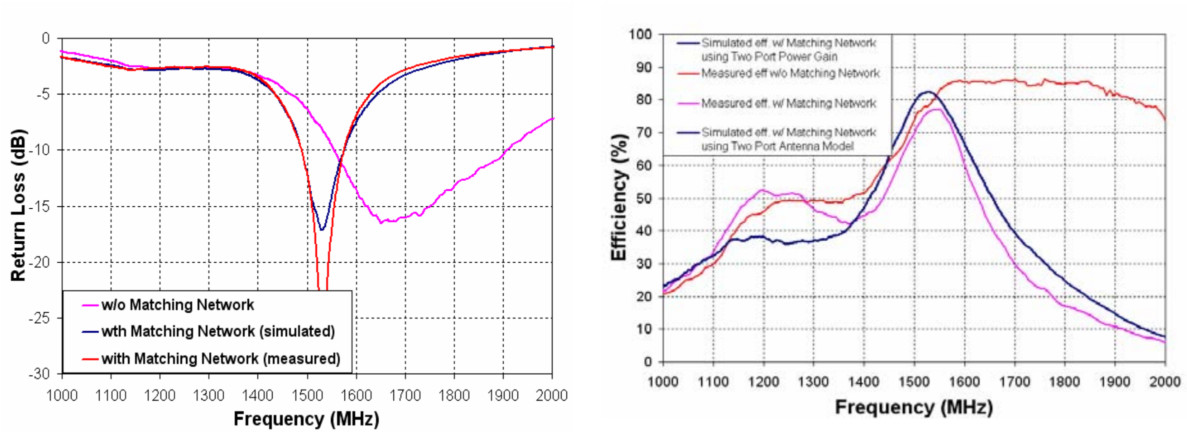


Figure 4: Schematic of the T-matching network combined with the two-port mode of antenna



(a) (b)

Figure 5: (a) Return losses and (b) overall efficiencies (in percent) of the antenna and matching network.

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