Transformerless Bandpass Matching Network Design for Y-Shaped Monopole Antenna

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Abstract

In this paper, a transformerless bandpass matching network design procedure is presented. The Real Frequency Techniques are powerful numerical methods to design wideband lossless 2-port networks such that filters and matching networks. In these techniques, the value of the termination resistance of the designed network could not be yielded as 50 Ω by numerical package. Hence, a transformer is also required for 50 Ω termination which is not practical for high frequency applications. Also in this study a novel wideband monopole antenna is presented. The proposed antenna is consisting of two major elements; Y-shaped impedance matching plate and hemi-circular radiator. Moreover Y-shaped impedance matching plate connected to a feeding probe excites the suspended hemi-circular radiator via air gap. and its frequency band is expanded by using transformerless bandpass design procedure.

1. Introduction

Increasing demands of wireless communication systems, wireless sensors, radar technologies and positioning systems are spurred research and development on ultra wideband systems. Further, the advantages of these systems over narrowband wireless communication systems are their low transmitting power level and high data rate features. In addition to this, rapid developments in wireless communication systems bring up the need for the antennas with wideband impedance bandwidths, low-profile configurations and low cost.

The wideband bandpass matching network design is one of the major problem in communication systems. The Real Frequency Techniques (RFT), are powerful numerical techniques to design wideband lossless 2-port networks [1,2]. In RFT, lossless 2-port network is described in terms of its driving point impedance $Z_{in}(jx)$ in Darlington sense (Fig. 1). In this representation variable "x" designates the real frequency variable of the 2-port network.

The Real Frequency-Direct Computational Technique (RF-DCT) is one of the RFT design procedure such that Parametric Approach and Simplified Real Frequency Technique (SRFT). By using RF-DCT, the driving point impedance $Z_{in}(jx)$ of the lossless 2-port network could be computed by its even part $R(x^2)$ [1],

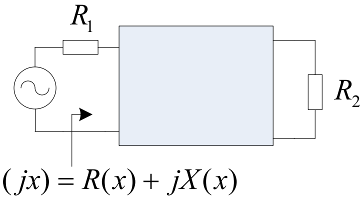


Fig. 1. Lossless 2-port network for prefixed R_1 and R_2 termination impedances.

$$R(x^2) = \frac{A_0\, x^{2ndc}\, \prod_{i=1}^{nz}\left(x_i^2 - x^2\right)^2}{\frac{1}{2}\left[c^2(x) + c^2(-x)\right]} = \frac{A_0\, x^{2ndc}\, \prod_{i=1}^{nz}\left(x_i^2 - x^2\right)^2}{B_1x^{2n} + B_2x^{2(n-1)} + \cdots + B_nx^2 + 1} \tag{1}$$

where, $c(x) = c_1x^n + c_2x^{n-1} + \cdots + c_nx + 1$ is defined as an auxiliary polynomial with real coefficients c_i, ndc is the total number of transmission zeros at DC, nz is the total number of finite transmission zeros and $A_0 = R_2$ is the prefixed termination of the far-end of the 2-port network. For many practical problems, R_2 is selected as 50 Ω and its normalized value is unity.

Although, the bandpass matching networks can be designed by using general form of $R(x^2)$ in (1) where $ndc \geq 1$, in most cases termination resistance R_2 is not equal to 50 Ω. Therefore, to obtain 50 Ω termination resistance, lowpass to bandpass transformation equations [3,4] are substituted in (1). For this purpose, ndc and nz should be 0.

$$x = \frac{(\omega^2 - \omega_0^2)}{(\alpha\omega)} \tag{2}$$

where,

$$\omega_0 = \sqrt{\omega_1\omega_2}$$
$$\alpha = \omega_2 - \omega_1$$
$$\omega_1: Lower\ end\ of\ the\ passband$$
$$\omega_2: Higher\ end\ of\ the\ passband$$

By algebraic manipulations, the new form of even part is,

$$R(\omega^2) = \frac{A(\omega^2)}{B(\omega^2)} \tag{3}$$

$$= \frac{A_0\, \alpha^{2n}\, \omega^{2n}}{(\sum_{i=1}^{n} B_i(\omega^2 - \omega_0^2)^{2(n-i+1)} * [(\alpha\omega)^2]^{(i-1)}\,) + (\alpha\omega)^{2n}}$$

Eventually, the driving point impedance of the bandpass lossless 2-port matching network can be computed by parametric representation [1] from (3).

2. Y-Shaped Monopole Antenna with Hemi-Circular Coupling Element

As shown in Fig. 2, Y-shaped impedance matching plate acts as a monopole antenna as well as impedance matching element. The upper edge of the impedance bandwidth has a strong dependence on the feed gap distance [5-6]. In the proposed antenna, Y-shaped impedance matching plate mainly comprises a trapezoidal – rectangular monopole element and a matching portion. The matching portion is parallel to ground plane. Also the trapezoidal - rectangular monopole element is vertical to matching portion. A major challenge in designing Y-shaped impedance matching plate is the height of the feed probe and sizes of the matching portion. Therefore, by adjusting the sizes of the matching portion, wide operating bandwidth can be achieved [7-8].

This paper presents a new wideband directional antenna for wireless applications which has Y-shaped impedance matching plate and hemi-circular radiator. Y-shaped impedance matching plate excites the suspended hemi-circular radiator via air gap and these two elements radiate cooperatively. Then the air gap between two plates of the antenna operates electromagnetic coupling [9-10]. Also, the antenna can achieve stable radiation performance with gain greater than 7 dBi across the operating bandwidth.

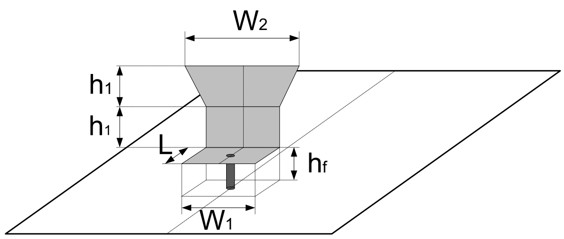
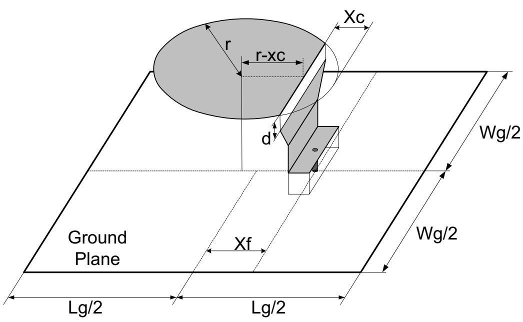
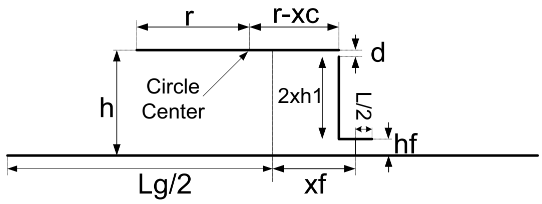


Fig. 2. Y-shaped impedance matching plate geometry.



(a) Overview



(b) Side view

Fig. 3. Proposed antenna geometry.

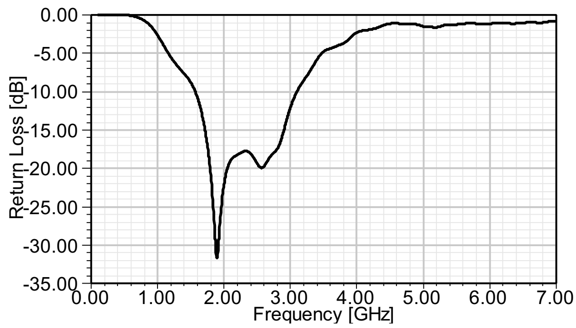


Fig. 4. Return loss of the proposed antenna.

Fig. 3, shows the geometry of the proposed antenna. The dimensions of the elements which comprise the antenna are given in Table I and dimensions of the antenna are determined by optimization and simulation over specified radiating bandwidth.

Square planar monopole antenna has been studied by M. J. Ammann [5] who proved the dimensions of the square planar monopole element corresponding to the lower edge frequency of the bandwidth. Also a formula for the frequency corresponding to the lower edge of the impedance bandwidth was proposed by J. A. Evans and M. J. Ammann [6] for planar trapezoidal antennas.

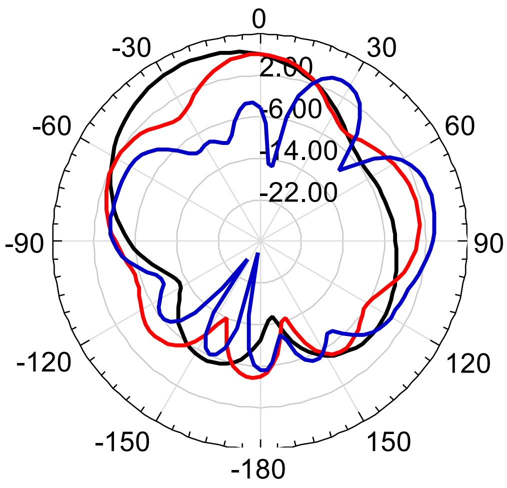
A trapezoidal-rectangular monopole element and matching portion constitute Y-shaped impedance matching plate that acts as a monopole antenna (Fig.2). Furthermore, Y-shaped impedance matching plate is suspended above a ground plane (160 mm x 160 mm) and the antenna is fed by N-type connector (50 Ohm) located at (x_f, 0) 25 mm away from the center (0, 0). The simulated return loss of monopole antenna (Y-shaped impedance matching plate) is shown in Fig. 4.

Table 1. Optimized Antenna Dimensions (In Millimeters)

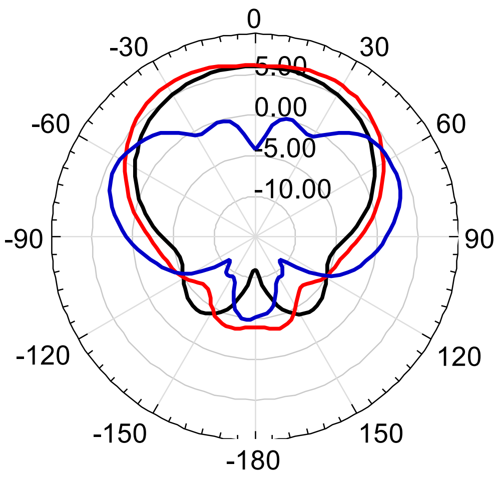
W_g	L_g	h_f	W_1	L	h_1	x_c	x_f	r	d
160	160	5.5	24	10.5	13	7	25	34	0.7

$$W_2 = 2x_c\sqrt{2r/(x_c - 1)} - 3d \tag{4}$$

The electromagnetic coupling between the radiator and the feeding plate expands radiating bandwidth and a broadband impedance matching is achieved [9-10]. In the proposed antenna (Fig. 3), the electromagnetic coupling exists between the Y-shaped impedance matching plate and hemi-circular radiator. Additionally, Y-shaped impedance matching plate excites the suspended hemi-circular radiator via air gap. Furthermore the air



(a)



(b)

Fig. 5. Radiation pattern of the proposed antenna (Black: 1.5 GHz, Red: 2.6 GHz and Blue: 4.5 GHz); (a) E-Plane, (b) H-Plane

gap between two plates of the antenna operates electromagnetic coupling. The radiation pattern of the antenna is shown in Fig. 5.

3. Transformerless Matching Network Design with RF-DCT

In this section, a transformerless bandpass matching network for Y-shaped monopole antenna is desinged as described in the first two sections. The initial values for the matching network are, lower cut-off frequency $f_1 = 1500\ MHz$ and upper cut-off frequency $f_2 = 4500\ MHz$. Furthermore, the coefficients of the auxiliary polynomial of the lowpass prototype,

$$c(x) = [4.1548 \quad 1.6864 \quad -1.8443 \quad -0.9697 \quad -1.8717 \quad -1.4960]$$

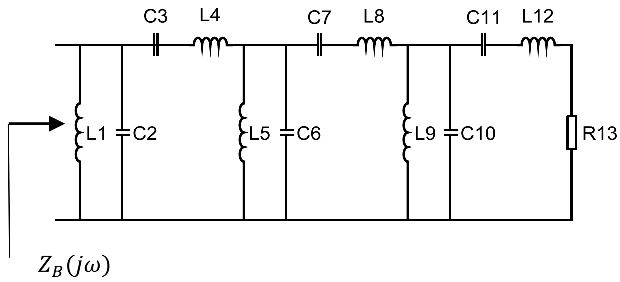


Fig. 6. Transformerless bandpass matching network schematic.

By using the coefficients above, the denominator coefficients B_i of the even part in (1) and transformed even part in (3) and the numarator and the denominator polynomials of the driving point impedance $Z_B(j\omega)$ of the 12 element matching network are computed respectively. Consequently, the matching network is synthesized according to $Z_B(j\omega)$ that depicted in

Fig. *6*6. Also, the element values of the matching network are given in Table 2.

Table 2. Element Values (inductors in nH, capacitors in pF, resistors in Ohm)

	Transformed RF-DCT	Optimized
L1	2.19	96.18
C2	1.71	1.17
C3	0.7	2.01
L4	5.38	4.1
L5	2.16	2.19
C6	1.74	1.95
C7	0.83	0.83
L8	4.52	4.71
L9	3.92	2.39
C10	1.62	1.24
C11	1.69	3.63
L12	2.2	1.03
R13	50	50

This design procedure gives the optimum element values for the specified design parameters. The second optimization by using the element values computed from RF-DCT could give better result. In this example, the second optimization is run to achieve this. As seen in Fig. *7*7, the return loss of the optimized network is better than the initial RF-DCT return loss.

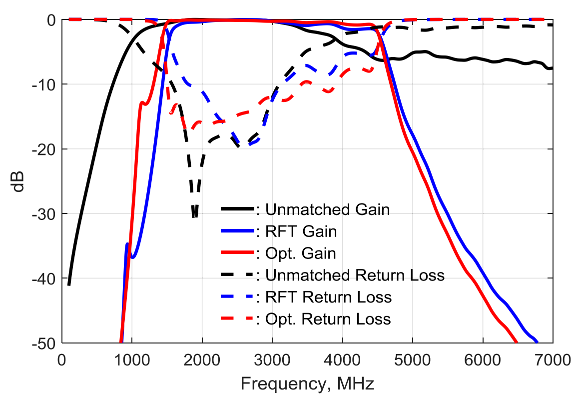


Fig. 7. TPG and return loss graphic.

4. Conclusions

In this paper, design of a transformerless bandpass matching network for Y-shaped wideband monopole antenna is presented. As described in the first section, transformerless design is investigated for 50 ohm termination since it is useless for high frequency systems. In the design procedure a MatLab code is employed based on Real Frequency Techniques. It is seen that gain performance of the system is enhanced especially at the corner of upper frequency of spectrum. Hence, a wider bandwidth is achieved by employing RFT for this structure. One can be convinced by yielded performance of the matching network for wideband, high frequency transformerless design of communication systems.

Acknowledgement

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5. References

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