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Structure and characteristics of two-element ultra-wideband antenna

***Abstract**: The paper presents results of a computer simulation of a two-element ultra-wideband (UWB) antenna. A computer analysis was made in 6-8.5GHz frequency range, according ETSI. An excitation network was designed as a broadband hybrid. A novel idea presented in the paper is a modification a well-known ideal model of a hybrid using additional T-structure circuit. Frequency characteristics of a two-element antenna and a broadband hybrid were discussed in the paper. The analysis presented in the paper is important for solving various EMD problems.*

***Streszczenie**: Artykuł przedstawia wyniki komputerowej symulacji dwuelementowej anteny ultraszerokopasmowej w paśmie ETSI UWB 6-8,5GHz. Zaprojektowany został układ wzbudzenia anteny w postaci ultraszerokopasmowej hybrydy oraz jego modyfikacja z wykorzystaniem dodatkowych obwodów mikropaskowych kształtu T. (**Struktura i charakterystyki dwuelementowej anteny ultraszerokopasmowej**).*

Keywords: planar UWB antennas, excitation of antennas, broadband hybrid.
Słowa kluczowe: planarne anteny ultraszerokopasmowe, układy wzbudzenia anten, szerokopasmowa hybryda.

Introduction

Ultra-wideband is a technology that still has a significant interest of scientists and manufacturers of telecommunications equipment. There are a lot of different structures of UWB antennas that can be used in UWB systems [1-5]. Among these various structures a class of planar antennas is well worth considering. Single and double-elements planar antennas were the subject of interest and analysis in the previous works of the authors of the paper [7-9].

A planar symmetrical two-element antenna array for UWB application in 6-8.5GHz frequency range is described in this paper. This antenna array was designed in a symmetrical stripline technology. An excitation network – broadband two-port uncoupler (hybrid) was synthesized and described [6]. Different matrices describing these two elements were used for EMC and EMD analysis of UWB antennas.

Multiport antenna with excitation network

Taking into consideration a cascade connection of a multiport antenna and excitation network (Fig.1,a), a total scattering matrix of this connection is [6]:

$$\mathbf{S} = \mathbf{S}_{\alpha\alpha} + \mathbf{S}_{\alpha\beta}\mathbf{S}_{\mathrm{A}}\,(\mathbf{1} - \mathbf{S}_{\beta\beta}\mathbf{S}_{\mathrm{A}})^{-1}\,\mathbf{S}_{\beta\alpha}\,, \tag{1}$$

where: $\mathbf{S}_{\alpha\alpha}$, $\mathbf{S}_{\alpha\beta}$, $\mathbf{S}_{\beta\alpha}$ and $\mathbf{S}_{\beta\beta}$ - blocks of scattering matrix $\mathbf{S}_N$ of double-side 2*n*-network *N*; $\mathbf{S}_{\mathrm{A}}$ - scattering matrix of the antenna array (Fig.1,a).

The double-sided multiport network N is named the *uncoupled-matched network* if it has *zero* diagonal blocks of scattering matrix: $\mathbf{S}_{\alpha\alpha} = \mathbf{S}_{\beta\beta} = \mathbf{0}$ [6]. Then, the *total scattering matrix* of this cascade connection is *diagonal*:

$$\mathbf{S} = \{s_i\} = \mathbf{V}_{\mathrm{A}}^{+}\,\mathbf{S}_{\mathrm{A}}\,\mathbf{V}_{\mathrm{A}}\,. \tag{2}$$

where s_i - eigenvalues of the normal matrix $\mathbf{S}_{\mathrm{A}}$; $\mathbf{V}_{\mathrm{A}}$ - complex *unitary* matrix of eigenvectors of matrix $\mathbf{S}_{\mathrm{A}}$. In this case *all input ports* of cascade connection (Fig.1,a) are mutually ideally *uncoupled* and this uncoupled-matched network is named as uncoupler for given *n*-port load.

The total normalized average power absorbed by the multiport antenna array (Fig.1,a) for arbitrary excitation vector **a** is given by normalized hermitian form (Rayleigh ratio) and is limited by the *minimum* and the *maximum* eigenvalues of the dissipation matrix [7]:

$$d_{\min} \le P_{ant}/P_{\max} = \mathbf{a}\,\mathbf{D}_{\mathrm{A}}\,\mathbf{a}/\mathbf{a}^{+}\mathbf{a} \le d_{\max}\,. \tag{3}$$

where $\mathbf{D}_{\mathrm{A}} = \mathbf{1} - \mathbf{S}_{\mathrm{A}}^{+}\mathbf{S}_{\mathrm{A}}$ - a *dissipation* matrix of the antenna.

These mathematical bases may be used for EMC and EMD analysis of a two-element UWB antenna with broadband two-port uncoupler - *hybrid*.

Structure and characteristics of planar two-element UWB antenna

The structure and dimensions (in mm) of the analyzed two-element UWB antenna array are presented in Fig.1,b. This planar antenna array consists of two equal elliptical radiators with two-section matching transformers. The length of matching lines equals 20mm and the length of the front and back metallization is 0.56mm shorter and equals 19,46mm. Total thickness of the antenna is 3.15mm (1.575mm is a thickness of a single layer of the dielectric); ε_r = 2.2. Elliptical radiators are connected to the middle wire of excitation section of the array. All the calculations were made in 6-8.5GHz ETSI UWB frequency band using commercial software IE3D.

UWB antenna discussed in the paper is a symmetrical array, so its impedance, scattering and dissipation matrices are as follows:

$$\mathbf{Z}_{\mathrm{A}}(j\omega) = \begin{bmatrix} z_{11} & z_{12} \\ z_{12} & z_{11} \end{bmatrix},\ \mathbf{S}_{\mathrm{A}} = \begin{bmatrix} s_{11} & s_{12} \\ s_{12} & s_{11} \end{bmatrix},\ \mathbf{D}_{\mathrm{A}} = \begin{bmatrix} d_{11} & d_{12} \\ d_{12} & d_{11} \end{bmatrix}. \tag{4}$$

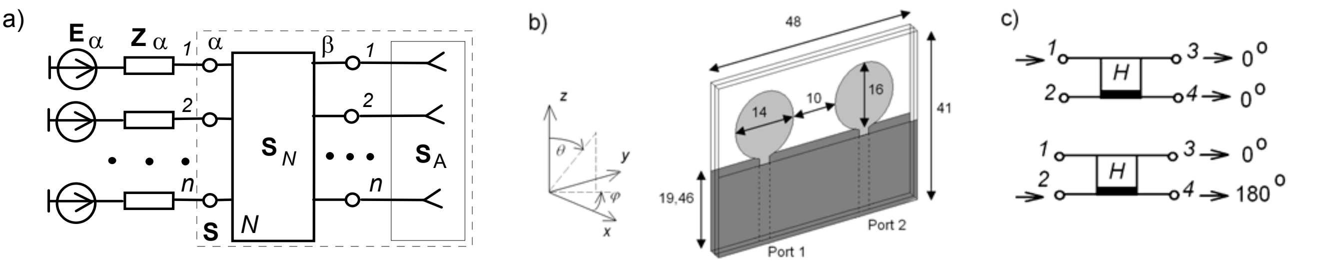

Fig. 1. Cascade connection of excitation network and antenna array (a), planar two-element UWB antenna (b) and principle of the hybrid operation (c)

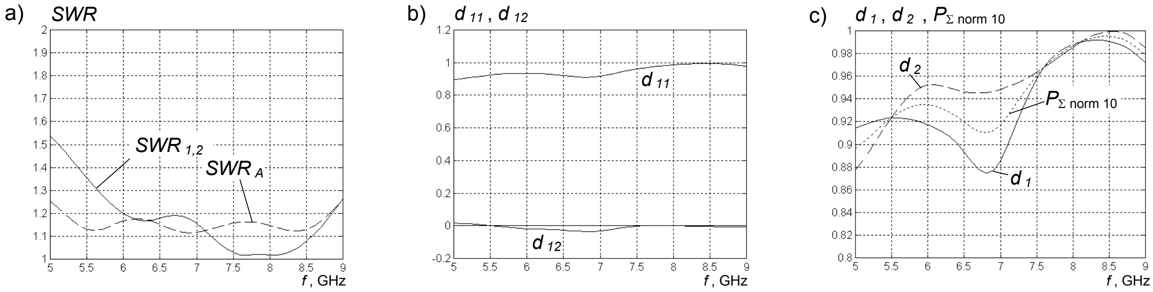

Fig. 2. Scattering matrix (a), dissipation parameters of UWB antenna (b,c)

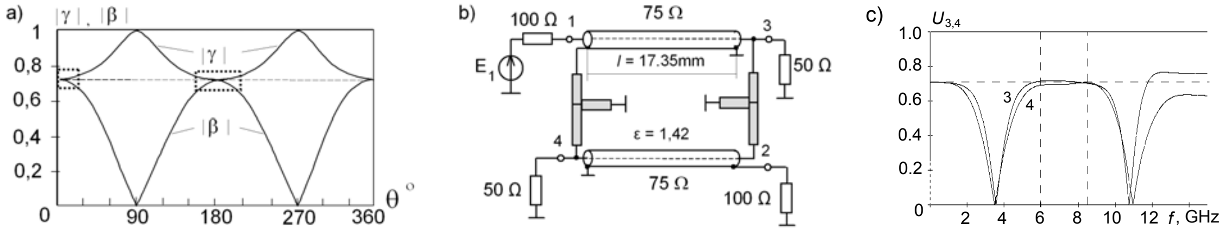

Fig. 3. Transmission coefficients of ideal hybrid (a), structure (b) and characteristics (c) of the broadband half-wave microstrip hybrid

All these matrices have the same real orthogonal eigenvectors (5) and similar formulas for the eigenvalues:

$$(5)\qquad \mathbf{V} = [\mathbf{V}_1\ \mathbf{V}_2] = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}, \quad \begin{matrix} z_{1,2} = z_{11} \pm z_{12} \\ s_{1,2} = s_{11} \pm s_{12} \\ d_{1,2} = d_{11} \pm d_{12} \end{matrix} \; .$$

Fig.2,a shows *SWR* of 2-element antenna in comparison with SWR_A of a single antenna (a prototype for the analyzed array – a half of the structure visible in Fig.1,b). Fig.2,b,c show dissipation parameters.

Design of broadband hybrid

The hybrid (balun) is a base element for the synthesis of different order of broadband uncouplers [6]. It realizes in-phase and anti-phase excitation of 2-element antenna (Fig.1,c). Characteristics of transmission coefficients of theoretical model of hybrid are represented in Fig.3,a. These elements of the scattering matrix of hybrid may be calculated for a chosen electrical line length θ [7]:

$$(6)\qquad \beta = 1/(\sqrt{2} + i\,\mathrm{tg}\,\theta)\,, \qquad \gamma = \beta \sec\theta\,,\ \theta = 2\pi\, l/\lambda\,.$$

This structure ensures an equal ratio power division and the equal / opposite phases of the output signals with a switching of inputs (Fig.1,c) for small electrical length or about $\theta = k\pi$ only. For electrical length $\theta = 0.5(2k+1)\pi$ this hybrid transmits the whole signal on one output only. This property allows using a balun as a frequency commutator – different distribution of output signals in different frequency bands may be obtained [6,7].

An example of the balun realization as a symmetric microstrip lines (or stripline) is represented in Fig.3,b. The length of connections between ports 3-2 and also 4 and a shield of 1 in basic theoretical structure of a hybrid equals 0. In this paper it is proposed a half-wave length hybrid (Fig.3,a for $\theta \cong 180°$). Instead of „zero-length” connecting lines the authors suggest an optimal microstrip (or stripline) T-structures (Fig.3,b).

An example of frequency characteristics of this microstrip hybrid is shown in Fig.3,c. It is seen that this hybrid has almost equal-ratio power division in the whole frequency band for UWB systems.

Conclusions

Results of a computer simulation of a two-element UWB antenna array, including excitation network, for use in 6-8.5GHz UWB band, according ETSI, are presented in the paper. A broadband hybrid was proposed as the excitation network for the analyzed antenna. That circuit provides an in-phase and anti-phase excitation for a two-element antenna array. A new idea presented in the paper is using a half-wave length hybrid with microstrip T-structures instead of an ideal model of hybrid with zero-length connections. It was shown that properties of this hybrid enable it to work in ETSI UWB frequency band.

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