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SOME ASPECTS CONCERNING THE DESIGNING OF ULTRAWIDEBAND AND PULSE ANTENNAS

A.N. Titov

Scientific Research Institute of Instrument Design
Zhukovsky ,140180, Moscow region, Russia

The principally attainable antenna characteristics are discussed, including the ultrawideband antennas. Antenna configuration is pointed out as a principle factor for the antenna characteristics to approach the potentially attainable ones. Both the similarities and the distinctions are considered as regards the approaches to the ultrawideband and the pulse antenna designing. General recommendations are expounded as to the choice of the antenna type and structure for the transmission and reception of pulse electromagnetic signals.

1. Introduction

Out of the most significant successive stages in the development of the antenna technology during the last 50 years, one can point out these.

1. The definition of ways in order to essentially increase the antenna work band. If in the 1950s the antenna with a 10 % work band was a wideband one, nowadays the work band maximal to minimal frequency ratio may be up to 30…50 [1,2]. In most applications this amount exceeds the capacity limits of the antenna-employing devices (transmitters/receivers).
2. The development of the antenna array theory and practice, including the phased and adaptive arrays. The successes and achievements in this field are widely known and related to bands from tens of MHz to the optical one.
3. The search of ways in order to create the ultrashort pulse signal transmission and reception devices. In this case are washed away the differences between the usual in radio techniques notions of the carrier frequency and the mode of modulation of radio signal. Nowadays the attempts are made at the creation for various purposes of radio technical devices employing the ultrashort pulses. Despite the long-term and numerous investigations by numerical methods on powerful computers for calculating the time-pulse electromagnetic processes, serious difficulties are encountered in practice in the design of effective antennas in this regard.

2. Ultrawideband Antennas and Their Features

The ultrawideband antennas are often called frequency independent [3]. Wherein the independence of the antenna parameters on frequency is meant. However even a comparatively simple antenna avails of about 20 parameters of a quite different behavior each as signal frequency varies. The examples in Fig. 1 are to prove this statement. For a linear antenna with its size much less than the radiation wavelength (Fig. 1(a)), the spatial pattern in the band, the directivity factor and the radiation field polarization structure are invariant for a wide band. Whereas, for example, the input complex impedance of the antenna varies essentially.

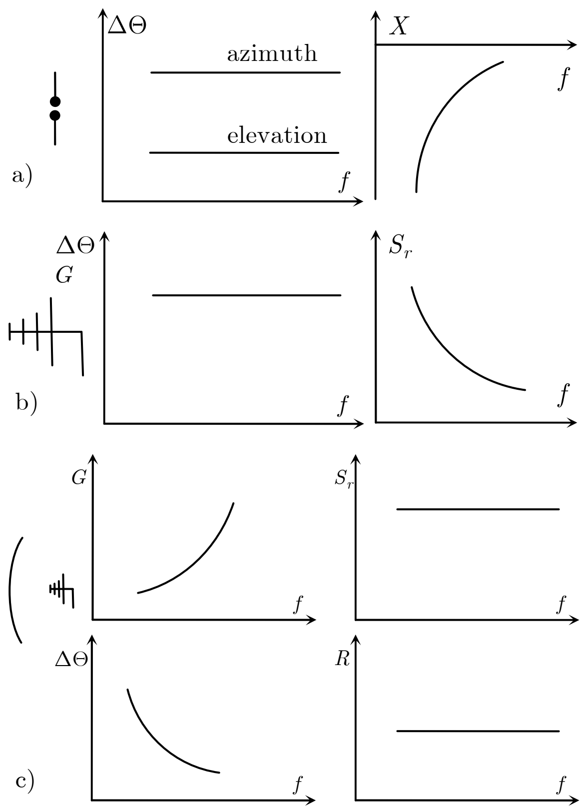

Fig. 1.

Fig. 1(b) concerns the antennas made as the logo-periodic structures [3]. In such antennas the gain and the directivity pattern width remain constant in the band. At the same time such important characteristics as the effective height and the receiving area of the antenna do experience a sharp decrease as frequency increases. A principal feature of these antennas is that at any frequency in the band only one resonant part of the antenna is excited and the rest ones are a useless ballast. Evidently, the wider is the working band of a suchlike antenna, the slighter are the relative coefficients characterizing its overall dimensions, the cost, the material capacity, upon the higher frequencies in the band.

However, when the logo-periodic antennas are employed as the irradiators of the compound antennas (Fig. 1(c)), the situation changes. The receiving area of the antenna remains the same, and sufficiently efficient, in the band. Likewise is non-varied the antenna input impedance. The gain goes up by the proportionality law λ^{-2}, acquiring at any frequency the value close to the maximal possible one for the given overall dimensions of the antenna. Correspondingly, the antenna beam gets contracted proportionally to the wavelength.

Thus, designing any particular ultrawideband antenna it is necessary to ensure the frequency independence primarily of those antenna parameters which mostly affect the quality of the radio technique system considered.

It is of much practical importance to find out principal relations between the minimal possible overall dimensions of the antenna and such its parameters as the amplification coefficient, the degree of the matching in the band, and the efficiency. The ideas in this regard have been proposed and advanced by Chu [4], Harrington [5], Fano [6], Hansen [7]. Of the recent researches in the field, one should point out [8] where the relationships are obtained relating the antenna overall dimensions to the achievable level of its matching in a given band.

The expansion of the radiator fields in terms of the spherical harmonics has turned out to be very fruitful. Each harmonic is expressed in terms of Legendre functions and spherical Bessel functions. Formally the infinite number of harmonics can be truncated via the ratio N of the radius of a sphere circumscribing the antenna to $(2\pi)^{-1}\lambda$. Then, in accordance with [5], the lossless antenna gain may be up to values $N^2 + 2N$. Solid line in Fig. 2 is for the antenna gain dependence on D/λ ratio. Dotted line is for the attainable gain of the antenna with a plain aperture obtained by the known formula $G = \frac{4\pi}{\lambda^2} S_{aper}$, where S_{aper} is taken equal the sphere section passed through the diameter. It is seen that the volume antenna, especially a small one, is the energy advantageous over the plain one. Also, in this figure there is the gain of a half-wave vibrator. By gain the latter is inferior to the plain and, especially, to the volume antenna conditioning that all the three are circumscribed with the sphere of half-wavelength diameter.

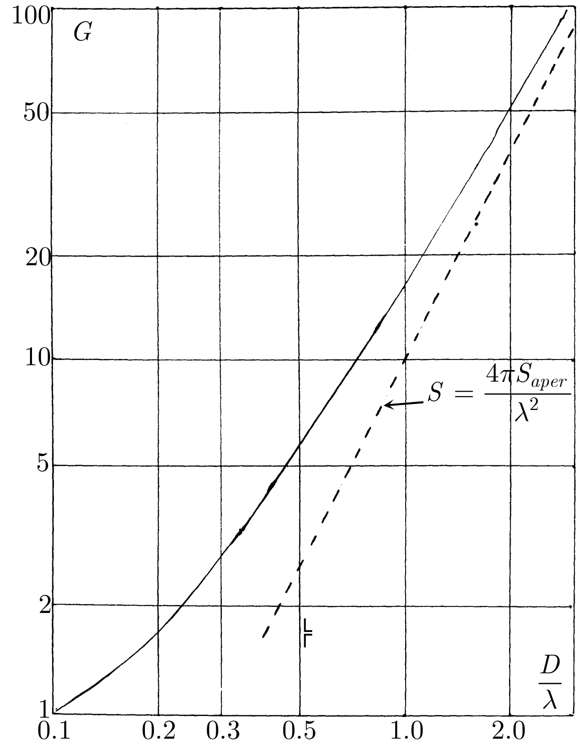

Fig. 2.

In Fig. 3 there are the curves concerning the principal relation between the reflection coefficient at the antenna input, the diameter of a sphere circumscribing the antenna, the maximal wavelength and the degree of the antenna widebandness. As an indicator of the widebandness is taken the ratio $f_{\max}$ to $f_{\min}$, i.e. the work band maximal to minimal frequency.

The curves in the figure correspond to the antenna efficiency equaling 1. The similar curve families can be plotted for the lesser efficiencies. At that the curves will shift towards lesser $D/\lambda_{\max}$.

With these figures one can have indicated the achieved quality of any particular worked-out antenna. The analysis from this point of view of a good many antennas in scientific publications demonstrates that a vast majority of the antennas possess characteristics very much worse than the potentially achievable ones. In Fig. 3 there are the best antennas' design results. These are the wideband plane spiral antenna [1] and the symmetric vibrator antenna the arms of which are spherical cones with vertex an-

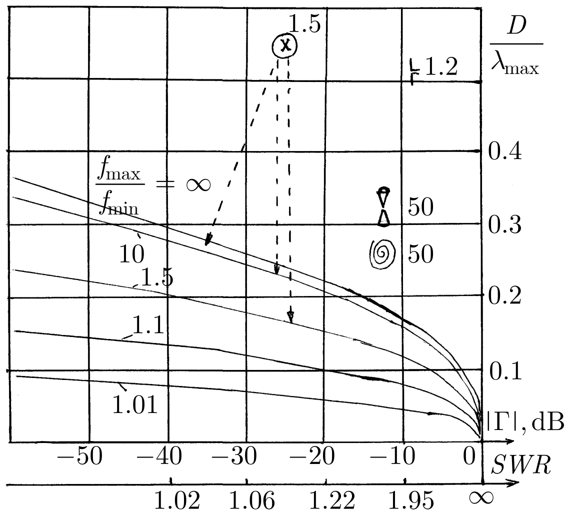

Fig. 3.

gle 100°. Also in this figure there are the characteristics of the symmetric half-wave vibrator supposed to have the bandwidth corresponding to f_{max} / f_{min} at the reflection coefficient level of −10 dB.

Besides, some certain hypothetical antenna with the reflection coefficient –25 dB in the band $f_{max} / f_{min} = 1.5$ circumscribed with the sphere of $0.55\ \lambda_{max}$ diameter is denoted with an encircled cross in this figure. Evidently, the optimization of this antenna while the band is kept the same could have potentially led to either its overall dimensions 3 times lessening or its overall dimensions 2 times lessening and its bandwidth expanding up to $f_{max} / f_{min} = 10$ simultaneously. The optimization of this antenna could have been directed as well to its reflection coefficient lessening at a simultaneous lessening of the dimensions and expansion of the work band.

The analysis of the structures and characteristics of the ultrawideband antennas in publications permits also to arrive at the conclusion that their characteristics approach the potentially achievable ones closer so far as the better the antenna configuration can be circumscribed with a sphere. In order to illustrate this thesis, in Fig. 4 there are different antenna configurations in their growth of preference order. There are successively the following antenna types in the figure: 1 – linear antenna, 2 – plain symmetrical vibrator antenna ("butterfly"), 3 – plain spiral antenna, 4 – symmetrical vibrator with spherical-cone arms, 5 – TEM-horn.

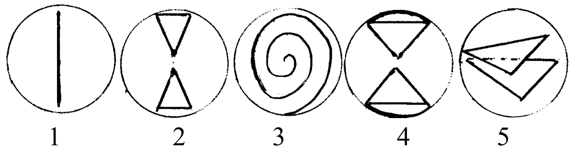

Fig. 4.

In this way, the following practically useful conclusions can be drawn up:

1. Any arbitrarily electrically small antenna can be well matched in a certain band without losses.
2. Any arbitrarily electrically small antenna can be well matched in some fairly wide band at the expense of diminishing its efficiency.
3. The overall antenna dimensions should be regarded as a resource permitting to enlarge its widebandness and quality of the matching.
4. If the overall dimensions are kept up, the antenna dimensionality (linear, plain, volume) can also be considered a resource allowing to enlarge the widebandness, the quality of the matching and the antenna amplification coefficient.
5. The transition, at the kept-up maximal wavelength, from a wideband antenna to an ultrawideband one requires in fact only an insignificant enlargement of its dimensions.

As a consequence: if a radio technical system has several work bands at a uniform radiation polarization, it does make sense testing the possibility of using a common antenna. In this case the functions of signals separation should be given over to such feeder line elements as the commutators and filters.

3. Some General Aspects of the Pulse Antenna Design

The principal distinction of the pulse antennas from the wideband ones resides in the following. As regards the ultrawideband antennas, it is supposed first that frequency spectrums of the signals exciting the antenna and of the fields formed by it are identical and second that these signals spectrums are much narrower than the work band of the antenna. As regards their pulse counterparts, those spectrums differ and practically fill up the whole antenna bandwidth. Moreover, they are generally distance-and-direction-dependent related to the pulse radiator. The next peculiarity resides in that the radio technique systems employing the ultrashort electromagnetic signals are essentially short-ranged. These short ranges may not only fall inside the Fresnel zone, but may be less than the wavelength of the signal spectrum central frequency.

The arising problems are also concerned with that all of the antenna parameters have been introduced for the antenna excitation by a continuous sinusoidal signal of a certain frequency. The pulse antennas do require other, more effective, parameters enabling a comparison between different pulse antennas and also to analyze and design the radio technique system as a whole. Such parameters as the complex gain, the pulse and transient responses of the four-poles, so much effective in the linear electronic circuit analysis, are evidently unsatisfactory in this case. Correspondingly, serious methodological and hardware problems are available as regards the pulse antenna design. Therefore the empirical methods based on the experimental investigation of the system as a whole prevail in the pulse antenna design for any particular system. The experience accumulated by now due to a good many researchers' labour permits to put down the following recommendations to be made use of in the pulse antenna design.

1. From the view-point of providing the required bandwidth, the previous-section statements concerning the ultrawideband antennas can be a basis. As the energy condition in the systems employing ultrawideband pulse signals is not, as a rule, strained and, first of all, it is necessary to produce a compact pulse without "tails", one can recommend an enlargement of losses in the antenna as a way to expand the bandwidth. For this purpose various absorbents of electromagnetic energy can be used; such as the ballast resistors, conductors made of poor conductivity materials, radio absorbing materials round the antenna elements, including the ferrite one. There are certain examples that the antenna efficiency reduction only to 0.5 can expand essentially the antenna bandwidth [10, 11].
2. The basic type of oscillations in the pulse antenna must be TEM wave as a wave without dispersion.
3. The pulse antenna bandwidth has to exceed significantly the spectrum width of the signal exciting the antenna. It appears that the thin temporal structure of any electromagnetic pulse radiated by antenna, the 'tails' of this response are dependent on the antenna characteristics outside the given band [1].
4. In the antenna one should avoid to use the dense-dielectric elements longitudinal related to a propagating signal. This is a protective measure against transformations of the TEM-wave into types with dispersion [12].
5. In the antenna one should avoid the cross-wise dielectric plates of the width over $\lambda_{\min} / 20\sqrt{\varepsilon}$. This measure is to diminish the risk of undesirable resonance phenomena to emerge in the work band.

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НЕКОТОРЫЕ ВОПРОСЫ ПРОЕКТИРОВАНИЯ СВЕРХШИРОКОПОЛОСНЫХ И ИМПУЛЬСНЫХ АНТЕНН

А.Н. Титов

Рассматриваются потенциально достижимые характеристики антенн, в том числе сверхширокополосных. Подчеркивается принципиальное влияние конфигурации антенн на степень приближения характеристик антенны к потенциально достижимым. Обсуждается сходство и различие в подходах к проектированию сверхширокополосных и импульсных антенн. Излагаются общие рекомендации, связанные с выбором типов и конструкций антенн, предназначенных для излучения и приема импульсных электромагнитных сигналов.

ДЕЯКІ ПИТАННЯ ПРОЕКТУВАННЯ НАДШИРОКОСМУГОВИХ ТА ІМПУЛЬСНИХ АНТЕН

А.М. Титов

Розглянуто потенційно досяжні характеристики антен, у тому числі надширокосмугових. Підкреслено принциповий вплив конфігурації антен на ступінь наближення характеристик антени до потенційно досяжних. Обговорюється схожість та відмінність у підходах до проектування надширокосмугових та імпульсних антен. Викладено загальні рекомендації, пов'язані з вибором типів і конструкцій антен, призначених для випромінювання і прийому імпульсних електромагнітних сигналів.