Design of Active Non-Foster Circuit Matching Electrically Small Antenna

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Abstract

According to the negative impedance transformation characteristics of non-Foster circuit, the realization process of non-Foster circuit matching small antenna is studied. The operational amplifiers are used to design the negative impedance converter, and the network circuit is analyzed in combination with the characteristics of the ideal operational amplifier. Through simulation and experiment, a good match between the non-Foster circuit and the electrically small antenna in the frequency band of 10MHz to 20 MHz is realized. The results show that in the frequency band of 10MHz to 20 MHz, the input impedance of the electrically small antenna matching non-Foster circuit is matched to 50Ω; the return loss of the antenna is less than -25dB in the whole frequency band.

Keywords

Non-Foster circuit, negative impedance converter, electrically small antenna, impedance conversion.

1. Introduction

With the development of wireless mobile communication networks, wireless communication devices are rapidly developing toward miniaturization, so that electrically small antennas have been a research hotspot in the field of antenna design [1]. However, because of its structural characteristics, the electrically small antennas have large reactance and small radiation resistance. Consequently, they have very high radiation quality factors (Qs) and are difficult to match. Therefore, many scholars have attempted to use the passive matching circuit to match the electrically small antennas. But the passive matching circuit is limited by Bode-Fano constraints [2], not improving the bandwidth and gain at the same time.

This paper introduces an active non-Foster circuit, which can break through the limitation of the gain-bandwidth, then improve the impedance matching characteristics of the electrically small antennas, widen its operation bandwidth, enhance its gain.

2. Theoretical analysis of non-Foster circuit

2.1 Basic theory of non-Foster circuit

The concept of non-Foster circuit is proposed according to the reactance theory of Foster [3], which can be simply stated as: For a passive lossless one-port network, the input reactance and susceptance are both the strictly increasing function of frequency, that is, that is, the slope of its input reactance function $X(\omega)$ or the input susceptance function $B(\omega)$ is always greater than zero [3]. Obviously, in the non-Foster circuit there are:

$$\frac{\partial X}{\partial \omega} < 0, \frac{\partial B}{\partial \omega} < 0 \tag{1}$$

Therefore, the non-Foster circuit can be equivalent to a negative capacitance, a negative inductance, or their combination.

2.2 Implementation method of non-Foster circuit

The non-Foster circuit consists of a negative impedance converter and a load, and the negative impedance converter is implemented using active devices. The implementation of the negative impedance converter can be divided into two types of transistors and operational amplifiers according to the types of active devices. Because the operational amplifiers have the characteristics of high linearity, large open-loop gain, wide operating bandwidth and simple circuit, it is especially suitable for the implementation of the broadband negative-impedance converter to use the high-speed operational amplifiers. Then this paper introduces a ground-type negative-impedance converter composed of the operational amplifier [4], as shown in Fig.1.

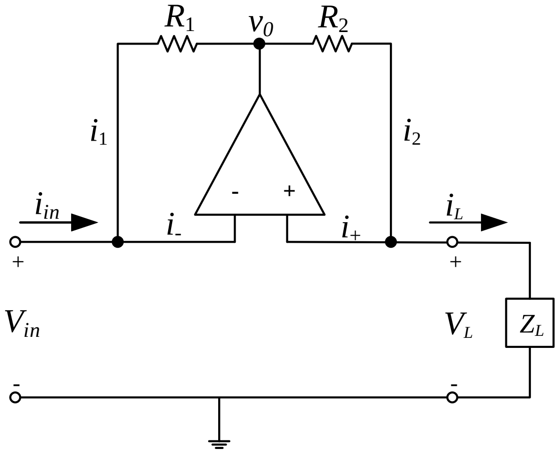


Figure.1 a ground-type negative-impedance converter based on the operational amplifier

In Fig.1, the following equations are derived based on Kirchhoff's laws and golden rules available for ideal op-amps. Namely,

$$i_+ = i_- = 0, v_0 = 0 \tag{2}$$

$$V_{in} = v_0 + V_L \tag{3}$$

$$i_{in} = i_1 = V_L / R_1 \tag{4}$$

$$i_L = i_2 = V_L / R_2 \tag{5}$$

Then,

$$i_{in} = \frac{R_2}{R_1} i_L \tag{6}$$

Therefore,

$$Z_{in} = \frac{V_{in}}{i_{in}} = (-\frac{R_1}{R_2})(-\frac{V_L}{i_L}) = -\frac{R_1}{R_2} Z_L = -KZ_L \tag{7}$$

In Eq. (7), $K=R_1/R_2$, which is the transformation coefficient of negative impedance. It can be seen clearly that the input impedance of the circuit is the opposite of the load impedance, and the desired negative impedance can be obtained by changing the transformation coefficient *K*, satisfying the theory of the non-Foster circuit.

3. The design process of non-Foster circuit matching electrically small antenna

According to the above theoretical analysis, in order to design a reliable non-Foster circuit, the working frequency band and equivalent circuit must be determined firstly. Second, an appropriate operational amplifier need to be selected as an active device for implementing a non-Foster circuit.

In order to study the operation performance of electrically small antenna in the short-wave band, the frequency range of 10 MHz to 20 MHz is selected as the frequency band of research. After the working frequency band is determined, the equivalent circuit of the electrically small antenna needs to be obtained in this frequency band. The specific process is to test the antenna by using a vector network analyzer, and save the test results of the antenna as the S1P file, and then import the S1P file into the ADS. Then, simulation results such as S11, real part and imaginary part of the antenna are obtained. According to the antenna equivalent circuit model proposed in [5] and the above simulation results, the equivalent circuit of the antenna is obtained, as shown in Fig.2.

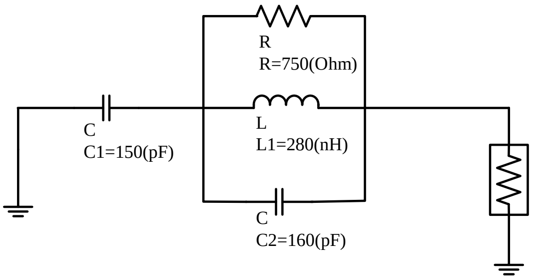
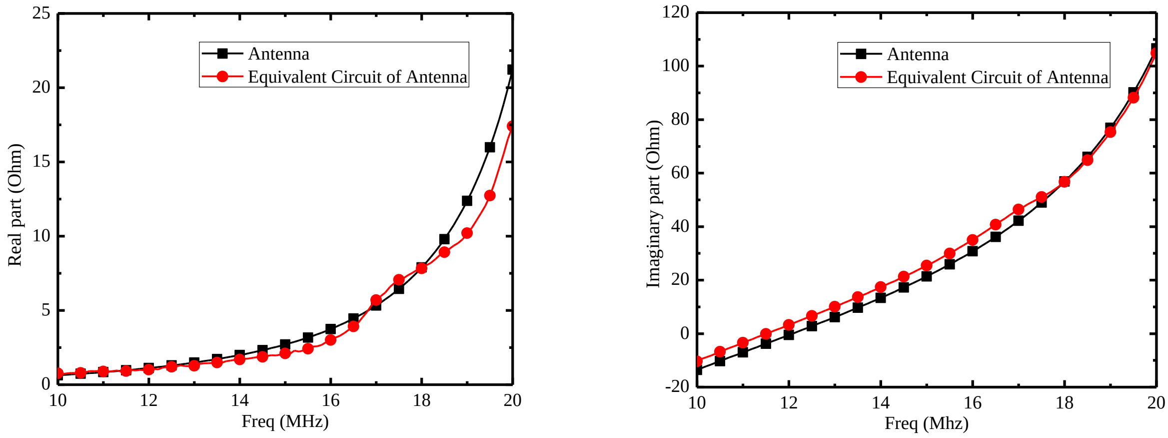


Figure.2 the equivalent circuit of the antenna

Then, the simulation results of the equivalent circuit are compared with the simulation results of the equivalent circuit, as shown in Fig.3. It can be seen from the Fig.3(a) and (b) that the degree of fitting is better, indicating that the equivalent circuit can be used to replace the actual small antenna for simulation analysis.



(a) The real part of the antenna and its equivalent circuit

(b) The imaginary part of the antenna and its equivalent circuit

Figure.3 the simulation results of the antenna and its equivalent circuit

In addition, this paper select the operational amplifier AD8009 as the active device of implementing the non-Foster circuit. Therefore, This paper designs a simulation model for the non-Foster circuit matching the electrically small antenna in the ADS, as shown in Fig.4.

According to the theoretical analysis, if the values of R1 and R2 in the Fig.4 are appropriate, the desired input impedance can be obtained. After the optimization and analysis of simulation, R1=31 Ohm and R2=30 Ohm are selected. In this simulation design, the load consists of inductor L2 and resistor R3, where L2 = 26nH and R3 = 48Ohm. The purpose of loading the inductor L2 is to convert it into a corresponding negative reactance by a negative impedance converter to cancel the reactance part of the antenna; the purpose of loading the resistor R4 is to achieve impedance matching of the input to 50 Ohm.

Then,the simulation results are shown in the Fig.5 and Fig.6. Figure.5 is the comparison of the input impedance of antenna without/with non-Foster circuit. It can be seen from the Fig.5 (a) and (b) that the reactance of antenna with non-Foster circuit is about 0 Ohm, the resistance of which is about 50 Ohm, indicating that (1) the non-Foster cancels out the reactance part of antenna to a large extent, which proves the negative impedance transformation of the non-Foster circuit; (2) the antenna with non-Foster circuit can match well with 50Ω receiver/ transmitter.

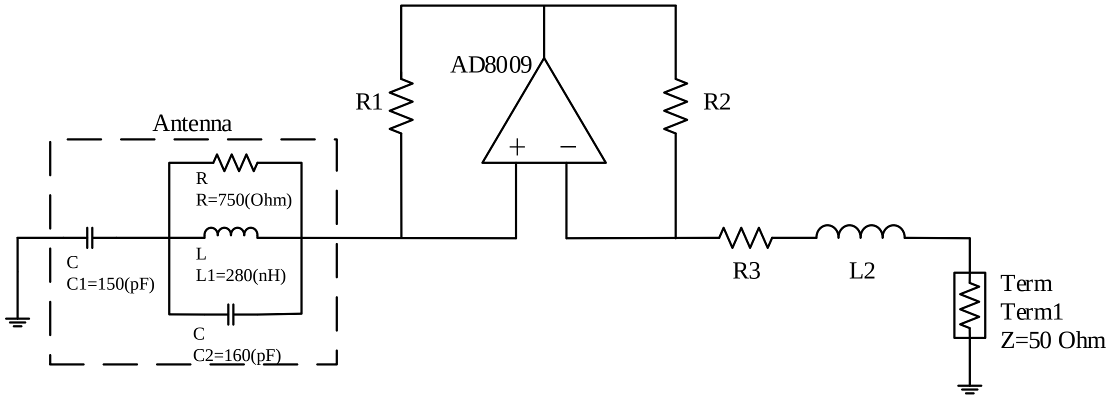
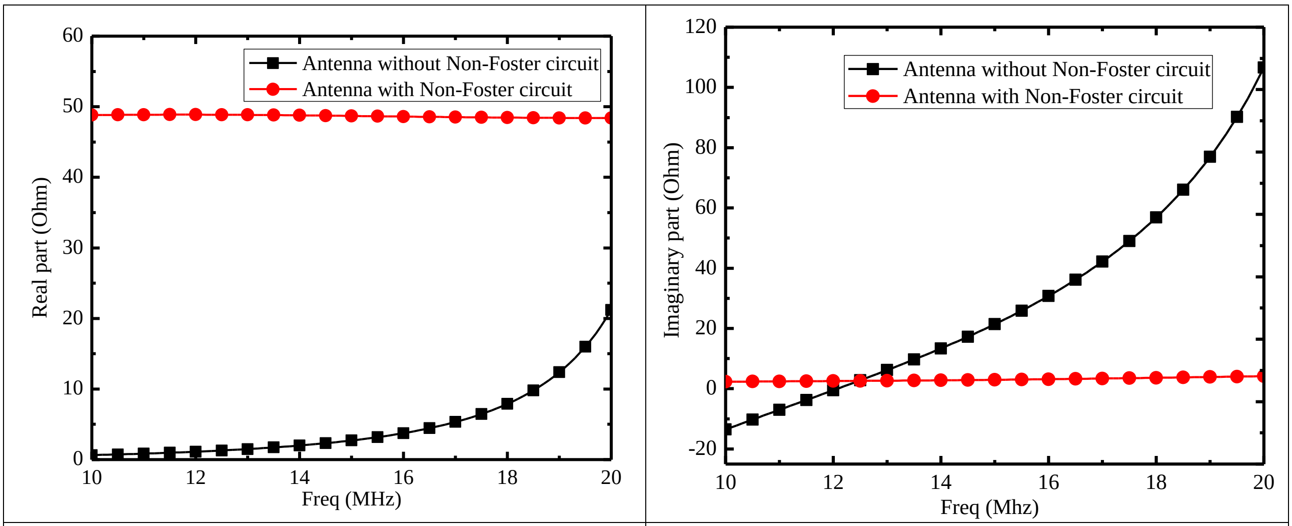


Figure.4 the simulation model



(a)Comparison of the real part (b)Comparison of the imaginary part

Figure.5 Comparison of the input impedance

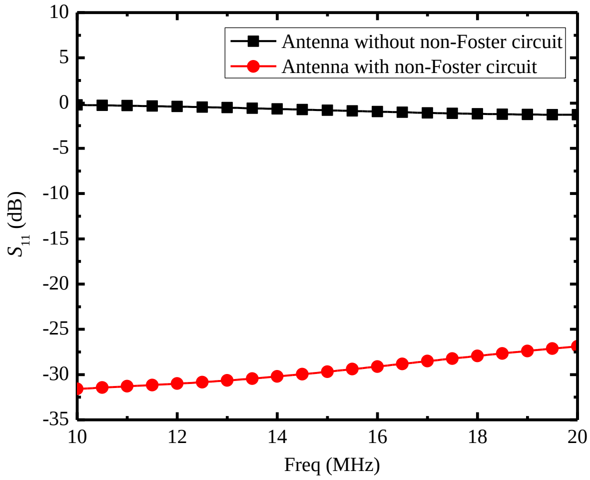


Figure.6 S11 of antenna without/with non-Foster circuit

Figure.6 is S_{11} of antenna without/with non-Foster circuit. It can be seen from the Fig.6 that in the whole frequency band (10 MHz~20 MHz), S_{11} of antenna with non-Foster circuit has been improved,which is less than -25dB, indicating that the antenna with non-Foster circuit can work well.

4. Conclusion

In the frequency band of 10MHz to 20 MHz, this paper designs an active non-Foster circuit matching the electrically small antenna in the ADS. The simulation results show that the input impedance of the electrically small antenna matching non-Foster circuit is matched to 50Ω; the return loss of the antenna is less than -25dB in the whole frequency band.Therefore, the electrically small antenna matching non-Foster circuit can work well.

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