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# Theoretical analysis and simulation for avoiding antenna oscillations without distributed resistance

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ABSTRACT

The so-called Wu and King antenna pattern is widely used in GPR because of its simple design and construction features. The main disadvantage is its limited efficiency due to transmitter energy losses which occur through lumped resistors. Based on the analysis of the electromagnetic field behaviour across the antenna, it is possible to replace the effect of the resistors by either storing the energy of the electric pulses, or damp them by means of one matched resistor, which will theoretically improve the efficiency of the antenna. In this paper we provide a theoretical analysis using a modified transmission line model together with simulation based on delayed potentials among other electromagnetic software, and measurement results using an impulse transmitter with fast MOSFET switches and a matched resistor that support this idea.



## 1. Introduction

The task of an impulse radar antenna, as is true for any antenna, is to transfer the energy delivered by the transmitter into the target medium in the most efficient way. Based on electromagnetic theory, this can be done with a simple dipole, which has the limitation that it works best only for narrow band signals.

In order to radiate a broad band signal efficiently, it is necessary to modify the dipole antenna. This has been traditionally done by means of a lumped resistive pattern based on a logarithmic model, derived originally by Wu and King (1965). The antenna resistors gradually reduce the energy of the positive and negative electric pulses, as they progress from the centre of the dipole to its ends. The underlying idea is to let the pulses reach the outer part of the dipoles with minimal energy, allowing to radiate only one or one and a half monocycles.

If the goal of radiating only one or one and a half monocycle can be achieved by another means, which can minimize energy losses and simplify the antenna design, this will result as well in a large improvement of the efficiency of the radar system. This paper proposes a theoretical approach based on several simulation algorithms and some basic measurements that allow the removal of the resistors without adding extra ringing.

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## 2. Analysis of a simple dipole antenna with no resistors

A dipole can be considered as a modified transmission line, which retains the physical behaviour of the antenna. The transmission line equations (Eq. (1)) correspond to the one-dimensional wave equation, meaning that any waveform inserted into the inner terminals (at $z = z_1$) will then propagate through the line toward the outer terminals, with a speed given as a function of the intrinsic parameters of the line:

$$\frac{\partial^2}{\partial z^2}X(z,t) = LC\frac{\partial^2}{\partial t^2}X(z,t), \tag{1}$$

where $X(z,t) = V(z,t)$ or $I(z,t)$ are the voltage or current waveforms developed in the line, and $L$ and $C$ are the distributed inductance and capacitance parameters, respectively. In this case both intrinsic parameters $L$ and $C$ are normally constant along the line.

As shown in Fig. 1, together with the voltage and current travelling waves, an electric field signal – also a magnetic signal, not shown – $\bar{E}(z,t)$ propagates as well, which is indeed the real physical entity together with the electric charges that travels along the antenna at the same speed, which is a function of the intrinsic parameters.

This electric field, in this case extending perpendicular to the transmission lines, is the crucial phenomenon when analysing the dipole as a transmission line with open arms. Not considering the natural losses associated to the ohmnic impedance of the line cables, but taking into account the constant distance between these lines, it can be assumed that the shape and energy of the signals remain constant. Thus the electric and magnetic fields generated between the electric charges do not change within the transmission line.

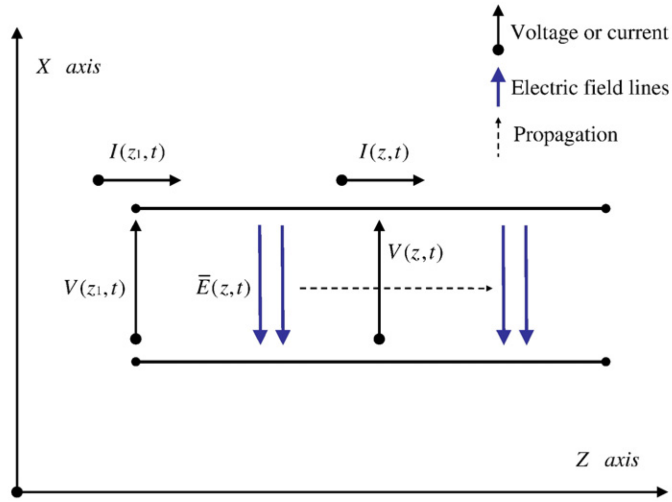


**Fig. 1.** Signals in a normal transmission line.

This effect is no longer valid in a dipole, simply because the distance between the charges is continuously changing, demanding continuous delivery of energy to expand the electromagnetic field, energy which is taken from the kinetic energy of the charges. This physical effect can be mathematically expressed through the non-constant intrinsic parameters of the distributed capacitance $C(z)$ and inductance $L(z)$ (see Eq. (2) and Fig. 2), where $E(r,t)$ is now a function of the spatial vector $\bar{r}=(x,z)$.

$$\frac{\partial^2}{\partial z^2}X(z,t) = L(z)C(z)\frac{\partial^2}{\partial t^2}X(z,t) \qquad (2)$$

Based on the transmission line model, and taking into account that the speed of the electric field lines in a nearly perfect electric conductor is comparable to the speed of light in free space, and assuming that the transmitter has a high conductivity, the following temporal sequence (Fig. 3a, b, c and d) shows how the electric field should propagate around an antenna without lumped resistors.

A simulation, based on an electromagnetic software, was run to confirm the expected physical behaviour. A wire dipole located in free space, and excited by a pulsed voltage was tested. Fig. 4 (a, b, c, and d) shows the results, which closely agree with the transmission line model.

The outer ends of the dipoles act as an open circuit and the inner ends act as a closed one. According to transmission line theory, both ends react as perfect reflectors, as it can be seen in Figs. 3 and 4. The outer ends reflect the signal without changing the sign, and due to low voltage source impedance the inner ends reflect the signal changing its polarity. This behaviour implies a high level of oscillation, and the decay observed in real antennae is attributable to the ohmnic losses and the energy delivered to propagate the electromagnetic field.

For GPR antennae it is common to locate the pulse circuit at the dipole centre, so the distance between the generation and the feeding point is not significant for our analysis. This condition was adopted in our simulations and implemented in our measurements.

## 3. The Wu and King antenna

Based on the physical behaviour of the dipole with no resistors, we can analyse the electric field of a Wu and King (1965) antenna in a qualitative manner.

Any Wu and King antenna or a derived one rely their design on a resistively lumped pattern following a logarithmic curve. The core idea is to diminish the energy of the electric pulses, decreasing thus the electric current density so no further reflections will occur, accepting no more than one or one and a half monocycles, depending on the environment and the specific application requirements.

As Kappen and Mönich (1987) illustrate, charge pulses start losing energy while they are travelling through the arms of the antenna, presenting an evident dispersion effect smeared over the antenna's length, affecting the second half of the first monocycle, resulting in a non-symmetrical cycle. Therefore the electric charges return to the inner ends of the antenna with very low energy, through a recombination process and producing no new reflections. Most of all the lost energy is dissipated into the resistors by means of heat. Thus the Wu and King antennae have a relatively low efficiency.

As could be seen from the former section, the electric field lines, as electrostatic theory claims, start attached to the electric charges. While the charge pulses travel outward within the antenna, the electric field spreads outwards through the surrounding space, describing a circular curve pattern in a planar representation or a spherical shape in space. After these charges reflect at the outer ends of the dipoles and start travelling to the inner ends, the electric field lines cannot immediately follow the charges, which now are moving in an opposite direction behind the lines, at an almost similar speed, describing an umbrella-shaped curve. Finally, when both charge pulses with opposite polarity meet at the centre of the antenna, a zero net charge is produced, forcing the extended electric field lines to close onto themselves and detaching from the sources. At this very moment an electromagnetic field is radiated.

After the charges meet at the centre of the antenna, they cross the transmitter due to its low impedance, exiting into the other arm of the dipole, which can be understood as a reflection with polarity change. This new charge departure is the beginning of a new monocycle that will follow the first one already generated.

The core idea in implementing a dipole antenna with no resistors is that if it is possible, by some means, to capture this electric charge which represents electric energy, thus avoiding the new charge departure from the inner part of the antenna, the extra oscillations will be cancelled. Moreover, if this electric charge could be reused in the following radiation process, the overall efficiency would increase.

Figs. 5 (a and b) and 6 show the results of a simulation, based on an electromagnetic software, using two similar 35 meter-long dipoles –

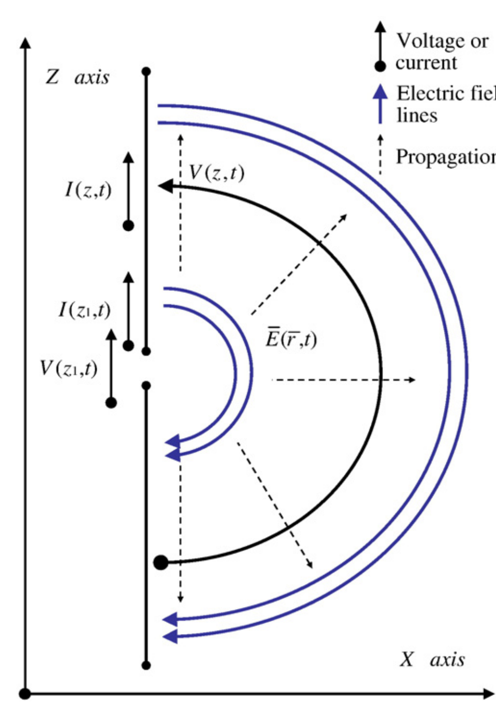


**Fig. 2.** Signals in a modified transmission line.