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Estimation of Parameter Variation of Wideband Signals and their Fields in Media with Attenuation

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Abstract—Wideband signals and their fields in media with frequency-dependent attenuation have been considered using an example of the analysis of propagation of ultrasonic signals in biological media. An analytical expression for the spatial frequency response of the layer of biological tissue with frequency-dependent attenuation for diagnostically meaningful frequency range was obtained by using a linear approximation of the problem under consideration. Quantitative estimates of the impact of a layer of biological tissue with attenuation on a radio pulse with Gaussian envelope were obtained. The presence of frequency-dependent attenuation in medium was shown to result in variation of spatial selectivity of antenna during its operation with wideband signals. The estimates of variation of spatial selectivity parameters are presented in case of using the radio pulses with Gaussian envelope.

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INTRODUCTION

The use of wideband (WB) signals (short pulse simple signals or complex signals) in problems of sounding of media and objects of different origin makes it possible to obtain high resolution in terms of range (depth) that is one of conditions for obtaining data about the internal structure of tested objects with a high degree of confidence. The above media and objects include natural media (geological rocks and bodies of water), biological media, objects of artificial (technogenic) origin, etc.

The tested media generally possess frequency-dependent attenuation that distorts the sounding WB signal and deteriorates the range resolution [1, 2]. For example, in biological media the behavior of the frequency response is close to linear for ultrasonic waves of megahertz range [3]; the slimy marine sediments are characterized by the presence of power-law (in particular, quadratic) frequency dependence of attenuation for ultrasonic waves [4]; the wet clay is characterized by the power-law (of order 1.4) frequency dependence of attenuation for electromagnetic waves in gigahertz range [5]. In addition, a significant change of the probing signal spectrum can lead to the variation of spatial selectivity with respect to the selectivity calculated without due regard for the frequency-dependent attenuation. Unfortunately, the issues related to the impact of media with frequency-dependent attenuation on WB signals and their fields have not been sufficiently studied yet.

The proposed paper is devoted to the estimation of the impact of frequency-dependent attenuation on parameters of WB signals and their fields. The consideration of the specified issues was conducted for the case of propagation of ultrasonic (US) signals in biological media and directed on the estimation of the impact of frequency-dependent attenuation in biological medium on the deterioration of potential resolution in terms of range and in the transverse direction of medical ultrasonic diagnostic systems (USDS).

The USDS application should ensure the possibility of obtaining information about any point of the tested biological object. The pattern of US wave propagation in biological object is determined by inertial and elastic properties of tissues and also by the loss mechanisms operating therein. The density and contractibility of biological tissue determine the speed of sound; spatial changes of this tissue result in refraction of acoustic waves. The spatial fluctuations of density, contractibility or sound absorption lead to scattering or reflection of waves. Attenuation, i.e. complete loss of acoustic energy in biological tissue, is determined by combined action of reflection, scattering and absorption of ultrasound.

Thus, mechanisms attenuating the feedthrough signal and forming a reflected (scattered on inhomogeneities) signal operate simultaneously practically in any biological object. Such media as amniotic fluid, vitreous humor, crystalline lens, and cystic fluid are an exception. If pathologic changes are not present in the above specified media, the changes of scattering and attenuation practically do not occur in them [3].