

A Novel Antenna Feeding Network with Separately Resonant Frequency and Impedance Matching Tunable Capability

Linzhi Liu, Qianyin Xiang^{*}, Dengyao Tian, and Quanyuan Feng

Abstract—A novel *C-L-L* π -type feeding network is presented to tune the working frequency and impedance matching of antenna. Two varactors are used in the tunable feeding network as tunable elements for antenna resonating frequency and impedance matching tuning. The tunable capability of the network is studied, and a patch antenna is used to verify the tunable feeding network. The tunable feeding network is designed, fabricated and measured. The measurement results show that the patch antenna can be tuned from 630 MHz to 1.04 GHz with a maximum impedance bandwidth of 24 MHz of S_{11} less than -10 dB.

1. INTRODUCTION

Nowadays, antennas are widely used in various electronic products such as mobile devices, military and aerospace applications. Antenna is an important part in transmission and reception system, but it is difficult to achieve optimal transmission and reception effects by relying on the structure of antenna itself [1–3]. Therefore, an effective feeding network for the antenna which can make it achieve good performance is necessary [4–7]. The impedance of antenna is changed because it is easily interfered by the external environment. So, it is necessary to design a matching network which can adapt to the change of impedance and frequency [8–14]. Recently, some tunable matching networks have been proposed. A dual-band matching using a dual-band quarter-wave line is presented in [15], and a broadband UHF RFID antenna using double-tuned impedance matching is proposed in [16]. However, broadband circuit structure is complicated, difficult to design, and does not have tuning capability. The impedance matching equation is shown in Formulas (1) and (2), where BW is the maximum fractional matching bandwidth, $BW = (\omega_H - \omega_L)/\omega_0$, ω_0 is the resonant frequency, $\omega_0 = \sqrt{\omega_H\omega_L}$, and n is the tuned stages. Q_L is the load quality factor.

$$BW = \frac{1}{Q_L} \frac{1}{b_n \sinh \left[\frac{1}{a_n} \ln \left(\frac{1}{\Gamma} \right) \right] + \frac{1 - b_n}{a_n} \ln \left(\frac{1}{\Gamma} \right)} \quad (1)$$

$$Q_L = \omega_0 RC \quad (2)$$

Based on above theory, when $n = 1$, $a_n = 1$, $b_n = 1$, the fractional bandwidth about single-tuned matching is written as Formula (3); when $n = 2$, $a_n = 2$, $b_n = 2$, the fractional bandwidth about double-tuned matching is written as Formula (4).

$$BW = \frac{1}{Q_L} \frac{2\Gamma}{1 - \Gamma^2} \quad (3)$$

$$BW = \frac{1}{Q_L} \frac{2\sqrt{\Gamma}}{1 - \Gamma} \quad (4)$$

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* Corresponding author: Qianyin Xiang (qyxiang@swjtu.edu.cn).

The authors are with the School of Information Science and Technology, Southwest Jiaotong University, Chengdu 611756, China.

Above formulas show that the larger the reflection coefficient is, the larger the bandwidth is, and large bandwidth leads to poor reflection coefficient [18]. Therefore, both frequency tuning and input impedance tuning are needed for the antennas to meet the requirement of broadband operation.

In this paper, a novel antenna feeding network with resonant frequency and impedance matching tunable capability is designed. The tunable matching network is analyzed, designed, fabricated, and measured. The measurement results show that the matching network connected antenna can be tuned from 630 MHz to 1.04 GHz with a maximum impedance bandwidth of 24 MHz with S_{11} less than -10 dB. In Section 2, the basic design theory is explained. Sections 3 and 4 discuss the simulation and measurement, respectively. The conclusion is given in Section 5.

2. TUNABLE FEEDING NETWORK DESIGN

2.1. The Antenna for Tuning

To design a feeding network, the antenna must first be measured and modeled. The antenna shown in Fig. 1 is used [17]. When the antenna is touched by hand as shown in Fig. 2, its impedance changes. The vector network analyzer is used to test S parameters of the antenna. Fig. 3(a) shows S_{11} parameters from 0 to 3 GHz. Fig. 3(b) shows the input impedance in Smith chart from 600 MHz to 1.2 GHz. The red and blue lines indicate the impedance of the antenna when free space is touched by hand. The impedance values at different frequencies are shown in Table 1.

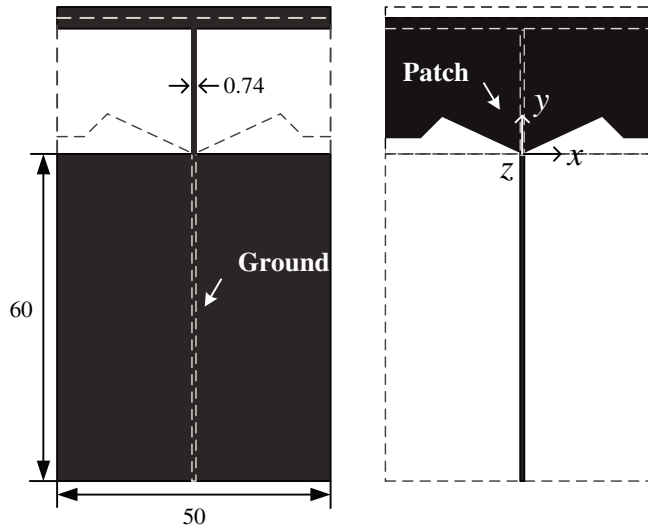


Figure 1. Geometry structure of antenna.

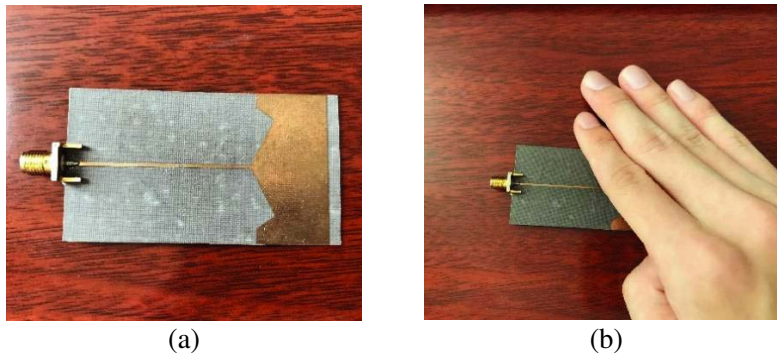


Figure 2. (a) Photo of antenna. (b) Antenna touched by hand.

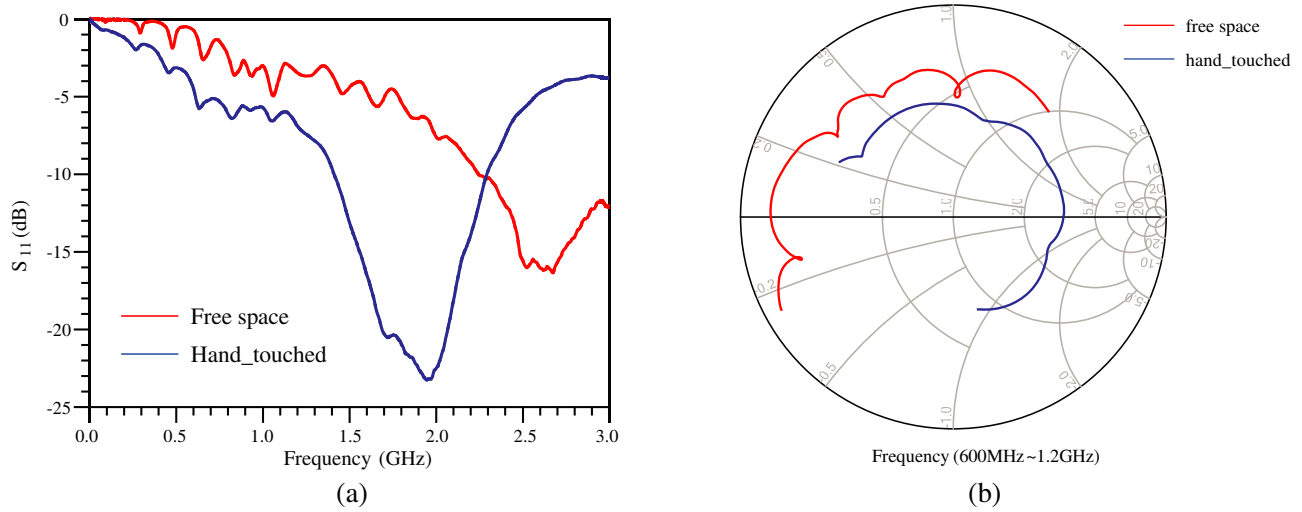


Figure 3. (a) measured S_{11} parameters of antenna, (b) input impedance for Smith chart.

Table 1. Impedance of antenna at different frequencies.

Frequency	600 MHz	800 MHz	1. GHz
impedance in freespace (Ω)	$2.2 - j12.6$	$7.5 + j13$	$14 + j39$
impedance touched by hand (Ω)	$13.4 + j10.8$	$36.7 + j46.6$	$157.4 - j0.6$

2.2. Tunable Matching Network Design

Figure 4 shows the circuit model of the proposed tunable matching network. This model is a double-tuned π -type matching network. Lumped LC elements are used in this circuit model due to the low operating frequency. L_1, L_2, C_2, C_3 constitute a $C - L - L$ π -type matching network. The circuit model contains two tunable elements, and C_1 and C_2 are two SMV varactors. Applying DC bias at both ends can change the capacitance values of C_1 and C_2 . L_1 is designed to offset C_2 capacitance value, and Z_{ant} is the equivalent impedance circuit of antenna. In this tunable matching network, L_1, L_2, C_2, C_3 and the structure of antenna itself constitute a new resonant structure. The resonant topology diagram is shown in Fig. 5, and the output impedance of matching network is shown as:

$$Z_r = \frac{1}{\frac{1}{\frac{1}{j\omega C_3} + j\omega L_1 + \frac{1}{j\omega C_2}} + \frac{1}{j\omega L_2}} \tag{5}$$

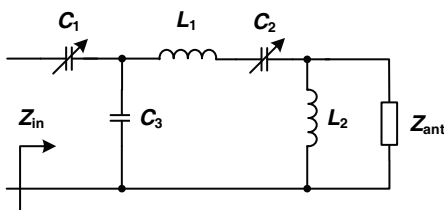


Figure 4. Circuit model of tunable matching network.

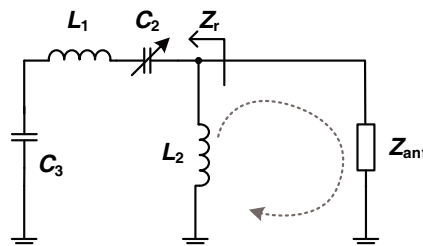


Figure 5. Resonant topology diagram.

When $\text{Im}(Z_r) = \text{Im}(Z_{ant}^*)$, the matching network works in resonant state, and the resonant point of antenna changes when the capacitance value of C_2 changes. When the matching network is connected with antenna, the overall input impedance of circuit is written as:

$$Z_{in} = \frac{1}{\frac{1}{\frac{1}{Z_{ant}} + \frac{1}{j\omega L_2}} + \frac{1}{j\omega C_2}} + j\omega C_3 + \frac{1}{j\omega C_1} \quad (6)$$

The circuit reaches zero reflection matching state when Z_{in} is 50Ω , and the input reflection coefficient is shown as:

$$S_{11} = \Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \quad (7)$$

where Z_0 is the characteristic impedance of input port, and it is 50Ω here. Fig. 6 shows S_{11} when C_1 and C_2 change at different frequencies, and the value of Z_{ant} is shown in Table 1. The capacitance values of C_1 and C_2 can be tuned to adjust the impedance. Therefore, both the working frequency and the reflection coefficient can be tuned by the proposed feeding network.

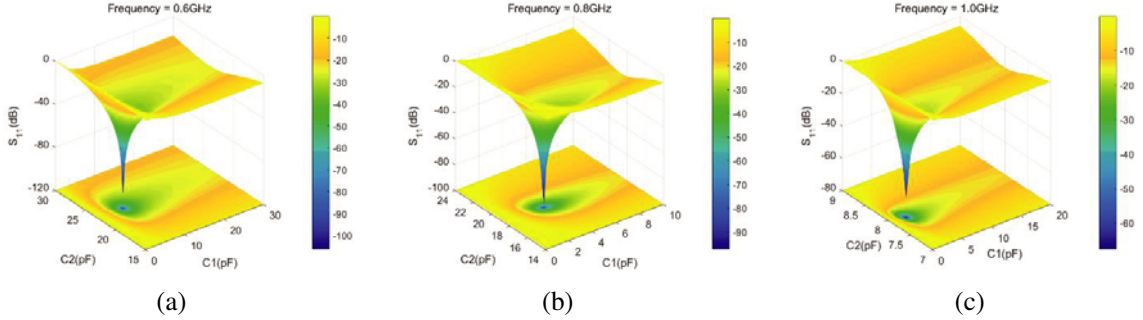


Figure 6. (a) S_{11} at the frequency of 0.6 GHz, (b) S_{11} at the frequency of 0.8 GHz, (b) S_{11} at the frequency of 1.0 GHz.

3. TUNABLE MATCHING NETWORK SIMULATION

Based on the above discussion, the tunable feeding network is designed as shown in Fig. 7. The circuit is designed on a substrate of F4B-2 ($h = 0.8$ mm, $\epsilon_r = 2.65$, $\tan \theta = 0.001$). Skyworks SMV1130 varactor diode is chosen as a tunable capacitor C_1 and C_2 , and the capacitance for single varactor diode is 27.6 pF to 1.8 pF at 0 V to 25 V reverse bias voltage. The lumped inductors and capacitors are from *Coilcraft*

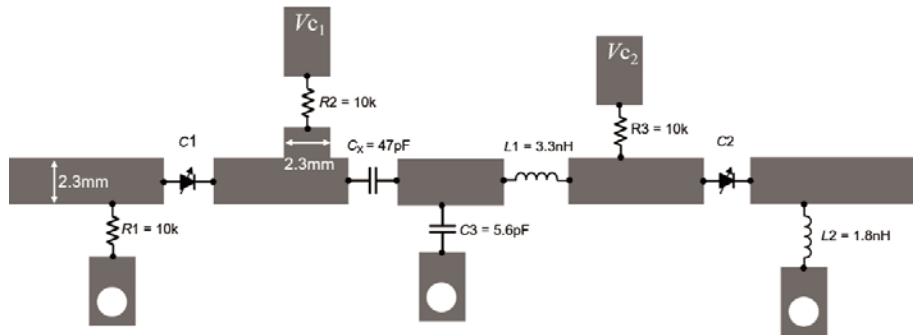


Figure 7. Layout of tunable antenna feeding network.

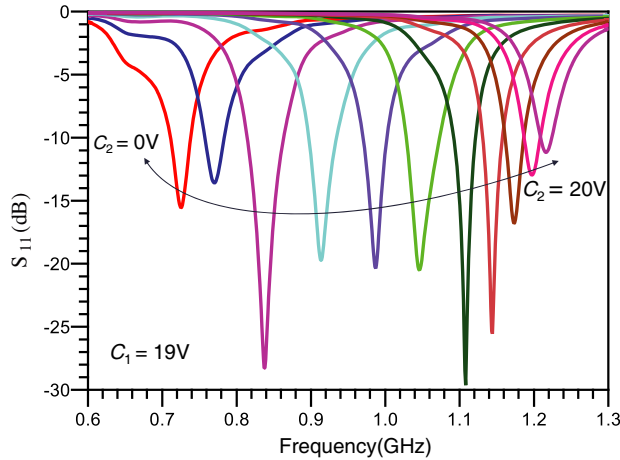


Figure 8. Simulated reflection coefficients of matching network.

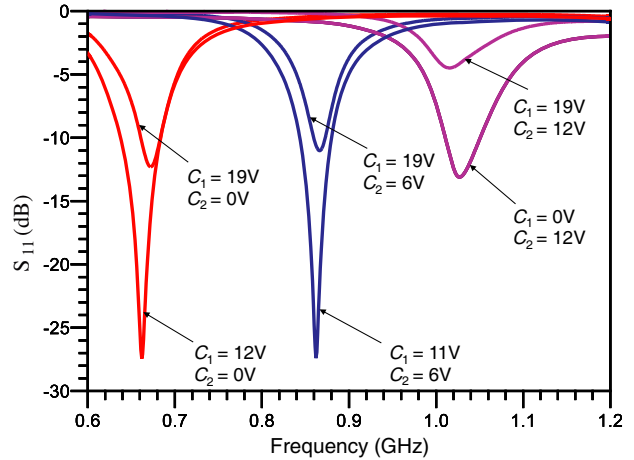


Figure 9. Simulated reflection coefficients tuned by capacitor C_2 .

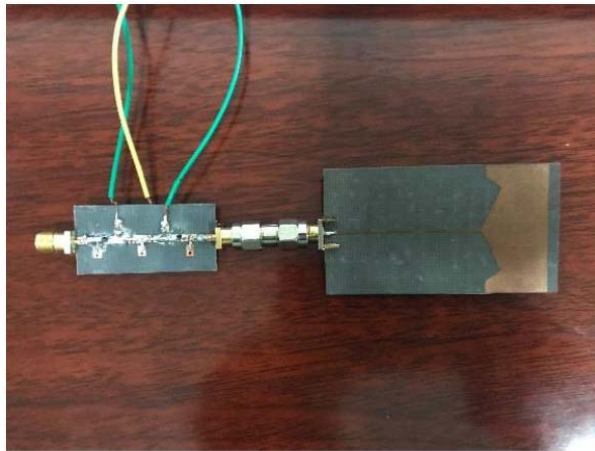


Figure 10. Fabricated feeding network with antenna.

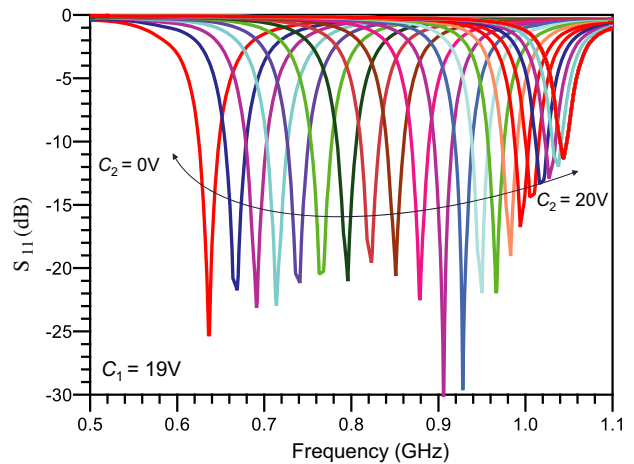


Figure 11. Measured reflection coefficients of matching network.

and *American Technical Ceramics*, and the element parameters of the designed circuit shown in Fig. 6 are: $C_3 = 5.6 \text{ pF}$, $L_1 = 3.3 \text{ nH}$, $L_2 = 1.8 \text{ nH}$, $C_X = 47 \text{ pF}$. All the lumped elements are connected by 50Ω microstrip lines.

Figure 8 shows the simulated reflection coefficients of feeding network. The bias voltage of capacitor C_1 is set to 19 V. The voltage of capacitor C_2 is tuned from 0 V to 20 V, and the center frequency tuning range is from 720 MHz to 1.21 GHz. When the antenna is touched by hand, the input impedance changes; impedance matching effect deteriorates; tuning the bias voltage of capacitor C_2 and the reflection coefficients can be optimized. Fig. 9 shows reflection coefficients when antenna is touched by hand and reflection coefficients optimized by C_2 . Simulation results show that the capacitor C_2 can adjust input impedance of antenna when external environment changes.

4. FABRICATION AND MEASUREMENT

The fabricated feeding network with antenna is shown in Fig. 10, and the feeding network size is 40 mm \times 20 mm. The reflection coefficients of the tunable feeding network are measured by Keysight E5071C vector network analyzer. The bias voltage of capacitor C_1 is tuned to 19 V, Fig. 11 shows the measured reflection coefficients of the feeding network connected antenna with the bias voltage from 0 V to 20 V

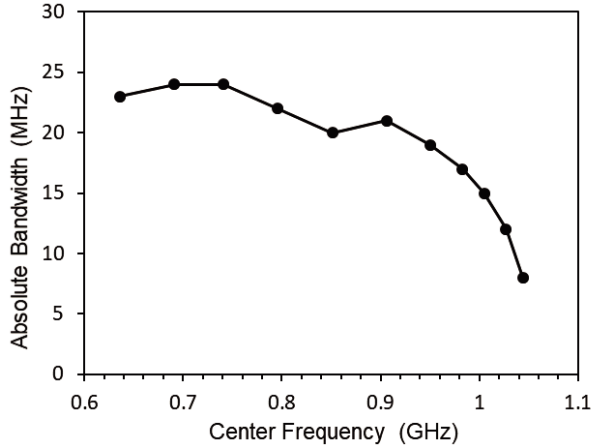


Figure 12. Absolute bandwidth of feeding network.

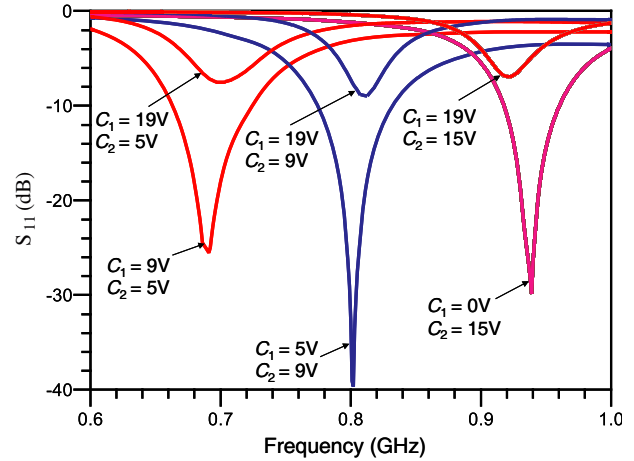


Figure 13. Measured reflection coefficients tuned by C_2 .

of C_2 . It shows that the center frequency tuning range is from 630 MHz to 1.04 GHz, and the absolute bandwidth with S_{11} less than -10 dB is about 8 MHz to 24 MHz and shown in Fig. 12.

Figure 13 shows reflection coefficients when antenna is touched by hand and reflection coefficients optimized by C_2 . It shows that the capacitor C_2 can adjust input impedance of antenna when external environment changes.

5. CONCLUSION

This paper presents a novel tunable feeding network. Two varactor diodes are used in the circuit for both working frequency and reflection coefficient tuning. A patch antenna is used to verify the tunable feeding network. The impedance of the tunable feeding network is modeled, and both frequency tuning and impedance tuning performance are studied by computer numerical calculation. The measurement results show that the feeding network connected antenna has a wide tuning range from 630 MHz to 1.04 GHz, and maximum impedance bandwidth ($S_{11} < -10$ dB) is 24 MHz. The proposed feeding network can be used in the reconfigurable RF front-end of frequency agile communication systems.

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