The design and simulation test of wireless antenna protection network

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Abstract. In this paper, a wireless antenna protection program has been designed. In the program, the TVS diode was used as the first lever for protection, and the π-type high pass filtering network as the second lever. As a result, the program not only has the traditional function of ESD protection, which can avoid the high voltage damage to the internal circuit, but also achieves the purpose of load matching, ensuring the signal source not to distort. The ADS simulation software was used to test the ability of this program for filtering and impedance matching, which proved the feasibility of this program. The wireless antenna protection network has been practically used, and its performance of anti-electromagnetic interference has been validated.

1. Introduction

Wireless Sensor Networks (WSN) are widely used in structural health monitoring, as the WSN device has the characteristics of flexible network topology, and easy for installation and maintenance. But the problem is that the antenna is easy to be damaged or affected by static electricity. The length of the antenna may reach 10 cm which makes the effects of external electromagnetic environment on antenna obvious, especially for the noise, static electricity, or thunder and lightning. This kind of electromagnetic interferences will cause great damage and even destructions once they get into the inside of WSN. Therefore, it is very important to take appropriate protective measures in engineering design, and to improve the anti-interference ability of the antenna, which has become the focus of engineering research [1].

The rapid change in strong magnetic field can be caused by electrostatic discharge and lightning induction, which would produce a high electric potential when the antenna of the WSN is close to the strong magnetic field. Experiment shows that the magnetic field generated by a 10 kV electrostatic spark discharge at 5 cm, is almost the same order of magnitude as the magnetic field generated by lightning induction in tens of meters. But the rising edge is much steeper in electrostatic discharge than that in lightning induction [7-8].

In this paper, a wireless antenna protection system with two levels has been designed. And the ADS simulation software was used to test the ability of this program for filtering and impedance matching, which proved the feasibility of this system.

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2. Protection system design

2.1. Formatting the title Wireless antenna protection system design

In the design of wireless antenna protection, the common measure is to placement electrostatic suppression absorbers, such as discharge tube, varistors or transient voltage suppressor (TVS), which can prevent the destructive current and surge caused by electromagnetic pulse. TVS has the advantages with high corresponding speed, low junction capacitance [2-3].

The ESD0P2RF TVS diode was selected as the first level protection system device, which could adaptation to 2.4 G frequency protection circuit. The maximum compliance voltage of this TVS is 38 V, with maximum current as 40 A, and the inter-electrode capacitance as 200 nF.

![Figure 1. IEC61000-4-2 VCL = f(t), 15 kV positiv pulse from pin 1 to pin 2.](image)

Figure 1 shows the result of IEC61000-4-2 electrostatic discharge immunity test for the TVS diode. The gray part in the figure 1 is standing for the range of withstand voltage of the wireless node. From the discharge waveform, it can be seen that the TVS clamped the voltage between electrodes in 162 V within 3 ns. After 70 ns the voltage was clamped in the safety range (the gray part). As the result, the second level protection system is needed for clamping the impulse voltage in the safe range instantaneously.

The second level protection system has to not only realize the function of instantaneous electromagnetic protection, but also ensure the impedance matching of the load and the source [4]. The common method to ensure the impedance matching is to insert passive matching network between the source and the load. The π-type network is selected in this program, because the bandwidth of π-type is much wider without a blind area. At the same time, the π-type network can also be used as high pass filter.

2.2. Protection circuit design

![Figure 2. The design of antenna protection system.](image)
Figure 2 shows the design of antenna protection system, in which D3 is the first level protection system device where TVS is used. C1 acts as a bypass capacitor, which can provide a low impedance pathway for 1 GHz electromagnetic pulse. The resonant circuit is composed of L1 and C1, which serves as a parallel frequency selection LC network. The second level is consisted of L2, C2 and L3, which can form the π-type matching network. The main function of this network is to filter out any signals whose frequency is less than 1 GHz, while the frequency of lightning and electrostatic discharge are within the filtered range [5]. Once the frequency of input signal is equal to the resonant frequency of the circuit, the resonance will occur in the parallel frequency selection LC network. The resonant frequency $f_0$ can be expressed as:

$$f_0 = \frac{1}{2\pi \sqrt{LC}}$$ (1)

In this formula, the carrier centre frequency $f_0$ is 2.4 GHz. The value of the bypass capacitor $C1=1/f$, in which $f$ means the frequency of interference signal. In this system, $f=1$ GHz, and $C1=1.0$ pF. The ESD0P2RF TVS diode can be equivalent to a capacitor of 200 nF in the impedance measurement. Therefore, $L1$ can be calculated as 3.6 nH.

The π-type network, which acts as the second level protection system, can be calculated by K-type 3 order normalized high-pass filter model. The calculation formulas of capacitance and inductance are as follow:

$$L = \frac{R}{2\pi f_c}$$ (2)

$$C = \frac{0.5}{2\pi f_c R} = \frac{1}{4\pi f_c R}$$ (3)

$$\Rightarrow LC = \frac{1}{8(f_c')^2}$$ (4)

In the formula $C$ is the series capacitor; $L$ is parallel inductance; $R$ is the resistor between both sides; and $f_c$ is cutoff frequency.

The value of resistance capacitance in the π-type matching network can be easily calculated by using the graphic method with Simth chart [9]. First of all, the load impedance $Z=R+jX$ should be normalized with feeder impedance $W$. Normalized impedance is represented by $z=Z/W = r+jx$. Secondly, two important circles should be drawn up in the chart. As shown in the figure 3, one is the normalized impedance-admittance circle and the other is the $r=1$ circle in the circles group.

**Figure 3.** Simth chart.
In this π-type matching network, the impedances of the two sides are 50 Ω, and the normalized impedance $z=Z/W=1$. The point express for the characteristic impedance in the chart is the center point of $z=1$. The point of load impedance must be on the admittance circle after parallel connection with the inductance $L_1$, marked as A. The r circle which across point A has the other node with the normalized impedance admittance circle marked as B. Only if the point of load impedance reaches point B after series connection with the capacitor $C_1$, it could return back to the center point after parallel connection with the inductance $L_2$. This allows the point of the load impedance in the same place with the characteristic impedance, which means that they match each other.

The coordinate values of x for A and B point in the chart are $\pm [r(1-r)]^{1/2}$, and the impedance of A is $z = r + [r(1-r)]^{1/2} j$.

The admittance point which is the center of symmetry point for A, is marked as $A'$. This point is on the circumference of the $r=1$ circle. The real part of $A'$ can be calculated as $g=1$, and the imaginary part as $b = \left(\frac{1-r}{r}\right)^{1/2}$. Set $A'=1-aj$, and $a = \frac{1-r}{r}$. The relationship of $a$ and $r$ can be found:

$$\frac{1}{r} = (1 + a^2)^{-1};$$

By calculating the reciprocal of $A'$, the value of point A can be found out: $z = (1 + a^2)^{-1} + \frac{a}{1+a^2} j$

Then calculating the values of x for A and B point:

$$x = \pm [r(1-r)]^{1/2} = \pm \left[\frac{1}{1+a^2} \left(1 - \frac{1}{1+a^2}\right)\right]^{1/2} = \pm \frac{a}{1+a^2}$$

$$\Delta x = \frac{a}{1+a^2} - \left(\frac{a}{1+a^2}\right)^2 = \frac{2a}{1+a^2}$$

$$X = \Delta x * W = \frac{2a}{1+a^2} \cdot W = \frac{1}{\omega C}$$

$$\Rightarrow C = \frac{1}{X \cdot 2\pi f_0} = \frac{1+a^2}{4aW\pi f_0}$$

(5)

Then calculating the values for $A'$

$$\Delta b = a \quad B = \frac{a}{W} \quad B = \frac{1}{\omega L}$$

$$\Rightarrow L = \frac{1}{B \cdot 2\pi f_0} = \frac{W}{2a\pi f_0}$$

(6)

According to the formulas of 5 and 6, it can be found that:

$$\Rightarrow LC = \frac{1}{(\pi f_0)^2} \cdot \frac{1+a^2}{8a^2}$$

(7)

In order to filter out the disturbance of impulse voltage with frequency less than 2.4 GHz, the value of $f_c$ must in the range of $1 \text{ GHz} < f_c < 2.4 \text{ GHz}$. According to the formula 4 and 7, the value of $a$ is $a > 0.21$.

Considering the attenuation characteristics of wave filtering and the specifications of the components, we choose the cutoff frequency $f_c$ as 1.6 GHz. The other parameters can be obtained by calculation:

$$a=0.89 \quad C_2=1.3 \text{ pF} \quad L_2=L_3=3.7 \text{ nH}$$

Figure 3 can be simplified as the figure 4 by combining L2 and L1, which is the final design plan.
3. ADS software simulation test

The ADS simulation software was used to test the ability of this program for filtering and impedance matching [10-11]. Set the input voltage curve according to the discharge waveform in figure 1, and use the oscilloscope to display the output voltage curve that after the effect of the antenna protection system. The simulation results are shown in figure 5.

![Figure 5. IEC61000-4-2 VCL = f(t), 15 kV positive pulse.](image)

From the figure 5 we can see that, through the first level protection system, the high voltage of 15 kV is limited and the peak voltage reduced to 162 V. The peak voltage entered the RF antenna was decreased to only 17 V through the second level protection system. This voltage is quite safe for the internal circuit. As the result, this wireless antenna protection system can achieve the purpose of protect the RF antenna circuit against the strong electromagnetic pulse and induction lightning.

![Figure 6. Test of S parameter. (a) Smith chart; (b) S11 S21.](image)

The matching function of the protection system is also be tested by using the ADS simulation software. Set the scan frequency as 0.3 GHz to 4.5 GHz, and the trajectory graph is shown in figure
6(b) with S(1,1) and S(2,1). The frequency bandwidth which meet the requirements with insertion loss S21 > -1dB and echo loss S11 < -10dB is 1.8 GHz~3.7 GHz. This reaches the actual application requirement [6].

The function of the antenna protection network has also been tested in the actual experiment. According to the IEC1000-4-2 standard, the performance test of the protection system was carried out at the experimental environment of temperature of 25. 0 ℃ and humidity of 50%. The experimental subjects are working wireless nodes, with the antenna of 12 cm in length. The wireless nodes is supplied by battery, and communicated every second.

In the first kind of iterative experiment, the electrostatic discharge simulator was used to indirect discharge on vertical coupling plate, and the wireless node was irradiated by the electromagnetic pulse caused by Electro-Static Discharge (ESD). The voltage in the experiment was increased from low to high, and the maximum is 15 kV. The communication performance of the wireless nodes was tested after each experiment, and the results show that the wireless nodes work normally.

In the second kind of iterative experiment, the electrostatic discharge simulator was used to contact discharge on the antenna of the wireless node. The voltage in the experiment was increased from low to high, and the maximum is 15 KV. The experimental condition was similar to that in indirect discharge, the wireless nodes work normally, too.

4. Conclusion
In this paper, a wireless antenna protection system has been designed. In the system, the TVS diode was used as the first lever for protection, and the π-type high pass filtering network as the second lever. As a result, the system not only has the traditional function of ESD protection, which can avoid the high voltage damage to the internal circuit, but also achieve the purpose of load matching, ensuring the signal source not to distort.

The ADS simulation software was used to test the ability of this system for filtering and impedance matching, which proved the feasibility of this system. The wireless antenna protection system has been practically used, and its’ performance of anti-electromagnetic interference has been validated.

References
[1] Siden J, Jonsson P and Olsson T 2001 IEEE Catalog Number 01EX484 371
[2] Albert W 2002 On-Chip ESD protection for integrated circuits (Kluwer Boston)
[3] Chen G, Feng H, Xie H, Zhan R, Wu Q, Guan X, Wang A, Takasuka K, Tamura S, Wang Z, and Zhang C 2004 IEEE RFIC Symp. 379
[4] Behzad R 2001 Design of analog CMOS interated circuit (The McGraw-Hill Companies)
[5] Georgiadis A 2007 Design of a 2.4 GHz Radio Transceiver for High Speed Wireless Data Networks
[6] Young J K, Bolme G and Lyles J 2007 IEEE Particle Accelerator Conference 2412
[7] Huang J S 1999 IEEE-IM, AUTOTESTCON’99 Aug.30-Sep.2(San Antonio)
[8] Greason W D 2008 J. Electrostat. 66 602
[9] Reinhold L and Bretchko P 2000 Rf Circuit Design: Theory and Applications (Prentice Hall)
[10] Finkenzeller K 2004 RFID Handbook: “Radio-Frequency Identifyaion Fundamentals and Applications” (Wiley)
[11] Li X P, Liu Y and Cao H Y 2006 J. Beijing University of Posts and Telecommunications 29 75