

# Optimization Design of Matching Networks for High-frequency Antenna

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**Abstract-** Real frequency technique is an efficient method for the optimization design of broadband matching networks. This paper mainly uses the real frequency technique for the design of HF broadband antenna impedance matching network. The network parameters were calculated for two real frequency methods by MATLAB and we compared the two methods of corresponding matching performance. On this basis, some optimization and improvement of the real frequency technique will be done to make real frequency technology more practical and scientific.

## I. INTRODUCTION

With the rapid development of modern wireless communication technology, there are more and more communication system for different purposes. Matching network is used in almost any transceiver system of a communication system. At the same time, the design of matching network has gradually tended to higher frequency and band broadening. Network matching problem now is not only an interesting theoretical problem, but also a widely encountered in practical engineering problems.

Antenna matching theory has experienced a long time. Matching problem was first introduced by Bode in 1945. In 1950, R.M.Fano [7] conducted a general study of the problem. In 1961, Schoeffler proposed the concept of compatibility impedance matching problem, studied the problem from different aspects. H.J.Carlin [4] proposed the real frequency technique in 1979. By using the load data directly, the real frequency method has great advantage in designing impedance matching network. Now the real frequency technique has been made several optimization, and other ways to design matching networks have been developed [8].

## II. THE ORIGINAL REAL FREQUENCY METHOD

As figure 1 shows,  $V_g(s)$  as the signal source,  $R_g(s)$  is the resistance of signal source,  $Z_l=RI(w)+jXI(w)$  is input impedance of antenna. Assuming that  $Z_q=RI(w)+jXI(w)$  is the driving-point function from the antenna input port to the matching network.

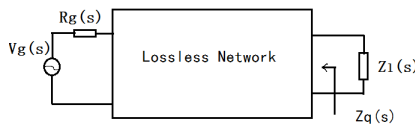


Fig.1. Matching network

$P_i$  is antenna's input power and  $P_a$  as the source's average output power.

The TPG is transducer power gain and it can be expressed as follows:

$$T(w) = 1 - |\rho|^2 \quad (1)$$

$\rho$  is the normalized reflection coefficient, according to the microwave basic knowledge:

$$\rho = \frac{Z_q + Z_l^*}{Z_q + Z_l} \quad (2)$$

$$Z_l^* = RI(w) - jXI(w) \quad (3)$$

Thus TPG can be calculated as:

$$T(w) = \frac{4Rq(w)RI(w)}{|Z_q(w) + Z_l(w)|^2} \quad (4)$$

TPG can also be shown as:

$$T(w) = \frac{4Rq(w)RI(w)}{|Rq(w) + RI(w)|^2 + |Xq(w) + XI(w)|^2} \quad (5)$$

In the above equation,  $Z_l$  can be measured by mathematical methods, so definite solution about TPG will be got if we know  $Z_q$ . On the other hand  $Z_q$  can be assumed to be a minimum reactance function, so the relationship between the real and imaginary parts of  $Z_q$ , becomes unique. The relation between the real and imaginary parts can be shown in the following integral equations:

$$Rq(w) = -\frac{1}{\pi} \int_{-\infty}^{+\infty} \frac{Xq(\lambda)}{\lambda - w} d\lambda + R(\infty) \quad (6)$$

$$Xq(w) = \frac{1}{\pi} \int_0^{+\infty} \frac{dRq(\lambda)}{d\lambda} \ln \left| \frac{\lambda + w}{\lambda - w} \right| d(\lambda) \quad (7)$$

A key step in the real frequency method is the approximation of the resistance function  $Rq(w)$  by a number of straight-line segments with break point from 0 to  $w_n$ . So we have:

$$Rq(w) = r_0 + \sum_{k=1}^n a_k(w)r_k \quad (8)$$

Where

$$a_k = \begin{cases} 1 & w_k < w \\ \frac{w - w_{k-1}}{w_k - w_{k-1}} & w_{k-1} < w < w_k \\ 0 & w < w_{k-1} \end{cases} \quad (9)$$

The  $r_0$  in (8) represent  $Rq(0)$  and it is normalized to 1.

With the resistance  $Rq(w)$  expressed as in (8), the reactance  $Xq(w)$  can be written as a linear combination of the same unknown resistive excursions. We thus have:

$$Xq(w) = \sum_{k=1}^n b_k r_k \quad (10)$$

Where

$$b_k = \frac{1}{\pi(w_k - w_{k-1})} \int_{w_{k-1}}^{w_k} \ln \left| \frac{y+w}{y-w} \right| dy \quad (11)$$

Based on the (5)、(8)、(10), the TPG can be expressed as follows :

$$T(w) = \frac{4Rl(w)[r_0 + \sum_{k=1}^n a_k(w)r_k]}{[Rl(w) + r_0 + \sum_{k=1}^n a_k(w)r_k]^2 + [Xl(w) + \sum_{k=1}^n b_k(w)r_k]^2} \quad (12)$$

In (12),T(w) is at most quadratic function of  $r_k$ , and he optimization function can be set to:

$$E = \sum_{k=1}^M |1 - T(w_k)|^2 \quad (13)$$

Once the  $r_k$  is calculated by optimization method, the Rq can be expressed as line form, Xq(w) also can be calculated through Hilbert transform. But in practice, when Rq (w) is expressed as several segments poly line, physically matching network can not be achieved. Rq should be fitted by a rational function. We usually use the following equation fitting Rq(w):

$$\hat{R} = \frac{A_0 w^{2k}}{1 + B_1 w^2 + \dots + w^{2n}} \quad (14)$$

In (14), if the matching network is a low-pass, then k = 0; if the matching network is a band-pass, then 1 < k < n; if the matching network is a high-pass, then k = n.

By changing the Rq(w) into the graph which can be physically realized, we already know the matching network driving-point function, then Zq(w) can be obtained by GEWERTZ method. Thus, Z (s) has been obtained, and then we will use knowledge of the network, integrated the Zq(w) into its matching network.

### III. IMPROVED REAL FREQUENCY METHOD

Improved real frequency method calculates  $r_k$  through least square method based on the conjugate matching principle. So it can avoid the initial selection about  $r_k$ .

Compared with the real frequency method, the improved method is more simple and available both on the theory and implementation, also avoid the original method of optimization of E function, which is one of the most complex steps in real frequency method.

Being similar to the original method, after a plus an antenna matching network, the transmission power gain is expressed as follow:

$$T(w) = \frac{4Rq(w)Rl(w)}{|Rq(w) + Rl(w)|^2 + |Xq(w) + Xl(w)|^2} \quad (15)$$

It is easy to know through the knowledge of antenna that if Zq (w) and Zl(w) conjugate match, antenna get maximum

transmission power at this time. This is entirely consistent with the conjugate match of physical meaning .

$$Rq=Rl(w) \quad (16)$$

$$Xq=-Xl(w) \quad (17)$$

Since the introduction of conjugate match, we need' t set function E and initial value of increments of each fold line as the original real frequency method.

Because the matching network design goal has been given by the conjugate matching theory accurately, we can directly use the least square method to calculate Rq (w).In addition, when using least squares method, if we combine the Rq (w) and Xq (w),we could get double expand sampling points, then reach a more accurate solution about  $r_k$ .

Based on (8)(10)(16), we can obtain the following matrix:

$$\begin{bmatrix} a \\ b \end{bmatrix}_{2M \times N} \bullet [r]_{N \times 1} = \begin{bmatrix} (R_a - r_0)' \\ -X'_a \end{bmatrix} \quad (18)$$

Thus process of solving the matrix  $[r]_{N \times 1}$  is much simpler compared with the original method and in the calculation of the actual programming matrix operations, we can directly call the function obtain the rest. Once we know the solution of the matrix  $[r]_{N \times 1}$ , we can obtain function Rq(w) by a number of straight-line segments by  $r_k$ . After this, the procedures to design the matching network is the same as the original real frequency method.

### IV. DESIGN OF MATCHING NETWORK WITH REAL FREQUENCY TECHNIQUE

In the process of designing impedance matching network, we use the sleeve antenna in reference [1], the impedance is shown in Table I:

TABLE I  
IMPRDANCE OF ATTENA

f(MHz)	R	X	f(MHz)	R	X
25.0	15.186	-50.945	35.4	107.78	-40.938
25.8	12.864	-28.789	36.2	66.988	-47.633
26.6	13.962	-12.807	37.0	44.611	-35.275
27.4	18.745	-1.006	37.8	38.941	-20.107
28.2	27.146	7.5225	38.6	43.502	-13.500
29.0	34.584	6.9609	39.4	45.232	-18.518
29.8	34.029	3.5625	40.2	34.791	-21.721
30.6	27.544	7.4600	41.0	24.585	-15.210
31.4	25.223	18.500	41.8	18.795	-5.1875
32.2	28.814	33.850	42.6	16.436	6.0557
33.0	43.561	52.582	43.4	16.746	18.769

#### 1 Design matching network by original real frequency method

Firstly the Rq(w) should be represented as a number of line segments. Many tests show, the Rq (w) is divided into five segments may achieve the ideal uniform. Once we get the form of Rq(w), we can calculate  $r_k$  using the optimized function E. The results are as follows:

$r_1=1.0323; r_2=1.2338; r_3=-0.3771; r_4=0.6973; r_5=-1.5218;$   
 Line segments of  $R_q(w)$  is shown in Figure 2:

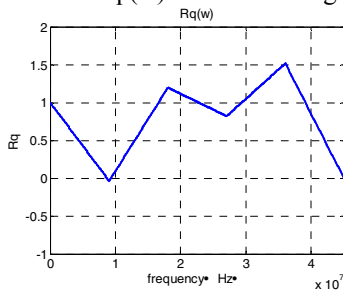


Fig.2.  $R_q$ (expressed in the form of fold line )

Now, the  $R_q(w)$  has been expressed as the fold line, in this case,  $X_q(w)$  can be calculated by using the Hilbert transform. So we can obtain the theoretical transmission power gain of matching antenna. Figure 3 shows:

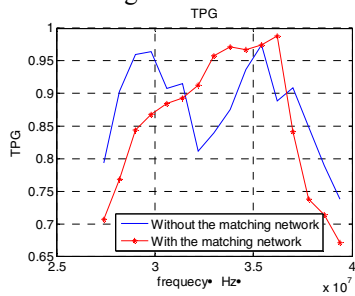


Fig.3. Theoretical TPG of antenna

However, because the  $R_q$  is fold line and it can not be implemented in physics,  $R_q$  should be fitted by a rational function. Then we obtain  $Z_q(s)$  through GEWERTZ method.

$$Z_q(s) = \frac{0.002889s^2 + 0.02489s + 0.06042}{s^3 + 8.6133s^2 + 22.8386s + 16.5449}$$

If the  $Z_q(s)$  is obtained, the specific form of the matching network can be calculated according to the circuit of knowledge. As shown in Figure 4:

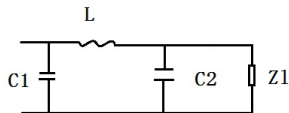


Fig.4. The impedance matching network

Circuit components inside the concrete is as follows:

$$C1=0.6922\mu F, L=0.007505\mu H, C2=6.371\mu F.$$

Transmission power gain obtained previously is the theoretical values, now according to the matching network, we calculate the transmission power gain again and get the result shown in Figure 5:

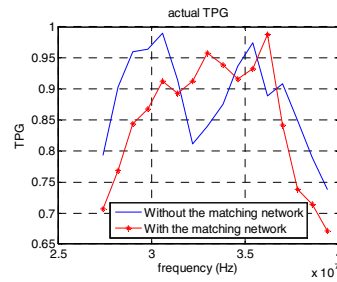


Fig.5. The actual TPG of antenna

There is relation in VSWR and TPG:

$$VSWR = \frac{1 + \sqrt{1 - TPG}}{1 - \sqrt{1 - TPG}} \quad (19)$$

Then we can calculate the VSWR of antenna. As shown in figure 6:

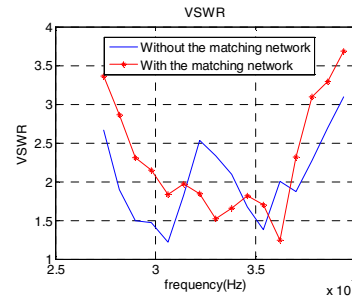


Fig.6. The actual VSWR of antenna

Some conclusions can be obtained based on the figure 3 and figure 4: First of all, the TPG of the antenna, especially near the center frequency, have significantly increased after adding the matching network, which indicating that the matching network, to a certain extent, improve transmission performance of the antenna and is conducive to antenna transmission power. Secondly, after adding matching network, the actual TPG is basically the same with the theoretical one, and somewhat less than the theoretical value, because the actual line  $R_q(w)$  is an ideal fit of the fold line.

## 2 Design matching network by improved real frequency method

Firstly,  $r_k$  can be calculated with the least square method:

$$r1=-5.0642; r2=8.9973; r3=-3.8411; r4=1.4451; r5=1.4344$$

Line segments of The  $R_q(w)$  is shown in Figure 7:

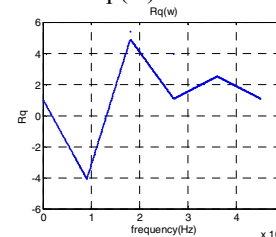


Fig.7.  $R_q$  (expressed in the form of fold line )

Then the theoretical transmission power gain of matching antenna can be obtained. Figure 8 shows:

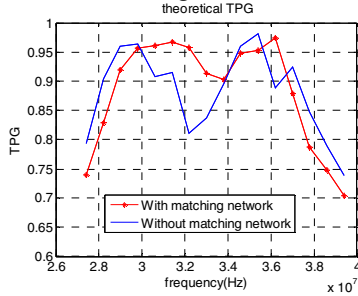


Fig.8. theoretical TPG of antenna

Next we obtain  $Zq(s)$  through GEWERTZ method:

$$Zq(s) = \frac{0.002049s^2 + 0.01808s + 0.0460}{s^3 + 8.824s^2 + 24.9157s + 21.7425}$$

The structure of the matching networks designed by improved real frequency method and what shown in figure 4 are identical. The circuit components inside matching network is as follows:

$$C1=0.976\mu F, L=4.17nH, C2=0.1072\mu F.$$

The actual transmission power gain can be calculated according to the matching network. To find the differences of the two matching networks and analyze the advantages and disadvantages between the original real frequency method and the improved real frequency method, we combine figure 5 with the actual TPG of network designed by improved real frequency method and get result shown in figure 9:

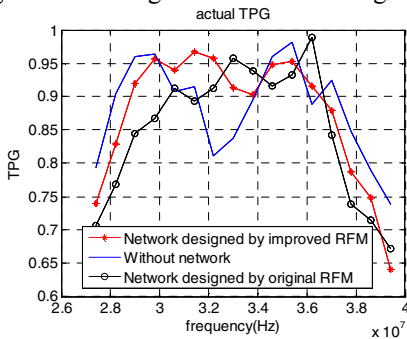


Fig.9. The actual TPG of antenna

Then we can calculate the VSWR of antenna. As shown in figure 10:

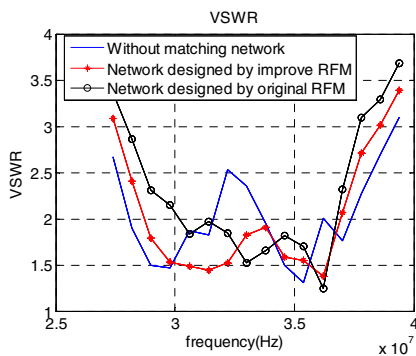


Fig.10. The actual VSWR of antenna

We could know from the figure 10 that the matching network can improve the antenna transmission power gain in different degree and improved real frequency method has better matching effect than the original real frequency method. The matching can sacrifice the gain of two sides band to improve the transmission power gain of center frequency band.

## V. CONCLUSION

This paper mainly introduces the importance of antenna matching network transmission and make the theoretical analysis and experimental research on designing matching network via real frequency technique. In the application research, we design two different impedance matching networks for HF broadband antenna with the original real frequency method and the improved real frequency method. In the past, most researches about real frequency technique stay in the stage of theoretical analysis of transmission power gain. This paper not only calculate both the theoretical TPG and the actual TPG but also analyze the difference between the two matching networks. In fact, there is a certain gap between the actual matching network and in theory, which should caused attention of antenna designers. The experimental results show that the matching network can effectively improve the antenna transmission power gain. This method is using very frequently in modern engineering applications.

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