

MATCHING NETWORK DESIGN AND BROADBAND ANTENNA REALIZATION VIA “SIMPLIFIED REAL-FREQUENCY TECHNIQUE”

Ferhat BEKTAŞER

e-mail: ferhatbektas@mersin.edu.tr

Mersin University, Engineering Faculty, Dept. of Electrical-Electronics Eng., Çiflikköy, 33343 Mersin

Caner ÖZDEMİR

e-mail: cozdemir@mersin.edu.tr

Key words: Real-Frequency Technique, Broadband Antenna Design, Matching Network Design

ABSTRACT

In this study, an efficient and practical approach is proposed to increase the bandwidth of narrow-band antennas by designing lossless impedance matching network with the simplified real frequency technique. Our algorithm does not require prior knowledge of network analytical topology of the load impedance that is to be matched. Any frequency-dependent data such as antenna radiation data (either measurement or simulated) can be easily matched via the proposed algorithm. The matching network realized by this technique is relatively simple and gives superior gain properties compared to that obtained by other methods. The proposed method is tested with various data sets for different antenna configurations. The results validate the effectiveness and the success of the algorithm.

I. INTRODUCTION

Matching of narrow-band antennas has been a real challenge for microwave engineers for years. Many techniques have been proposed and applied for different antennas to achieve broadband designs [1-2]. Among them, Simplified Real Frequency Technique (SRFT) has gathered a lot of attention recently due to its robust features such as its applicability to any circuit topology, even for random data varying with frequency [3-4]. SRFT is an extension of “Real Frequency Technique” (RFT) that Carlin first used in 1977 [2, 5]. SRFT usually gives better results when compared to classical approaches such as Chen’s open formulas and Fano’s analytic bandwidth theory [3, 6]. With the introduction of SRFT, Hilbert transform operation in Carlin’s RFT becomes redundant. This produces more efficient circuits in terms of being simple topology and having better gain features. Although there are different broadband matching techniques available such as Cuthbert’s grid-based approach [7] and classical Smith chart tools, SRFT algorithm is a powerful and effective tool for designing broadband lossless matching networks.

It is obvious that some useful antennas such as microstrip patches have the undesired property of being narrow-

banded and therefore, their use in most of the applications becomes very limited [8]. In this work, we propose a method to increase the bandwidth of narrow-band antennas by designing a lossless impedance matching network (LIMN). While designing the LIMN, the basic procedure in SRFT is implemented [3, 4]. The paper is organized as follows: In Sec. II, the details of the SRFT as its application to our method is given. In the next section, design of the LIMN for antenna radiation is presented. In Sec. IV, two different antenna data is fed to the algorithm to test the validity and the effectiveness of our method. As demonstrated in this section, our proposed method has substantially increased the efficiency and produced quite successful results.

II. SIMPLIFIED REAL-FREQUENCY TECHNIQUE

SRFT is a powerful tool for matching frequency-dependent load impedance to the source impedance. In SRFT, the designer first decides the choice of the finite frequency points at which the desired gain values will be attained. In Fig.1, the equivalent circuit that represents complex antenna radiation impedance; $Z_L(\omega)$, arbitrary source impedance; $Z_G(\omega)$ and the lossless impedance matching network (LIMN) is drawn.

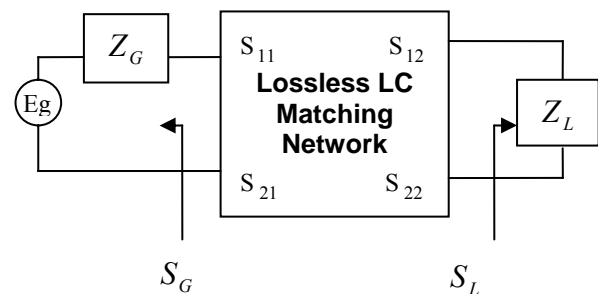


Figure 1. Circuit equivalent of antenna impedance matching problem.

It is assumed that the zeros of LIMN are at $\omega=0$ and $\omega=\infty$ providing that it has the feature of minimum phase. With this assumption, it is guaranteed that the LIMN consists of only passive, reactive elements; i.e., inductors

(L) and capacitors (C) and the only coupled element occurs at the transformer section of the network [3]. In the synthesis of LC matching network, we do not need to know the circuit topology of the LIMN thanks to SRFT. Let's assume that the reflection coefficient $S_{11}(s)$ can be written as the following rational;

$$S_{11}(s) = \frac{h(s)}{g(s)} = \frac{h_0 + h_1s + \dots + h_ns^n}{g_0 + g_1s + \dots + g_ns^n} \quad (1)$$

Generally, $h(s)$ and $g(s)$ are polynomials of order n . In fact, the order n represents the total number of reactive elements in the LIMN. According to Belevitch representation [9]; other scattering parameters of a 2-port network can be obtained from $S_{11}(s)$ as given below;

$$S_{21}(s) = S_{12}(s) = \pm \frac{s^k}{g(s)} \quad (2)$$

$$S_{22} = -(-1)^k \frac{h(-s)}{g(s)} \quad (3)$$

The integer number k determines the transmission zero at the origin. Since the LIMN is lossless, the following is true

$$|S_{11}(s)|^2 + |S_{21}(s)|^2 = 1 \quad (4)$$

Then, one can write as losslessness equation:

$$g(s)g(-s) = h(s)h(-s) + (-1)^k s^{2k} \quad (5)$$

If the coefficients of $h(s)$ are known, $g(s)$ can be easily obtained from Hurwitz factorization [3]. Our algorithm can be summarized as follows:

- 1) Get the following Hurwitz polynomial
 $g(s)g(-s) = h(s)h(-s) + (-1)^k s^{2k} = G_0 + G_1s^2 + \dots + G_ns^{2n}$ that has the entries;
 $G_0 = h_0^2$
 $G_1 = h_1^2 + 2h_2h_0$
 $G_t = h_t^2 + 2(h_{2t}h_0 + \sum_{j=2}^t h_{j-1}h_{2t-j+1})$
 $G_k = G_t|_{t=k} + 1$
 $G_n = h_n^2$.
- 2) Find the roots of $g(s)g(-s)$,

3) Select the left half plane roots of $g(s)g(-s)$ and put them in the form of $g(s) = g_0 + g_1s + \dots + g_ns^n$,

4) By using $h(s)$ and $g(s)$ polynomials, generate the real normalized S-parameters $s_{ij}(s)$ as;

$$s_{11}(s) = \frac{h(s)}{g(s)} \quad s_{21}(s) = s_{12}(s) = \mp \frac{s^k}{g(s)}$$

$$s_{22} = -(-1)^k \frac{h(-s)}{g(s)}$$

5) Get the antenna gain from source to load in terms of $h(s)$ and $g(s)$ polynomials form and write the transducer power gain (TPG) $T(w)$ as;

$$\hat{s}_{22}(w) = s_{22} + \frac{s_{21}^2 S_G}{1 - s_{11} S_G}$$

$$T(w) = \frac{[1 - |S_G(w)|^2][1 - |S_L(w)|^2]|s_{21}(w)|^2}{|1 - s_{11}(w)S_G(w)|^2|1 - \hat{s}_{22}(w)S_L(w)|^2} \quad (6)$$

$$= \frac{[1 - |S_G(w)|^2][1 - |S_L(w)|^2]|w^{2k}|}{|g(jw) - h(jw)S_G - (-1)^k S_G S_L g(-jw) + (-1)^k S_L h(-jw)|^2}$$

Once the coefficients of $h(s)$ are found, we use least-squares method (LSM) to optimize the TPG and therefore the coefficients of h_i 's ($i=0,1,\dots,n$) can be obtained at the end of the optimization..

We define the error function δ that is to be minimized as the following manner;

$$\delta = \sum_{i=1}^m (T(w_i) - T_0(w_i))^2 \quad (7)$$

where $T_0(w_i)$ is the desired transducer gain at frequency w_i . In the next step, we iteratively calculate the correction increments Δh_i 's by comparing the transducer power gain in (6) to $T_0(w_i)$ so that the error function δ is minimized. At the end of this iterative process, the best fit for the $h(s)$ and $g(s)$ polynomials is obtained [10].

III. MATCHING NETWORK DESIGN FOR ANTENNA PROBLEMS

The algorithm explained in the previous section is specialized to design LIMN for antenna problems. The frequency-dependent load impedance in Sect. II is now replaced by the measured/simulated antenna radiation impedance for a specified frequency band of interest. The source impedance is chosen to be equal to the nominal value of 50 Ω . Then the problem can be set as to match the antenna radiation impedance to a 50 Ω transmission

line that is connected to a source so that the resonance bandwidth of the antenna has to be increased as much as possible. The main goal is to increase the resonance bandwidth for the entire frequency band so that the reflection coefficient is always less than or equal to -10dB. The design procedure can be summarized as below:

- 1) First, either the reflection data; S_{11} or the radiation impedance data Z_L for the antenna is obtained for a band of frequencies.
- 2) At the source side, the impedance matching condition is decided. Generally, the load impedance (antenna radiation impedance) is chosen to be matched to a 50Ω transmission line.
- 3) Then TPG for each frequency point is decided. Nominal values of TPG are usually chosen to be between 0.85 and 1.0. We should also decide the order of the LIMN; n . This number also gives the number of the total reactive elements to be used inside the LIMN.
- 4) After putting all of the above parameters as inputs to our algorithm, we start with an initial guess of the values of $h(s)$ polynomial. This initial guess does not need to be good. Any random guess will also work. Of course, a good initial guess will reduce the convergence time while iterating. The constraint is set as $(S_{11})_{dB} \leq -10dB$ for the frequencies of interest while achieving the desired TPG value. To avoid numerical errors due to large numbers in frequencies, frequency normalization helps a lot when calculating the correction increments. To achieve this, all frequencies are normalized such that the highest frequency is set to 1. For the same reason, the impedances are also normalized with the source's impedance Z_0 which is usually 50Ω for this work. Then, TPG is optimized by the help of LSM algorithm. At the end, the values of $h(s)$ and $g(s)$ polynomials are determined and the corresponding impedance for the LIMN is obtained via $Z = (1 + S_{11}) / (1 - S_{11})$.
- 5) After having the impedance function of the LIMN for frequencies, next step is to use network synthesis methods to design the network with actual values for inductors and capacitors. We wrote a MATLAB® [11] code in synthesizing the impedance to reactive elements in the following Caue-I form;

$$Z_{LC} = sL_1 + \frac{1}{sC_1 + \frac{1}{sL_2 + \dots}} \quad (9)$$

- 6) If the desired broad-band matching has not been achieved with the input values of element

number; n and the frequency range. The element number can be increased and the frequency range can be reduced as well.

IV. NUMERICAL DESIGN EXAMPLES

We test the success and the validity of our method with two different numerical examples. The first example is the “Top-hat monopole antenna with shorting pin” whose side view is shown in Fig.2. The simulation of this antenna is performed by High Frequency Structure Simulator (HFSS) [12]. The radiation impedance curve for selected frequencies is plotted in Fig. 3(a). In Fig. 3(b), return loss for the antenna is plotted. We see that this antenna is not at resonance for the frequency band between 960 MHz and 1220 MHz. As an input to our method, we set the goal TPG value as 0.98 for the entire band. After applying our proposed algorithm, we obtained resultant TPG curve as in Fig. 4.

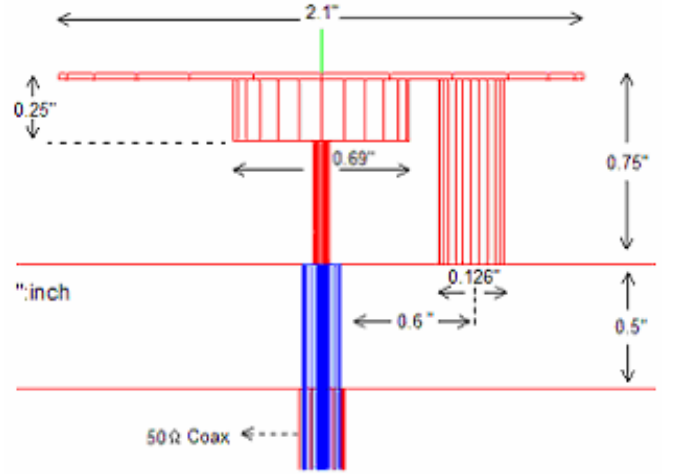


Figure 2. “Top-hat monopole antenna with shorting pin”

While applying our algorithm source impedance is chosen to be $Z_0 = 50 \Omega$. These values are converted to transmission coefficients using

$$T(w) = 1 - |S_{11}(w)|^2 \quad (10)$$

Then, we used our synthesis algorithm to actually find the values of the passive elements in our designed LIMN. The resultant LIMN together with optimized inductor and capacitor values are given in Fig. 5. The reflection coefficient seen before the designed LIMN is shown in Fig. 6. It is obvious that the antenna is matched almost the entire band of frequencies by the help of our method. In fact, this antenna has matched over the frequencies between 0.96-1.22GHz yielding a bandwidth of 23%.

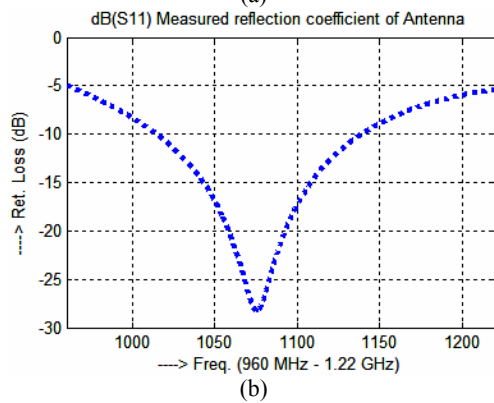
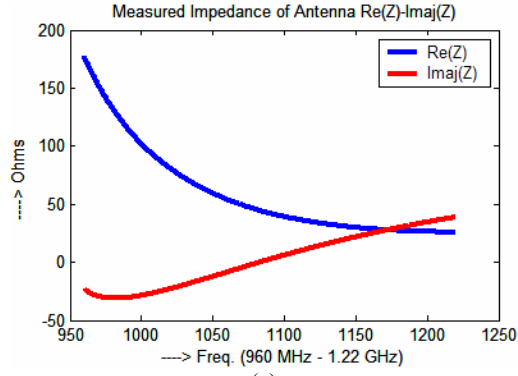


Figure 3. (a) Radiation impedance vs. frequency (b) S_{11} vs. frequency for the antenna in Fig.2

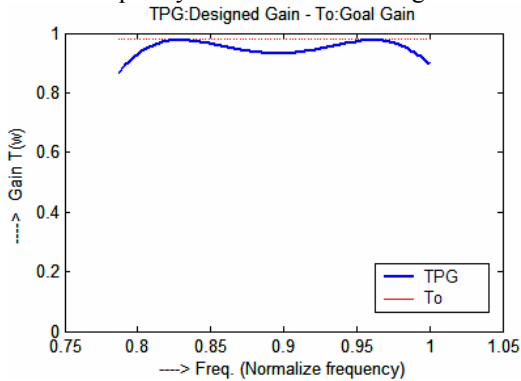


Figure 4. Resultant TPG curve after SRFT.

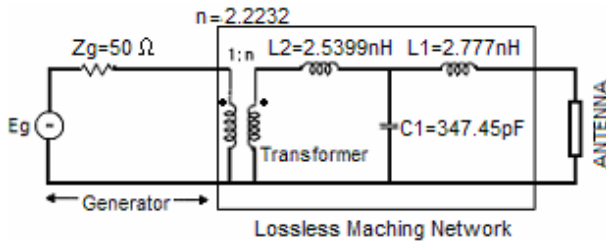


Figure 5. Designed Lossless Impedance Matching Network

As the second example, "Microstrip antenna with shorting pin" (Fig. 7) is considered. Microstrip antennas are known for their narrow-band behavior. The shorting pin is used to increase the radiation resistance to help easy matching of this antenna. The simulation of this antenna is done by HFSS and resultant radiation impedance values for frequencies from 960 MHz to 1220 MHz are plotted in

Fig 8(a). The resonance behavior of this antenna can be observed around 1090 MHz. In Fig. 8(b), return loss for the microstrip antenna with shorting pin is plotted.

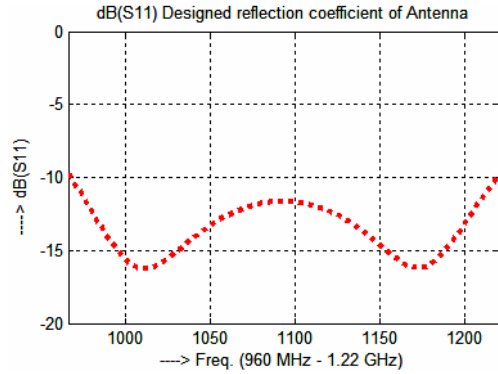


Figure 6. The return loss after applying the designed LIMN.

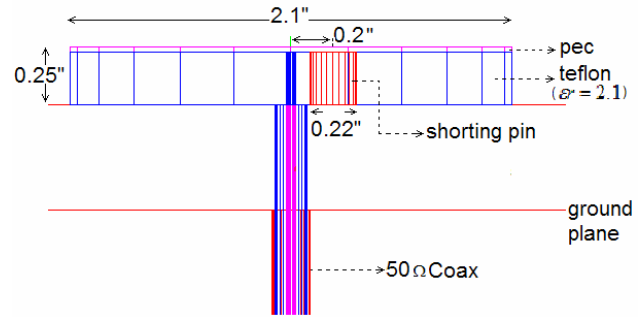


Figure 7. "Microstrip antenna with shorting pin"

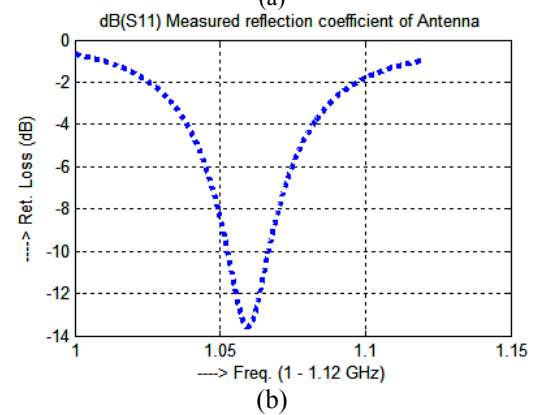
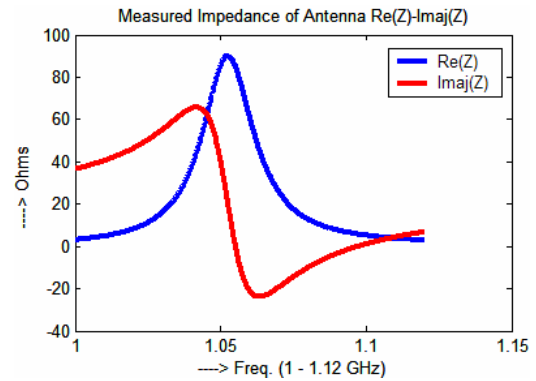


Figure 8. (a) Radiation impedance vs. frequency (b) S_{11} vs. frequency for the antenna in Fig.7

We start applying our algorithm by setting the goal TPG value as 0.98 for frequencies between 1- 1.12GHz. After running the code for SRFT, we obtained resultant TPG curve as shown in Fig. 9. Then using our circuit synthesis code, we obtained the passive element values of LIMN as plotted in Fig. 10. Finally, to test the frequency bandwidth of the resultant matched antenna with designed LIMN, the reflection coefficient is viewed. Fig. 11 shows S_{11} seen before the LIMN.

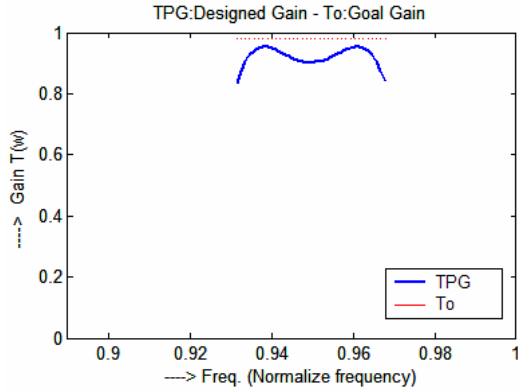


Figure 9. Resultant TPG curve after SRFT.

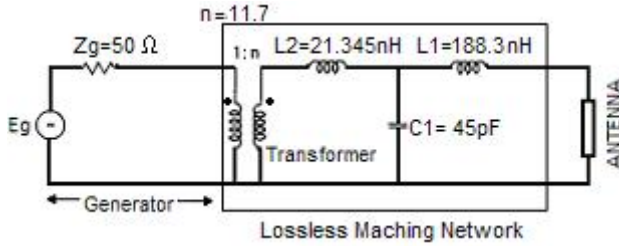


Figure 10. Lossless Impedance Matching Network designed for the antenna is Fig.7

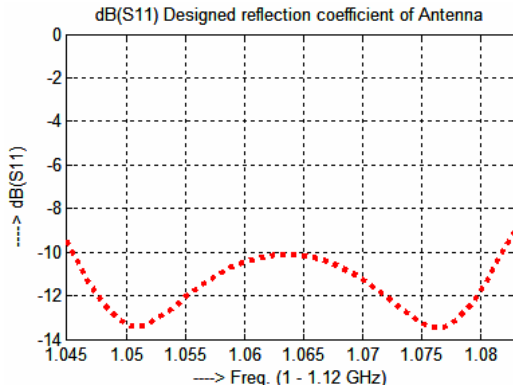


Figure 11. S_{11} curve for the microstrip antenna applying the designed LIMN.

V. CONCLUSION

In this work, we proposed a method that increases the bandwidth of narrow-band antennas by designing lossless impedance matching network with the simplified real frequency technique. Theoretical work together with associated formulation is given. Our method is based on SRFT and also applies Least Squares Method when

optimizing the transducer gain function over frequencies of interest. The methodology is presented in detail and numerical examples testing our algorithm are presented as well. All numerical results validate the effectiveness of our algorithm. Our method was able to match given antennas with providing a good wide-band match.

REFERENCES

1. Yi-Sheng Zhu, Wai-Kai Chen "Computer – Aided Design of Communication Network" World Scientific, Danvers, MA, 2000
2. H. J. Carlin, "A new approach to gain-bandwidth problems," IEEE Trans. Circuits Syst., vol. 24, no. 4, pp. 170-175, April 1977.
3. B. S. Yarman, and H. J. Carlin, "A simplified "real frequency" technique applied to broad-band multistage microwave amplifiers," IEEE Trans. Microwave Theory Tech., vol. 30, no. 12, pp. 2216-2222, Dec. 1982.
4. A. R. Van de Capelle, and bart. K. J. C. Nauwelaers, "Broadband Microstrip Antenna Design with the Simlified real frequency technique", IEEE trans. on antenna and propagion, vol. 42 no.2 February 1994.
5. H. J. Carlin and J. J. Korniak, "A new method of broad-band matching equalization applied to microwave amplifiers," IEEE Trans. Microwave Theory Tech., vol. 27, no. 5, pp. 401-405, May 1981.
6. Carlin, J. and Amstutz, P., "On Optimum Broad-Band Matching," IEEE-CAS, Vol.28, 5, May 1981.
7. Cuthbert, T., "Broadband Impedance Matching Methods, RF Design", August 1994.
8. D. M. Pozar, "Microstrip antennas", Proc. IEEE, vol. 80, no. 1, pp. 79-91, Jan., 1992.
9. V. Belevitch, "Elementary application of the scattering formalism to network design," IRE Trans. Circuit Theory, vol. 3, June 1956.
10. B. S. Yarman, "Modern approaches to broadband matching problems," IEEE Proceedings, vol. 132, Pt, H, 2, pp. 87-92, April, 1985
11. User reference for MATLAB, ver 7.0.0.19920, May 2004.
12. User reference for Agilent HFSS (High Frequency Structure Simulator), ver. 5.5, Dec. 1999.