

Broadband antenna for ground penetrating radar application in soil

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Abstract. The scope of the article embraces the features of design of antennas and arrays for GPR, their type and parameters and the expediency of the application of the antenna arrays in various purpose location systems of GPR.

Subsurface location refers to geophysical methods using radiolocation impulse signals to build images of objects and voids in soil with the use of a wide electromagnetic emission spectrum ranging from tens megahertz to few gigahertz. Selection of frequency band depends on requirements to resolution and a depth of object detection. The subsurface location systems (georadars) are based on the concept of classical radiolocation systems, but alternatively to them the signal emission is realized to a dielectric medium with loss, rather than to open space. To gain good resolution and acceptable depth of object detection it is necessary that antenna has a wide transmission band, high amplification factor, compact construction applicable in manpack sets.

Super-wideband antennas can be nominally classified by the criterion on relation between antenna size and a spatial length of an exciting pulse $\chi = c \cdot \tau$ (c is light velocity, τ is pulse length) into three basic types:

- travelling-wave antenna (dimensions exceed a bit χ),
- quasi-resonant antenna (dimensions are approximately equal to χ),
- elementary antenna (dimensions are much less than χ).

Prevalent travelling-wave antennas are TEM-horns. Their positive features are high efficiency and directivity of radiation and their imperfections are large overall dimensions, especially when χ amounts to few decimeters or meters.

Quasi-resonant antennas have less dimensions, but come short of efficiency and directivity of radiation as compared to travelling-wave antennas, moreover, they imply the use of complex loads intended to suppress generation of post-pulse oscillations in a radiated signal (Figure 1).

Elementary antennas are capable to radiate and receive super-wideband signals without post-impulse oscillations; they are applicable as single units and as elements of transmission and receiving antenna arrays designed to perform spatial processing of signals along with appreciable enhancement of GPR energy potential [1].



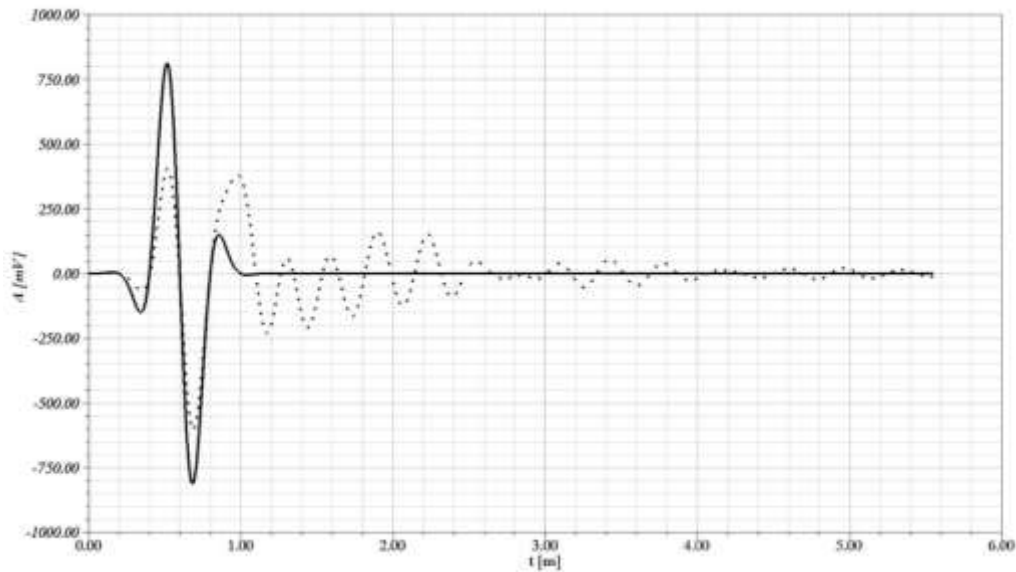


Figure 1. Super-wide band signal in input of a printing bicone.

The most popular are electromagnetic horn antennas with a single, but important imperfection, namely, large dimensions, compact antennas (printing bicones), Vivaldi antennas, dipoles, frame antennas, monopoles, etc. Printing antennas have notable advantages thanks to low cost, small size and weight. If antenna system has imperfect parameters, the greater capacity of a transmitter and accumulator battery is required with respective appreciation of GPR.

GPR can use a single receiving-transmitting antenna, one receiving and one transmitting antennas, one transmitting and few receiving antennas, or few transmitting and receiving antennas.

In design of antenna array it is imperative to consider specific features if its application, first of all its location near earth surface in order to use the effect of penetration into soil in order to diminish reflection of a survey surface. The near field effect should be taken into account in antenna design, the glancing angle effect can be limited as it hinders the 3D full visualization because of refraction index of soil [2].

A radiated pulse without side lobes is the principal objective in designing an antenna; it is rather complicated due to a number of factors, first, the components of most of electrically-powerful antennas radiate electromagnetic different-frequency fields with respective different-directivity diagrams. Given that position of the phase center of the antenna depends on frequency, the shape of an impulse is distorted as signals at each frequency are to pass different routes. Pulses at antenna input undergo distortions because of reflections in its propagation route along antenna and especially on antenna's edges. Cumulative reflections are capable to cause impulse tails on echo impulse in the time domain. The reason for this is that antenna represents a resonance structure of high Q-factor and of low transmission band, not enough to hold an impulse signal band.

Figure 1 presents calculation results on input impulse signals in "bow-tie" antenna (printing bicone) for 2 - 5 GHz frequency band obtained by Galerkin's discrete method in time domain. Soil layer of dielectric permeability equal to 6 was considered.

Super-wide band signal applied to antenna input is shown in solid line, a radiated pulse is in dotted line, signal spectrum is shown in Figure 2.

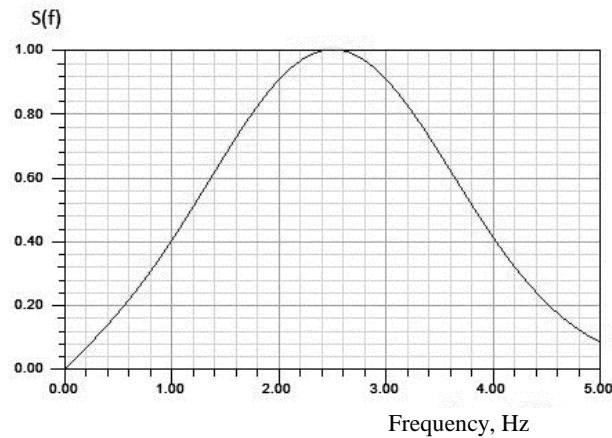


Figure 2. Spectrum of wide band signal.

In different-purpose GPR units the antenna arrays (AA) are applied to boost velocity of earthscape survey. There are two approaches for AA data design. In the first method few discrete elements connected to a controller are used, and data processing is individual for each element. In another approach AA system is developed, thereto, the system exhibits higher transition capacity and applies algorithms of synthetic aperture radars.

A single antenna element, let, a dipole has a limited potential in terms of amplification. Thus antenna array is applied to arrange a diagram of directivity with high amplification factor. There are two “point-point” and collinear types considering the orientation of elements relative to array axis. Expressions of radiation intensity $P(\theta, \varphi)$ for both types are formulas (1) and (2), provided that all the elements are uniformly excited in amplitude and phase (uniform array):

$$P(\theta, \varphi) = 15\pi \left(\frac{I\Delta l}{\pi} \right)^2 \frac{\sin^2 \left[\frac{N\pi d}{\lambda} \cos \theta \right]}{\sin^2 \left[\frac{\pi d}{\lambda} \cos \theta \right]} (1 - \sin^2 \theta \cos^2 \varphi) \quad (1)$$

$$P(\theta, \varphi) = 15\pi \left(\frac{I\Delta l}{\pi} \right)^2 \frac{\sin^2 \left[\frac{N\pi d}{\lambda} \cos \theta \right]}{\sin^2 \left[\frac{\pi d}{\lambda} \cos \theta \right]} \quad (2)$$

Where θ is angle, deg, λ wavelength, m, N – is number of radiating elements, φ is phase delay between elements, d is distance between elements, I is current, Δl is ascending length of array element.

A pitch between elements has strong influence on a multiplier of an array and on upper boundary of the actual frequencies band of the antenna. Larger pitch between elements gives a greater antenna gain. Nevertheless, as a rule inter-element pitch is selected less than $\lambda/2$ for undirected elements in order to eliminate a rise of diffraction lobes. Given that diffraction maximums come into existence, the array gain falls sharply [3].

Comparison of emission power in a plane in distance 20λ from 5-element array and 11-element array with inter-element pitch λ is shown in Figure 3. Special attention should be paid to the effect of increased number of array elements on the antenna gain and to the reduction in the level of side lobes.

Most conventional AA units have corporative feed circuit to provide a single input for array elements excitation or output of received power. A beam is formed under proper phasing of elements; thereto, phases of elements are fixed as a rule. In more complex methods the phases of elements can be controlled with possible adjustment of a beam and even pattern zero.

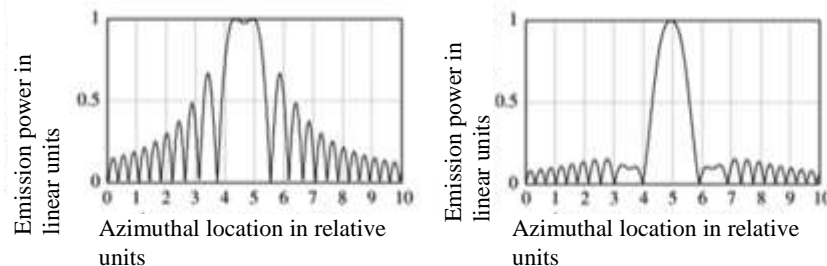


Figure 3. Comparison of emission power of 5-element and 11-element arrays.

In some array designs 2D array of matched transmitters and receivers is used to obtain an active image of an under-array area. This provides advantage of the use of few transmitters in radiation of an area under the wideband energy scanning, as well as a few receivers to detect reverse dissipative energy, and provides noise rejection through synchronization of several impulse radars in the time domain.

By applying independent control of launch and gating of every transmitter and receiver, the system focuses the radiolocation energy in a point and then moves this point to scan an area under the array (Figure 4). If sequence of impulses is controlled in time by means of differential delay in time between each element, then a position of the beam can be adjusted, though the delay between elements in time is limited by the maximum equivalent distance between each element [4].

All the array systems are oriented to obtain an image of hidden objects, and the accurate positioning of the elements is a constitutive factor to gain this target. Differential GPS (DGPS) in combination with inertial navigation systems can serve efficient instruments.

When an antenna array is over the earth the compensation of surface relief variation is required. It is preferable to consider one more aspect, it is a pitch between array elements. It should be large enough to provide a required resolution as a probability of detection of minor objects is closely related to density of elements in an antenna array [2].

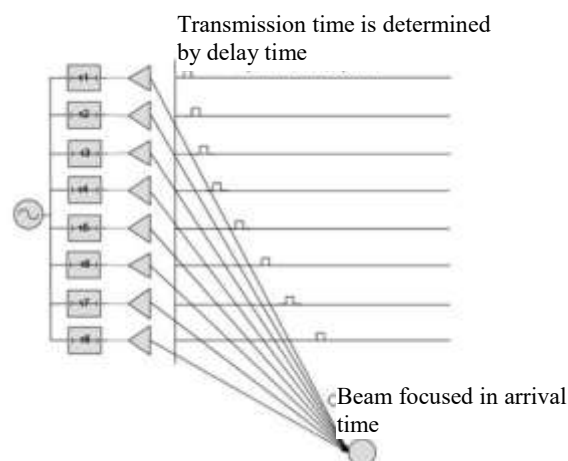


Figure 4. Adjustment of antenna beam by means of time delays for radiating elements.

Conclusions

Types of antennas used in geolocation systems for detection of hidden objects are determined by an operation frequency range and requirements for compactness and architecture of the system itself. In calculation of passing a super-wide band signal through a soil mass it is necessary to consider interface of media with different electrophysical properties. Numerical methods in the time domain can be helpful to analyze the influence of geometric and electric specifications of antennas on parameters of radiated and received impulses, be precise, on a rise of post-impulse oscillations.

References

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