Hai-Tao CHEN*, Hao HU

# Simulating the Time-Domain Response for Monopole Antennas Excited by DC Voltage Source

**Abstract:** When a monopole antenna is connected to or disconnected from a DC voltage source, the process of charge and discharge takes place. The time-domain response for the charge and discharge process is investigated by the finite difference time domain (FDTD) method in this paper. It is shown that a damping oscillation can be excited in the instant when the DC source is turn on or shunt off. By using FFT to analyze the time-domain response oscillation waveform, harmonic modes are observed and some parameters of the antenna, such as resonant frequency, impedance, can be obtained. It is indicated that the time-domain response of the charge and discharge process can be used to measure some parameters of antennas.

**Keywords:** antenna, time-domain response, FDTD

## 1 Introduction

Monopole antennas are widely used as transmitting antennas for high power HF and MF band wireless transmitting systems[ 1,2]. The whip antenna, vertical cage antenna, invert L antenna, T-shape antenna and MF tower antenna, which are very common in communication and broadcast system, can all be seen as a monopole antenna. The performance of the monopole antenna has been investigated so much in the frequency domain, including input impedance, radiation efficiency and broadband. This is because the harmonic source is used so far and wide in radio engineering. With the development of wireless technology, the time-domain performance of antennas has come to be of interest more and more, and there is a great deal of literature discussing this problem [3-6]. In the published research results, however, most focus on the response of antennas for the time-pulse signal.

In this paper, another type of time-domain problem for antennas is studied. What is concerned here is the time response of antennas in the instant when excited sources are open or shunt off. This time response can be named as the charge and discharge process of antennas, as the similar process of capacitors. Since high resonance modes can exist in antennas, the charge and discharge process will excite higher frequency signal which can be radiated to space by antennas. For a high power radio transmitting

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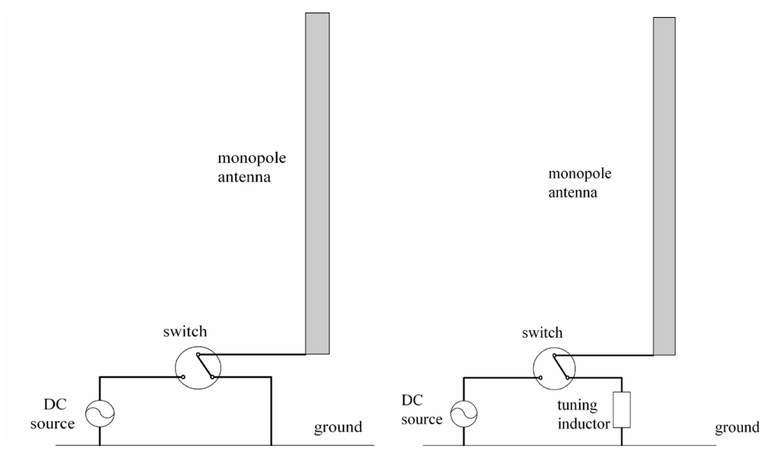
system, the effect of this high frequency mode on electromagnetic environment may be notable and should be taken into account by transmitting system designers.

The charge and discharge response of a monopole antenna excited with DC voltage source is analyzed in this paper. A FDTD code is developed to model the charge and discharge process in the instant when the DC voltage source is turned on or shunt off.

## 2 Theoretical model

Considering the charge and discharge process of a monopole antenna excited by DC voltage source shown in Figure 1. Two type of discharge are considered. In Figure 1a, the feed point of the antenna can be connected to the voltage source or the ground by the switch. When the antenna is connected to the source, a charge process is takes place due to the distributed capacitive of the antenna. As a result, there will be electric charge distribution along the antenna. Then, if the switch is connected to the ground, the electric charge stored along the antenna will flow to the ground, which is known as a discharge process. In fact, a monopole antenna working in lower frequency is always matched with a tuning inductor to the transmitter. So another type of discharge is considered in Figure 1b, in which the antenna is connected to the ground by a tuning inductor.




(a) discharge to the ground directly (b) discharge to the ground through the tuning inductor

**Figure 1.** The charge and discharge process of the monopole antenna.

The time performance of the antenna is suitable to be simulated by FDTD method [7,8]. The loss which will occur when the antenna current returns through the ground is one of the important factors that effects the performance of the antenna, especially for the antennas which work on a lower frequency. Modeling the effect of the real ground exactly is very difficult and is not the key point of our research. So the monopole is considered located on the PEC ground and a lumped loaded resistance at feed point is used to represent the losses of the real ground.

## 3 Numerical results and analysis

The charge and discharge performance in time domain is calculated for a whip antenna which height is 19m and radius is 50mm. The ground loss resistance is 10Ω, and the voltage of the DC source is 1V.

A FDTD code is developed in this work and used to model the time domain response of the monopole antenna. The charge process is shown in Figure 2. It can be seen that the time damping oscillation is excited in the charge process. Due to the loss caused by radiation and ground resistance, the charge oscillation waveform is dampens. Because of the existence of high modes, the oscillation waveform is very complex. In Figure 2, it is observed that the effect of the higher mode is more distinct in the first and second waveforms while the waveforms are approach to the sinusoidal wave with the lapse of time. It can be explained that the total resistance of the antenna increases with the increase of the frequency, and the attenuation of the higher mode is faster than the lower mode.

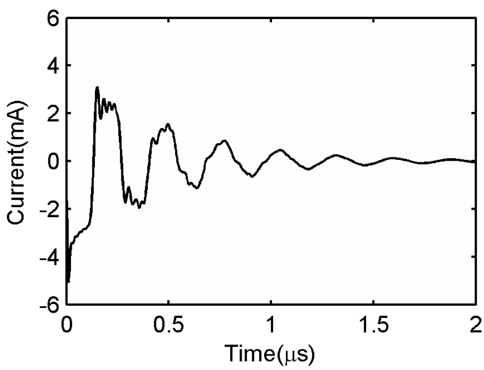



**Figure 2.** Oscillation wave of the charge process for the antenna.

When the Fourier transform to the time oscillation, the spectrum response of the charge can be obtained. The FFT result for the Figure 2 is shown in Figure 3. It can be seen that the first three resonant frequencies are 3.6MHz, 11.2MHz and 18.7MHz, which correspond to the 1st, 3rd and 5th resonant modes respectively. And with the increase of the number of order, the high frequency components decrease progressively. To antennas, the 2nd, 4th and 6th modes belong to the parallel resonant mode of which resistance is very large. So the signal of even modes is suppressed and can not be observed.

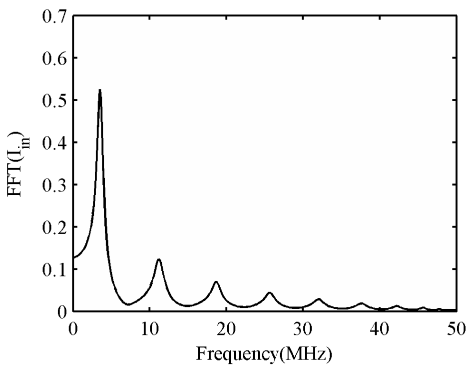



**Figure 3.** Spectrum of the charge process for the antenna

The discharge process of the antenna which is connected to the ground directly is shown in Figure 4. It is obvious that the discharge oscillation waveform is antipode of the charge oscillation waveform shown in Figure 2.

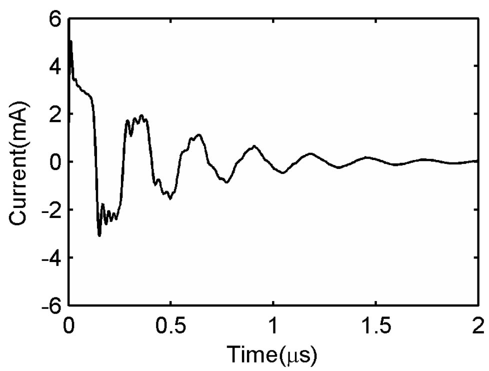



**Figure 4.** Oscillation wave of the discharge process for the antenna

The discharge process of the antenna which is connected to the ground by the tuning helix is shown in Figure 5, where the inductor L is 6μH. It can be seen that the high order modes are decreased much due to the filtering of the tuning coil. The waveform approaches a sinusoidal wave. The FFT result of Figure 5 is shown in Figure 6, in which only the 1st and 3rd resonant modes can be observed and the magnitude of the 3rd mode is much less than the magnitude of the 1st dominant mode. After loaded with the tuning inductor, the antenna's first resonant frequency is 2.9MHz. The reactance of the 6μH inductor at this frequency is 109.3Ω, which indicates that the input reactance of the antenna is equal to 109.3Ω at 2.9MHz.

According to the simulated results of EM software FEKO, the whip antenna shown in figure1 has a self-resonant at 3.7MHz and the input reactance at 2.9MHz is about to 120Ω, which are approach to the analysis results 3.6MHz and 109.3Ω from the charge and discharge oscillation waveform respectively. The difference of the results between FEKO and our analysis can be attributed to the difference between the FEKO (MoM) and FDTD method.

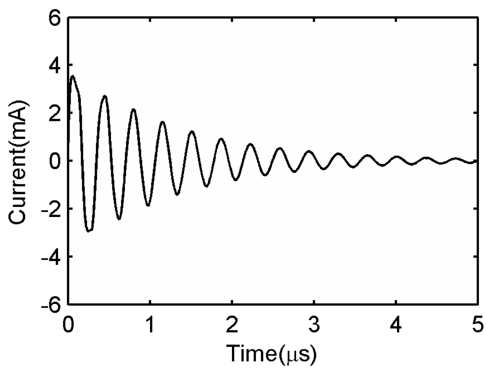



**Figure 5.** Oscillation wave of the discharge process for the antenna connected to the ground by tuning coil.

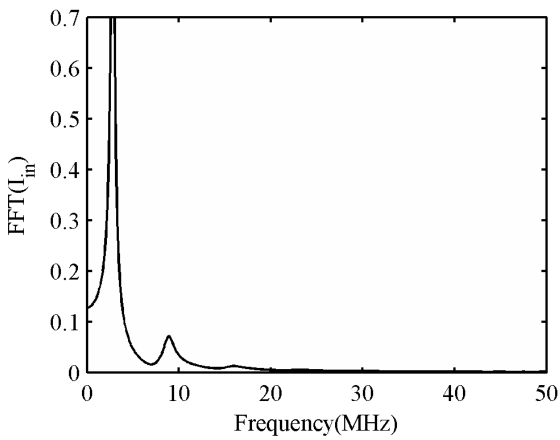



**Figure 6.** Spectrum of the discharge process for the antenna connected to the ground by tuning coil.

## 4 Discussion

The time domain waveform of input current for the monopole antenna excited by DC voltage source has been presented in this paper. And the charge and discharge process can be observed from the waveform, which is in accordance with the expectations. Based on the research of the charge and discharge process of the monopole antenna, two problems should be given attention. The first problem is the effect of the higher modes of the high power transmitting antenna when the transmitter is turned on or shunt off. For constructing a high power broadcast transmitting station, the level of high mode harmonic components is an important parameter and should be reduced as far as possible to reduce the disturbance to the other wireless signals. According to the analysis of this paper, however, the high modes will still be excited strongly even if the technique of suppressing high modes is utilized in transmitter. The duration of high modes depends on the working frequency and Q value of the antenna. The effect of high modes on the electromagnetic environment will not to be neglected for the antenna with very high power, low frequency and high Q value.

Another interesting problem is that the impedance parameters of the antenna may be measured from the charge and discharge oscillation waveform. Although the vector network analyzer (VNA) has been widely used in antenna measurement, the measurement for huge-scale antennas, however, is still difficult because of the high induced voltage on the antenna. Usually, the induced voltage on the very low frequency (VLF) transmitted antenna, such as the Cutler antenna of the U.S. Navy, can exceed 1000V or even more [9,10]. The high induced voltages will breakdown those costly RF instruments if they are connected to the antenna. According to the results of our research, the impedance and resonant frequency can be obtained from the discharge waveform of the antenna. And a high voltage DC source can be adopted to overcome the disturbance of the high induced voltage on the antenna. So it's workable to use a variable tuning inductor to measure the antenna's impedance at different frequency by recording the discharge time oscillation waveform.

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