ON RADIATION EFFICIENCY AND RADIATING CAPABILITY OF IMPULSE ANTENNAS

Prokhorenko V.P., Ivashchuk V.E. and Korsun S.V.

VIY, Transient Technologies, P.O. Box 28, Kyiv 02147, Ukraine
E-mail: office@viy.com.ua

Abstract

Electromagnetic radiation efficiency and radiating capability of impulse antenna are discussed at this paper. A term of impulse antenna is referred to an electromagnetic pulse radiation system with short pulse response. Relation between such antenna characteristics as storage factor, efficiency and radiating capability is considered here. Improvement methods of impulse antenna efficiency and radiating capability are discussed also.

Possibilities of impulse antenna efficiency improvement with high radiating efficiency preservation are discussed. It is shown that efficiency of impulse and resonant antennas may be commensurable if energy recuperation back into power supply is provided. Some methods to increase impulse antenna efficiency and radiating capability are described and discussed.

Keywords: Radiation efficiency, radiating capability, transient radiation, impulse antenna.

1. INTRODUCTION

Any process goes through transient and steady state stages. Steady-state electrodynamics assumes that sustained mode in the system is observed. In this case the system analysis in frequency domain is ideally suited and is quite wide utilized. Transient electrodynamics assumes that system parameters are time-dependent and their analysis in frequency domain takes a lot of time. It is more feasible the time domain approach utilization.

Concerning electromagnetic radiation theory it means that antenna parameters (input impedance, standing wave ratio (SWR), quality factor (Q-factor), directional pattern, antenna gain, etc.) are determined on steady-state operation. And for transient operation both antenna characteristics and material properties (permittivity and permeability) should be interpreted correctly.

This paper is devoted to discussion of some issues regarding to short electromagnetic pulse (impulse) radiation process. We will use 'impulse antenna' term that refers to electromagnetic impulse radiated structures and has short pulse response. The goal of this paper is a search of methods to increase impulse radiation intensity based on analysis of such antenna parameters as storage factor, radiation efficiency and radiating capability.

2. ANTENNA PARAMETERS

Above all we should find out what antenna parameters are able to use for transient radiation description and what do its mean. Let's consider common antenna parameters for transient radiation conditions.

2.1. ANTENNA STORAGE FACTOR

In steady-state electrodynamics quality factor (or Q-factor) Q is usually estimated as ratio of resonance frequency (f_0) to antenna bandwidth (BW) [1].

$$Q = \frac{f_0}{BW} . \tag{1}$$

For impulse antennas we propose to use term 'Storage factor' instead of 'Q-factor'. It is implied to ratio of storage energy (E_{acc}) into the antenna to loss energy (E_{loss}).

$$Q = \frac{E_{acc}}{E_{loss}} . \tag{2}$$

2.2. ANTENNA RADIATION EFFICIENCY

In steady-state electrodynamics antenna efficiency (η_a) is referred to ratio of radiated power (P_{rad}) to power (P_{apt}), accepted by antenna [2]. This definition can also be expressed via radiation resistance (R_{rad}) and loss resistance (R_{loss}) [3]:

$$\eta_a = \frac{P_{rad}}{P_{apt}} = \frac{R_{rad}}{R_{rad} + R_{loss}} \tag{3}$$

Radiation efficiency of perfectly conducted resonant antenna is practically equal 100 % because whole energy concentrated into the antenna will be radiated for a long time. This definition is not acceptable for impulse radiation for the sake of shape requirements. Since power and energy are different for transient

operation mode, we propose a term 'antenna efficiency' to use for description of ratio of radiated energy (E_{rad}) to energy, accepted by antenna (E_{apt}).

$$\eta_a = \frac{E_{rad}}{E_{apt}} \qquad (4)$$

2.3. ANTENNA-GENERATOR SYSTEM RADIATION EFFICIENCY

Let's consider radiation efficiency of whole system, including generator, feeder, balun and antenna itself. We estimate the antenna radiation efficiency is about 100 %. Feeder and balun bring additional losses (η_m) because of imperfect matching. Besides generator and antenna power matching assumes that the generator output resistance should be equal to radiation resistance of media. Generator to antenna system power matching (η_P) is 50 % in the best case. Therefore the generator-antenna system radiation efficiency (η) never exceeds 50 % [2].

$$\eta = \eta_P \cdot \eta_m \cdot \eta_a < 0.5 \qquad (5)$$

2.4. ANTENNA RADIATING CAPABILITY

To characterize antenna behavior in time we propose to use 'radiating capability' term (ψ_a) that is referred to ratio of instantaneous values of radiated power (P_{rad}) to power, accepted by antenna (P_{apt}). Otherwise 'radiation efficiency' and 'radiating capability' terms are indistinguishable for steady-state operation mode, but are useful for transient conditions.

$$\psi_a = \frac{P_{rad}}{P_{apt}} \qquad (6)$$

2.5. ANTENNA PARAMETERS RELATION

In antenna system at least two sources of energy losses may be noted. There are active losses because of power dissipation by antenna conductance, and electromagnetic radiation. If antenna is made with perfectly conducted material the energy losses are entirely connected with electromagnetic radiation. If antenna radiation capability is increasing the storage factor is reducing. It is agreed with dipole antenna's self-impedance dependence from length to diameter (l/d) ratio [4]. Reducing the l/d ratio results the antenna self-resistance and Q-factor decreasing too. The smaller antenna storage factor the shorter its pulse response. Therefore antenna with the lowest storage factor will be the most suitable for impulse radiation.

It is supposed that impulse radiated antenna system has naturally low radiation efficiency. This assertion is principally based on improper power matching of generator with antenna system and radiated impulse shape requirements. However if to provide ideal wideband matching, increase the antenna radiation capability, and apply special energy-saving efforts, the radiation efficiency of the UWB generator-antenna system could be commensurable with resonant systems, i.e. about 50 %.

3. ELECTROMAGNETIC RADIATION

3.1. RADIATION VIA POYNTING VECTOR

Consideration of electromagnetic radiation is quite indeterminate problem. Classical definition establishes that electromagnetic radiation is observed when antenna current or charged particles velocity are changing. There are two sides of this problem: antenna-generator interaction and antenna-ambient space interaction. Both sides are mathematically described and successfully used for antennas analysis. However they are not suitable for antenna synthesis purposes. Usually new antennas are intuitively designed and then mathematically analyzed and prototyped. If the results are agreed with designer's idea the antenna configuration was correctly created.

Electromagnetic radiation is usually estimated via antenna current of dipole moment behavior. We propose to consider radiation process from opposite side, which is originating from electromagnetic wave definition. The radiated energy can be derived from the Poynting vector (**S**) that is vector production of electric (**E**) and magnetic (**H**) fields [5].

$$\mathbf{S} = \mathbf{E} \times \mathbf{H} \qquad (7)$$

The Poynting vector (power density) is directed perpendicular both electric (**E**) and magnetic (**B**) fields and is observed when theirs fields are existed in one point of space and time simultaneously. Ratio E/H is determined by media impedance (Z), and can be expressed via permittivity (ε_0) and permeability (μ_0) of the vacuum, and dielectric (ε) and magnetic (μ) constants of media.

$$\frac{E}{H} = Z = \sqrt{\frac{\mu \mu_0}{\varepsilon \varepsilon_0}} \qquad (8)$$

Impedance of the vacuum (Z_0) is equal 120π (or about 377 Ohm).

$$Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 120\pi = 377\Omega \qquad (9)$$

We can establish that electromagnetic wave exists and propagates in the media if, first, **E** and **H** fields are present simultaneously and, second, E/H ratio is equal to media impedance. Using regression principle we can also suppose that if electromagnetic radiation is existed in far-zone it is also consequently existed in near-zone and is immediately arisen near the antenna surface. If the E/H ratio near the antenna surface is differed from ambient media impedance, matched part of energy is only radiated. The rest one is left near the antenna.

3.2. RADIATION VIA ENERGY TRANSFORMATION

Let's consider electromagnetic radiation via antenna system's energy behavior. Relationship between voltage, current, power and energy are shown in Table 1. Columns of the table represent correlation between electric parameters, fields and energy.

Table 1. Antenna parameters correlation.

Charge/Voltage	Current	Power
Static E Field	Dynamic E and H Fields	Electromagnetic Field
Potential Energy	Kinetic Energy	Energy Transformation

We assume that electromagnetic radiation is one of the losses components that are observed when energy into the antenna system is changing or transforming. It takes place during the antenna excitation, propagation condition changing due to media boundaries, antenna geometry, etc. We think that the more transformed energy amount and shorter transformation time the higher radiation intensity is observed. Regarding dipole antenna it agrees with the antenna edges and feed point, where whole antenna energy is transformed and maximum radiation intensity is taken place.

4. IMPULSE RADIATION IMPROVEMENT

Traditional way to provide UWB matching between impulse generator and antenna is to combine its together. As a result an active transmitting module is created. However output resistance of the generator is varied in wide range due to the antenna accepts insignificant part of energy, concerned with impulse generation.

This condition can be improved if the energy will be directly accumulated into the antenna system. In this case impulse generation process is separated to energy transfer and transformation. First energy is accumulated by antenna system and then it is transformed with accompanying electromagnetic radiation [6]. Drawback of this solution is high energy level in the system that brings to long antenna current oscillation (so-called 'ringing'). Therefore high radiation intensity is accompanied with unacceptable radiated impulse shape. The 'ringing' can be suppressed by appropriate resistive loading but this way reduces the radiation efficiency.

We propose to provide energy recuperation back to power supply with resistive dissipation of the left energy. In general accumulated energy (E_{acc}) consists of radiated energy (E_{rad}), dissipated energy (E_{diss}) and recuperated energy (E_{rec}).

$$E_{acc} = E_{rad} + E_{diss} + E_{rec} \qquad (10)$$

Radiation efficiency can be written as:

$$\eta = \frac{E_{rad}}{E_{acc} - E_{rec}} = \frac{E_{rad}}{E_{rad} + E_{diss}} \qquad (11)$$

If effective energy recuperation will be provided, the radiation efficiency could be considerably improved. Since radiated energy (E_{rad}) is proportional to accumulated energy (E_{acc}) whereas dissipated energy (E_{dis}) is connected with residual energy only.

$$E_{rad} \sim E_{acc}, \; E_{diss} \sim (E_{acc} - E_{rec}) \qquad (12)$$

The best power matching is observed when E_{rad} and E_{diss} are commensurable. In this case radiation efficiency of the pulsed antenna system is approaching to resonant one.

$$\eta \approx 0.5, \; if \; E_{rad} \approx E_{diss} \qquad (13)$$

5. CONCLUSIONS

Such antenna parameters as storage factor, radiation efficiency and radiating capability concerning to transient radiation are considered at this paper. Radiation descriptions via Poynting vector definition, and energy change and transformation are present also.

It is shown that impulse radiation efficiency can essentially be improved if the following requirements will be provided:

- Maximization of radiating capability by selection of appropriate antenna geometry;

- Providing of energy accumulation into the antenna system;

- Providing of energy recuperation to reduce the power dissipation.

Following of these recommendations allows realization of impulse-radiated antenna with efficiency up to 50 %.

REFERENCES

1. Kitra, M., McEvoy, P., Vardaxoglou, J.C. and James, J.R. 2003, 'A theoretical and simulation study of dielectrically loaded antennas and their contribution towards low-SAR', *INICA 2003 – Int. ITG Conf. on Antennas*, September 2003, Berlin, 245-248.

2. McLean J., Sutton R. and Hoffman R. 2002, 'Interpreting antenna performance parameters for EMC applications. Part I: Radiation efficiency and input impedance match', TDK RF Solutions Inc.

3. Walden M.C. 2003, 'On using the classical monopole for comparison with other electrically small self-resonant monopole antennas of equal height', *Proc. IEEE Int. Symp. Antennas and Propagation*, June 22-27, Columbus, Ohio, USA.

4. Jenn D. 'Basic antenna parameters and wire antennas', Lecture Notes, vol. II, Naval Postgraduate School, Distance Learning.

5. Gill E. 2004. 'Engineering 7811 (Antennas), Course Particulars', Memorial University of Newfoundland, Faculty of Engineering and Applied Science.

6. ProkhorenkoV., Ivashchuk V. and Korsun S. 2004, 'Drift step recovery devices utilization for electromagnetic pulse radiation', *Proc. 10th Int. Conf. Ground Penetrating Radar*, June 21-24, Delft, The Netherlands, 175-179.