

Large Current Antennas in GPR Applications

Abstract

Some aspects of Large Current Antenna applications for subsurface sensing at the depths down to hundred meters have been presented and discussed. The antenna has to operate in wide frequency band and transmit effectively electromagnetic power under the surface of the ground. Large Current Antenna designed on the basis of a Low Pass Filter scheme is one of the ways to implement it.

Development of modern Ground Penetrating Radar (GPR) for applications in Engineering Geology, in particular, for target detection at the depths down to several hundreds meters, requires to solve a set of the following problems:

1. Development of an antenna system which should meet inconsistent requirements; for instance, the antenna system is to be rather compact and effective at the same time.
2. Increase of depth resolution of probing signals in subsurface area.
3. Elaboration of mathematical algorithms for solving of inverse problems (obtaining of useful information on physical properties of underground objects using radar returns), etc.

GPR antennas for signals radiation and reception should meet the following requirements:

1. To provide radiation and reception of signals in a wide band of frequencies.
2. To provide good matching of antenna impedance with that of a feeder and a ground surface.
3. To have rather compact sizes for its easy movement over a ground surface.

Design of high efficiency antennas for GPR is a big challenge because deep undersurface sensing requires application of radar signals with rather low central frequency: from hundreds KHz up to several MHz. Using classical approach to the antenna design these requirements may be fulfilled only in the case when the antenna dimensions are commensurable with the wavelength related to the minimal frequency in

the signal frequency bandwidth. For relatively high-frequency range these requirements are met rather easily using well known methods for design of antennas for subsurface radar-sensing. In the low-frequency band the above mentioned antennas become too large for practical applications. Therefore application of Large Current Antennas that have rather small sizes may be an alternative. With reference to subsurface radar such antennas have been proposed by Harmuth [1]. Briefly the idea consists in the following. Radiation power of a dipole is proportional to square of a current flowing through it and to square of the ratio of the dipole length to signal wavelength. If the dipole current is increasing it leads to essential increase in transmitting power. That is why such kind of antennas may compete with the resonant antenna which has its sizes approximately equal to the wavelength of conventional radar signal. Harmuth [1] has suggested to apply a current loop, in which the return part is screened by the conducting shield for prevention of compensation of the far zone fields radiated by different parts of the loop.

In the paper the piece of a coaxial cable is used as the shielded return wire. Thus, the antenna has the simplified view shown in Fig. 1.

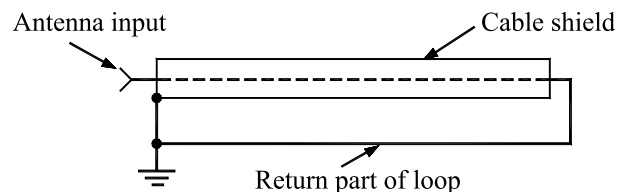


Fig. 1. Large Current Antenna simplified schematic.

At practical implementation of the antenna it is

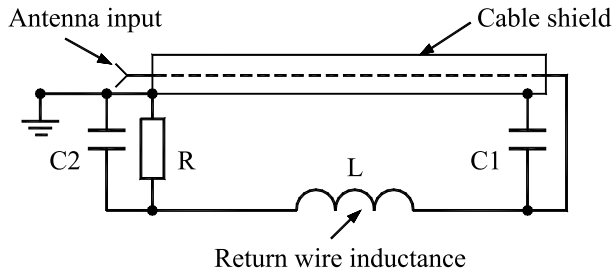


Fig. 2. Antenna-LPF view.

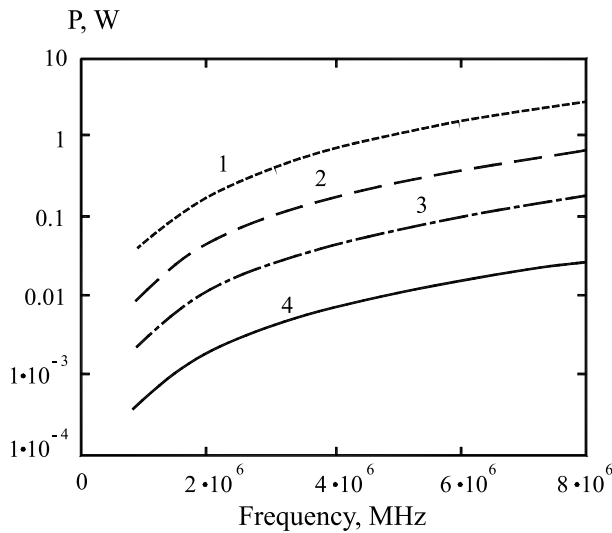


Fig. 3. Radiation power of Large Current Antenna as a function of frequency for various values of characteristic resistance R .

very difficult to conduct large currents in it owing to finiteness values of active and inductive resistance of a wire, and also owing to influence of a parasitic capacity between the coaxial cable shield and the central wire. Therefore more detailed analysis of efficiency of such type of the antenna was required.

Let's consider a Large Current Antenna as a part of a conductor (dipole) the size of which is less than the wavelength. Radiated power of such dipole is defined by the following equation [2]:

$$P_{\Sigma} = \frac{I_m^2 R_{\Sigma}}{2}, \quad (1)$$

where R_{Σ} is the radiation resistance.

For a dipole we have:

$$R_{\Sigma} = 80\pi^2 (l/\lambda)^2, \quad (2)$$

where λ is the signal wavelength, l is dipole length.

Let's consider, how the conductor's length, active and inductive resistance influence on the transmitted power. The current flowing through the antenna is defined by the following expression:

$$I_m = \frac{U_m}{R + j\omega L}, \quad (3)$$



Fig. 4. Experimental GPR sample.

where R and L are the active and inductive resistance of the conductor, respectively. It is known [2] that the active resistance of a conductor can be evaluated as follows:

$$R = k_R l,$$

where k_R is the coefficient depending on specific resistance of the conductor material and its geometry.

Similarly, the inductance of the conductor may be calculated as $L = k_L l$, where k_L is the coefficient depending on the conductor size and geometry. For a given conductor length, increasing the probe signal frequency will cause transition from the one area, where the conductor active resistance exceeds its inductive one, to another one, where inductive resistance begins to prevail over the active resistance. Let's consider those areas in details. In the first area, taking into account expressions (1),(2) and (3), the radiation power can be defined as follows

$$P_m = U_m^2 160\pi^4 \frac{\omega^2}{k_R^2 c^2}, \quad (4)$$

where c is the velocity of light.

In the second area this expression transforms to the following one:

$$P_m = U_m^2 160\pi^4 \frac{1}{k_R^2 c^2}. \quad (5)$$

Comparative analysis of these expressions leads to the following conclusions:

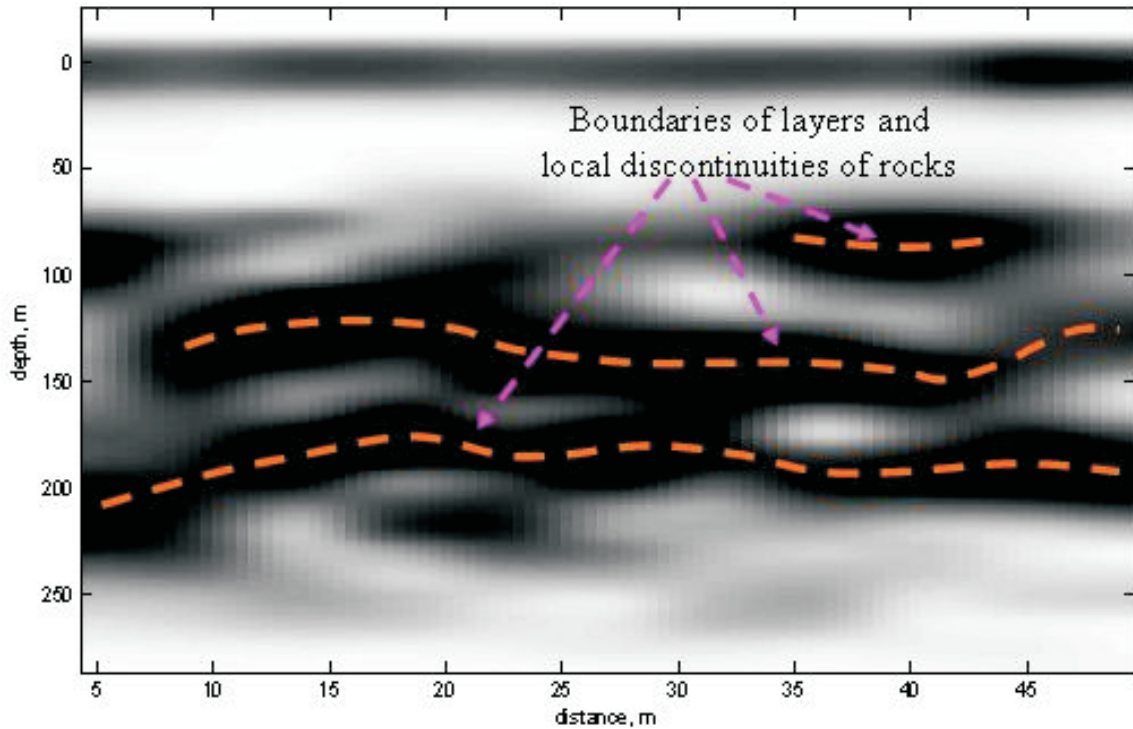


Fig. 5. Radar image of ground cross section.

1. In the both areas the radiated power does not depend on the conductor length.
2. For low frequencies band where the active resistance exceeds the inductive one, the radiated power is proportional to square of the probing signal frequency.
3. In the second area the radiated power achieves its maximum and does not depend on frequency.

In this way we arrive to the conclusion that the large current antenna realization requires such a length of the antenna conductor that in the given range of probing frequencies yields the prevailing of the inductive resistance over the active one.

On the other hand, we can try to adjust antenna as a low-pass filter (LPF) with surgeless amplitude characteristic in the given frequency range. So the antenna under consideration is to be transformed according to the scheme shown in a Fig. 2.

The antenna is adjusting like the LPF in which the cutoff frequency is the highest frequency of the antenna frequency bandwidth. Then the characteristic resistance of the LPF is defined as

$$R = 2\pi f_B L, \quad (6)$$

where f_B is a LPF cutoff frequency..

The antenna-LPF scheme analysis gives a conclusion that for increasing return wire current it

is necessary to reduce inductance of this conductor. Thus characteristic resistance (R) reduces, return wire current increase and radiation capacity increase too. Fig. 3 presents the calculated curves of radiated power as function of frequency for various value of characteristic resistance (R).

One can see that at $R = 12.5 \Omega$ in the middle of the frequency band the radiated power is about 1 W with DC power supply voltage 20 V. Another feature of the antenna-LPF is the increasing of transmitted power with frequency increase (to provide constant voltage amplitude at the load (R) in a required frequency range it is necessary that amplitude of current in inductance (return wire) is increased with frequency and compensated voltage slope on it).

In our case the mentioned above antenna was designed for GPR experimental sample being used in exploration geology for subsurface probing within the depth range from several hundreds meters up to 1 kilometer and more.

Short description of long range GPR:

In the mentioned GPR sample the Stepped Frequency Continuous Wave (SFCW) signal is used for estimation of an underground object range. It enables to work in any frequency band from units of kHz to 50 MHz using probing signals with step varying of the central frequency. The GPR enables measuring

amplitude-phase structure of signals reflected from subsurface structure of reflecting layers. Received GPR signals after quadrature phase detector output is transformed to digital form and stored in a microprocessor which controls all GPR units, including frequency synthesizers. The 5 m length Large Current Antenna is used in the GPR. Antenna enables to work in the frequency range from 100 kHz to 7 MHz with transmitted power about 2–3 W. Signal reception is performed either with the same antenna, if a ferrite circulator is used, or with the help of a single short dipole of 5m length. Experimental GPR sample appearance is shown in Fig. 4.

Detailed description of GPR probing results will be presented in feature, because it requires a long cycle of field tests in an area with a well known geology data about geomorphological subsurface structure down to several hundreds meters depths. So we present as an example the radar image of ground cross section (Fig. 5), obtained in frequency range from 100 to 700 kHz during GPR moving on profile of 50 m length with discrete step of 6 m.

Profile of moving was chosen at the territory of Kharkov Hydropark. This territory is characterized by absence of buildings and constructions and natural structure of layers.

Conclusion

It has been shown that a small sized Large Current Antenna constructed according to a Low Pass Filter scheme may be successfully used for power transmitting in subsurface sensing systems using frequency band where usual resonant antennas have rather large dimensions. On the experimental GPR sample with Stepped Frequency Continuous Wave signal it was demonstrated a possibility of implementing such kind of antenna for remote sensing of reflecting objects at depths more than several hundred meters under ground surface.

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References

- [1] H.F.Harmuth Nonsinusoidal waves for radar and radio communication. – N-Y. – 1981. – 376 p.
- [2] L.D.Goldstein, N.V.Zernov. Electromagnetic fields and waves. 2-nd edition. – M.: Soviet radio. – 1971. – 664 p. (in Russian)