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doi:10.15199/48.2017.12.09

Computer Simulation of Broadband Multiport Devices for Excitation of Antenna Array

***Abstract**. New structures of broadband multiport excitation devices for antenna arrays for radiocommunication systems are proposed in the work. These devices consist of special multiport phase commutators and broadband matching networks. Base properties, frequency characteristics and results of computer simulation of the multiport excitation devices with antenna array are presented. These devices may be used for reduction of electromagnetic disturbances in different radio systems*

***Streszczenie.** Zaproponowano nowe struktury szerokopasmowych układów do wzbudzenia układów antenowych systemów radiokomunikacyjnych. Układy te zawierają wielowrotnikowe komutatory fazowe i szerokopasmowe obwody dopasowujące. Przedstawiono ich właściwości, charakterystyki oraz wyniki symulacji komputerowych. Opracowane układy mogą być zastosowane do redukcji zakłóceń elektromagnetycznych w różnorodnych systemach radiowych (**Symulacja komputerowa szerokopasmowych układów wielowrotnikowych do wzbudzenia układów antenowych**)*

Keywords: multiport excitations devices, phase commutators, antenna arrays.
Słowa kluczowe: wielowrotnikowe układy wzbudzenia, komutatory fazowe, układy antenowe.

Introduction

The paper presents structures and frequency characteristics of multiport excitation devices with phase commutator and optimal broadband matching networks for antenna arrays.

Main topic of the paper are computer simulations of characteristics of different excitation structures based on uncoupled-matched networks (phase commutators) and matching devices synthesized for 4-port antenna array at given frequency band. Fundamentals of operation and design these networks are described in [1]. Broadband amplifiers with these networks dedicated to various radio systems are shown in [2-8]. Different structures of antenna arrays with phase multiplexing are in presented [8-14].

Use of multiport uncouplers and matching networks gives a possibility to obtain increases a power efficiency of the whole antenna complexes in radio system. These devices may be used for reduction of electromagnetic disturbances too in different radio systems.

Structures and characteristics of the multiports for phase channel multiplexing

Base blocks of multiport broadband excitation devices are multiport phase commutators [1-3, 8-14]. Phase commutator - double side multiport that provides a given phase distribution of output signals with excitation of separate inputs of the network. Inversely, phase commutator provides sum signal of all excitation generators in some one of output only for different phase distribution of the generators. With change of generator’s phase’s sum of the signals are in the some output of the device. The phase commutator can be used as broadband antenna uncoupler, after connecting this structure to the multiport antenna array with specific symmetry.

Main block for design of broadband phase commutators is two-channel device (hybrid) [1-3, 8-14]. Structures of scattering matrix of ideal hybrid is:

$$\mathbf{S}_N = \begin{bmatrix} \mathbf{0} & \mathbf{T}_t \\ \mathbf{T} & \mathbf{0} \end{bmatrix}, \qquad \mathbf{T}_2 = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}. \tag{1}$$

These matrices show that ideal hybrid has zero diagonal blocks and constant non-diagonal blocks. The multiport that has the zero diagonal blocks of the scattering matrix is called the uncoupled-matched network. It's mean that the inputs of this network are theoretically ideally matched and uncoupled in the work with matched loads.

These commutators may be synthesized with use of special two-channel phase blocks – hybrids (Fig. 1). This network realizes equal and opposite phases of the output signals with excitations of some inputs. Principle of the hybrid operation is shown in Fig. 1.

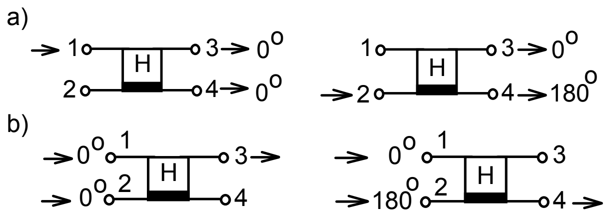


Fig.1. Principle of the hybrid operation: a) division of power, b) summing of power

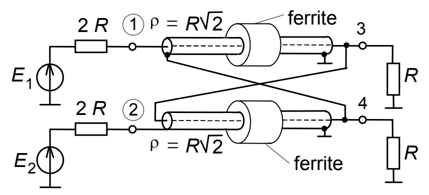


Fig.2. Structure of the cable hybrid (balun)

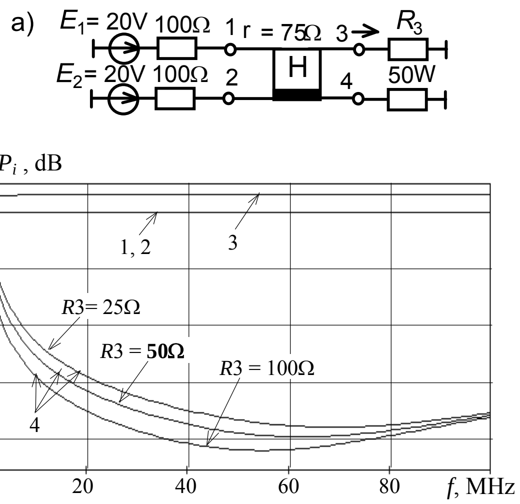


Fig.3. Structures of the excitation (a) and the characteristics (b) of the hybrid with unmatched loads

An example of the cable hybrid (balun) realization is shown in Fig. 2. The hybrid consist of two informal connected coaxial cables with next parameters: impedance of cables ρ = 75Ω ≅ $50\sqrt{2}$Ω, the lengths of cables 6.7cm, the electrical permeability of isolation ε = 2.2 (then the equivalent length of the lines is 10cm). The inductance of the cable shield, with ferrite core, that was used for reduction shunt effect of the inductance of transmission line shield on small frequencies, L = 10μH.

Structures of the excitation by in-phase signals of the generators (a) and the frequency characteristics (b) of the hybrid with unmatched loads are shown in Fig. 3. It is presented characteristics of hybrid: powers of generators (1,2), total output power (3) and unwanted signal (4), corresponding to the zero units of the scattering matrix of ideal hybrid (1) (Fig. 3,b). The analysis of the hybrid exciting was executed with different values of load of hybrid: R_3 = 25, 50 and 100Ω, corresponding to the standard value SWR = 2 of the received antenna.

We can see, that even on nominal value of the load R_3 = 50Ω on output (4) of real hybrid it is exists the unwanted signal of value -30-40dB.

The hybrid is a base element for design of four-channel phase commutator (Fig. 4,a). This commutator consist of four hybrids and provides four combinations of phase distributions (0° and 180°) or (+1) and (-1) - of output signals with excitations one from different inputs (Fig. 4,b).

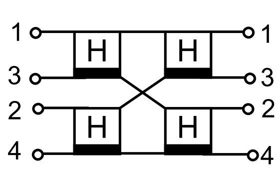
This 4-channell commutator is a main block for design of the antenna excitation devices.

Structures of the excitations and frequency characteristics of input and output powers of four-channel phase commutator with matched loads are presented in Fig. 5 and Fig. 6. These devices provide an in-phase distribution of output signals with excitation of separate inputs of the network (Fig. 5,a) and sum of the in-phase signals of all input powers in one output (Fig. 5,b).

For synthesis of the 4-channel commutator used to the hybrid with the same parameters. The hybrids have to be joint inputs with the same resistance for the correct work and matching of the commutator. It is decided to choose the value of common resistance's of inputs 100Ω, so inputs and outputs of the whole four-channel commutator have loads 50Ω (Fig. 5). Then resistance of generators R = 50Ω too and it was decided that E_i = 14.14V for assuring the power of generators $P_{\max}$ = 1W.

Characteristics of the power of the generator - amplifier (1), power on one of outputs (6) and powers on uncoupled inputs (2,3,4) are shown in Fig. 6,a.

a)



b)

$$\mathbf{T}_4 = \frac{1}{2}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & 1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix}$$

Fig.4. Structure (a) and transmission matrix (b) of 4-channel phase commutator

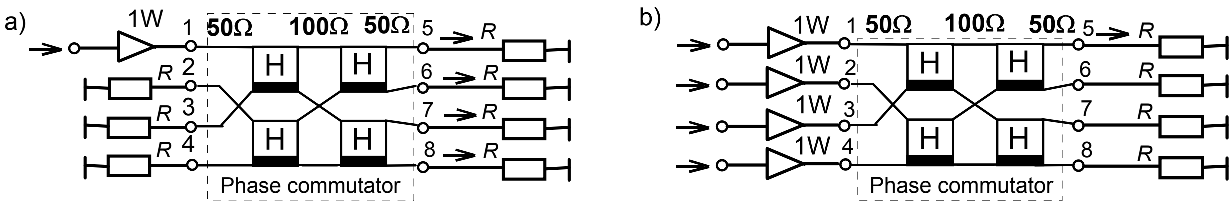


Fig.5. Structures of excitations of the four-channel phase commutator with dividing (a) and summing (b) of the power; matched loads

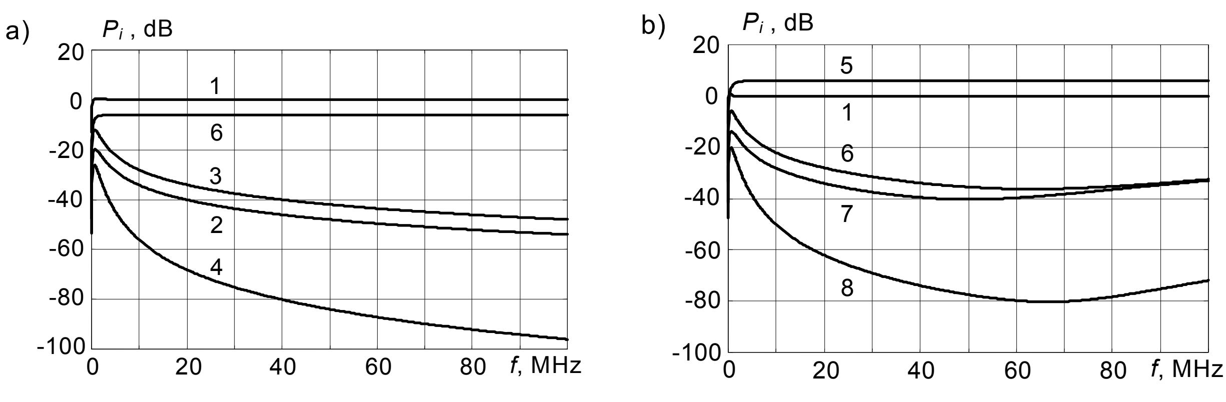


Fig.6. Frequency characteristics of the four-channel phase commutator with dividing (a) and summing of the power (b); matched loads

Values of uncoupling signals are 40-90dB. These levels secure almost independent work of the power amplifiers connected alternatively to the other inputs the phase commutator.

Results of computer simulation of the power on inputs and outputs of phase commutator with matched loads, when this one provides sum of the in-phase signals of all input powers in one output no. 5 are presented in Fig. 6,b. Values of signals on uncoupled outputs (6,7,8) of the commutator are also quite small: 30-80dB.

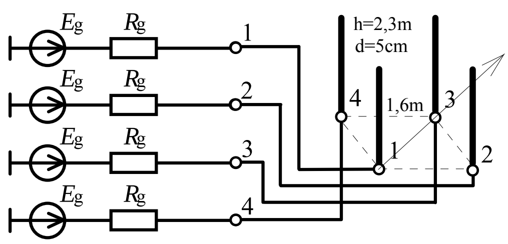


Fig.7. Structure and excitation of 4-port antenna array

Computer simulation of the 4-port antenna array

The 4-port antenna array as a quadrate of radiators for a radiocommunication base station was considered in this work. A length of the radiators are equal 2.3m, a diameter - 5cm, a side of the quadrate - 1.6m. Separate generators with power P_g = 1W (E_g = 14.14V, R_g = 50Ω) was connected to each antennas (Fig. 7); work frequency band: 40-70MHz. Because of circular symmetry, the scattering matrix of 4-port antenna array and its elements are given by:

(2) $$\mathbf{S}_A(j\omega) = \begin{bmatrix} s_{11} & s_{12} & s_{13} & s_{12} \\ s_{12} & s_{11} & s_{12} & s_{13} \\ s_{13} & s_{12} & s_{11} & s_{12} \\ s_{12} & s_{13} & s_{12} & s_{11} \end{bmatrix}.$$

For quadrate antenna array we can receive diagonally radiation for excitation with phases 0°, 90° and –90°. It is constant phase excitation (distinct from linear excitation). For change direction of radiation we must only switch these excitation phases to adequate radiators. A constant phase excitation that provided the antenna array radiation in the direction of the antenna 3 was given by excitation's vector:

(3) $$\mathbf{E}_g = \begin{bmatrix} j \\ 1 \\ -j \\ 1 \end{bmatrix}.$$

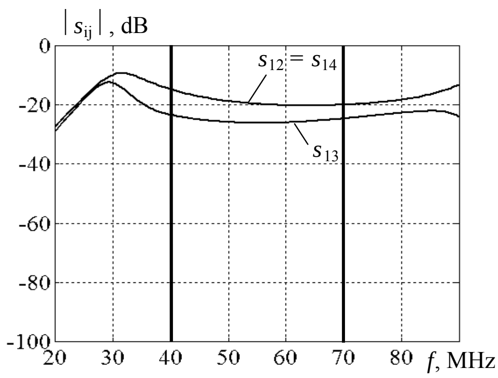


Fig.8. Characteristics of elements of scattering matrix of the antenna array

Frequency characteristics of elements of the scattering matrix of the four-element quadrate antenna array are shown in Fig 8. We can see that isolation between antenna ports has values near –15 ÷ – 25 dB. These values are not satisfactory.

Computer simulation of the 4-port antenna array with phase commutators

Four-channel phase commutator can be used as antenna uncoupler [1, 9]. Its use gives reduction of coupling between antenna array inputs. Structure of 4-port antenna array with four-channel phase commutator is presented in Fig. 9.

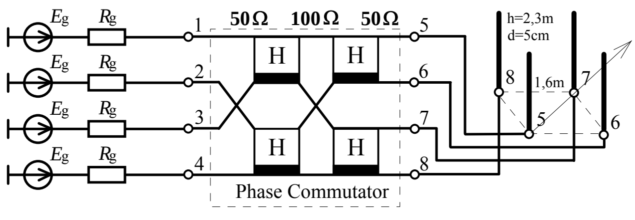


Fig.9. Structure of 4-port antenna array with four-channel phase commutator - uncoupler

In order to the antenna array radiated in the direction of the antenna 3, the operation of the phase commutator should be considered. Transmission matrix of the four-channel phase commutator was shown in Fig. 4,b. It was necessary to change phases of signals on the generators accordingly:

(4) $$\mathbf{E}_g = \begin{bmatrix} 1 \\ -1 \\ j \\ j \end{bmatrix}.$$

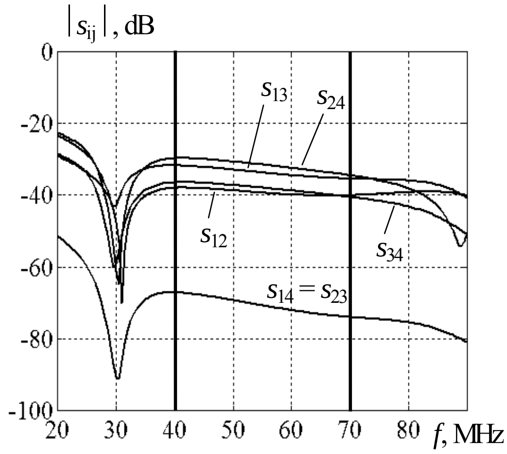


Fig.10. Characteristics of elements of scattering matrix of the antenna array with four-channel phase commutator

The results of computer simulations of antenna array with four-channel phase commutator are shown in Fig. 10. We can see that uncoupling values between generators increase about 15dB. Between the inputs 1-4 and 2-3 the uncoupling is even around 70dB. It means that our device can diminishes couplings between system elements and can assure improvement of work conditions base stations of radiocommunication systems.

Computer simulation of the 4-port antenna array with phase commutator and matching networks

Structure of analyzed 4-port excitation circuit is shown in Fig. 11. Matching networks are optimal Fano filters [1]. It does secure a certain matching level in the work frequency band. The matching network has been synthesized for a impedance of single antenna The signal phases of the generators were the same as in the previous case.

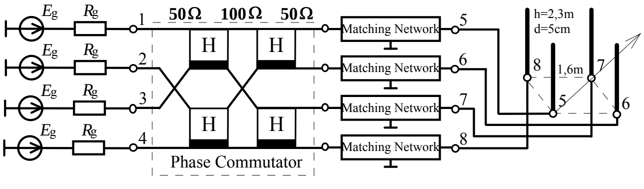


Fig.11. Structure of 4-port antenna array with four-channel phase commutator and matching devices

The characteristics of elements of scattering matrix of the antenna array with four-channel phase commutator and with connected optimal broadband matching networks are presented in Fig. 12. Values of uncoupling of the generators are similar as when antenna arrays with phase commutator worked without matching devices.

An example of characteristic of radiation of the analyzed antenna arrays is shown in Fig. 13. The shape of the radiation pattern is as expected.

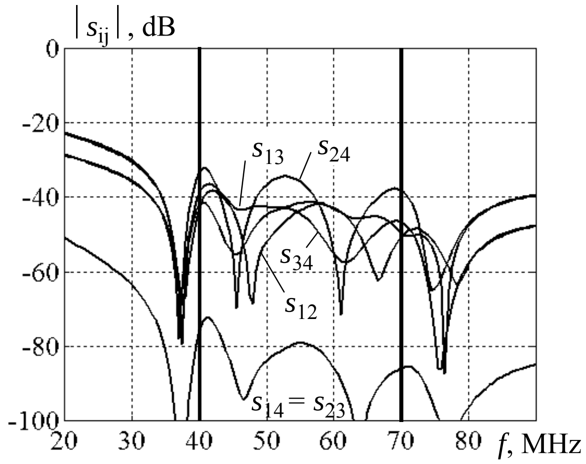


Fig.12. Characteristics of elements of scattering matrix of the antenna array with four-channel phase commutator and matching devices

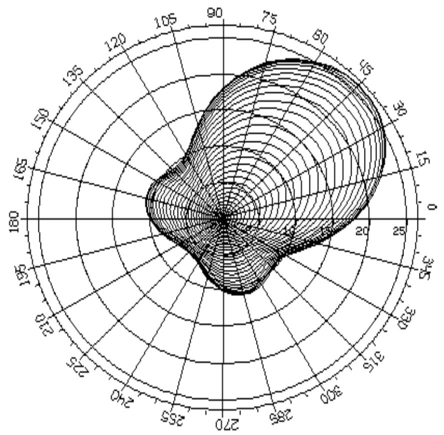


Fig.13. Characteristics of radiation of antenna arrays on 50MHz

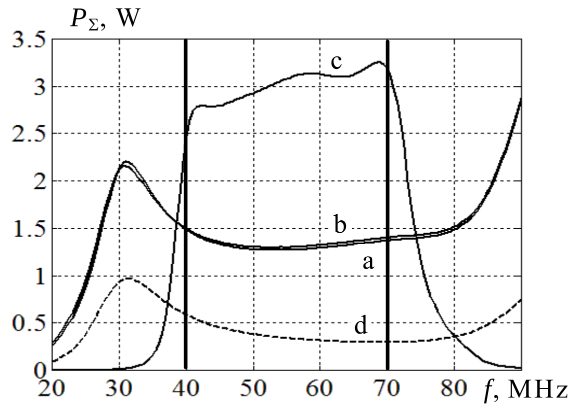


Fig.14. Characteristics of total power P_{Σ} radiation of the antenna array (a), antenna array with four-channel phase commutator (b) and antenna array with four-channel phase commutator matching devices (c), single antenna (d)

Characteristics of total power P_{Σ} radiation of the antenna array with different excitation circuits are presented in Fig. 14. Multiport phase commutators do not change values of radiated power of the antennas. The use of matching networks much increase the total power radiated by antennas.

Conclusions

Theoretical bases, structures and the results of the computer simulations of the broadband devices for excitation of the four-port antenna array with the multiports phase commutators and with the matching networks are presented in the article. The use of phase commutators significantly improves the value of uncoupling of generators used to excite radiators in antenna arrays. The proposed multiport excitation devices can reduce the electromagnetic disturbances in antenna systems.

Acknowledgment*: The research was conducted within the project S/WE/1/2015, financially supported by Polish Ministry of Science and Higher Education.*

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REFERENCES

[1] Aleksejew O., Gołowkow A., Czawka G. and others, Computer aided design of radiotransmitters, *Radio and communication*, Moscow, (1987)
[2] Grebennikov A., RF and Microwave Power Amplifier Design, *McGraw-Hill Education*, New York, (2015)
[3] Kumar N., Grebennikov A., Distributed Power Amplifiers for RF and Microwave Communications, Artech House, Boston-London (2015).
[4] Canning T., Powell J. R., Cripps S. C., Optimal Design of Broadband Microwave Baluns Using Single-Layer Planar Circuit Technology, *IEEE Transactions on Microwave Theory and Techniques*, 62 (2014), No. 5, 1183 - 1191
[5] Zhijiang Dai, Songbai He, and others, A New Distributed Parameter Broadband Matching Method for Power Amplifier via Real Frequency Technique, *IEEE Transactions on Microwave Theory and Techniques*, 63 (2015), No. 2, 449 - 458
[6] Haikun Jia, Baoyong Chi, Lixue Kuang, Zhihua Wang, A W-Band Power Amplifier Utilizing a Miniaturized Marchand Balun Combiner, *IEEE Transactions on Microwave Theory and Techniques*, 63 (2015), No. 2, 719 - 725
[7] Zongzhi Gao, Kai Kang, and others, A Broadband and Equivalent-Circuit Model for Millimeter-Wave On-Chip M:N Six-Port Transformers and Baluns, *IEEE Trans. on Microwave Theory and Techniques*, 63 (2015), No. 10, 3109-3121
[8] Czawka G., Litwinczuk N., Analysis of multiport broadband amplifiers with antenna arrays, *Przegląd Elektrotechniczny*, (2012), nr 8, 46-47
[9] Czawka G., Litwińczuk N., Wielowrotnikowe urządzenia wzbudzenia układów antenowych, *Przegląd Telekomunikacyjny* CD, (2012), nr 4, 189-193
[10] Czawka G., Litwińczuk N., Układy wzbudzenia anten z wykorzystaniem wzmacniaczy wielowrotnikowych na podstawie komutatorów fazowych, *Przegląd Telekomunikacyjny i Wiadomości Telekomunikacyjne*, CD, (2011), nr 6
[11] Czawka G., New multiport broadband amplifiers for SDMA and MIMO radiocommunication systems, *Polish Journal of Environmental Studies*, Vol. 20, (2011), nr 5A, 52-56
[12] Chavka G., Sadowski M., Litwinczuk N., Structure and computer modeling of mobile base station of radiocommunication systems, *17th International Wrocław Symposium and Exhibition on Electromagnetic Compatibility*, Wrocław, (2004), June 25-28, 135-138
[13] Czawka G., Structures and characteristics of new multiple broadband amplifiers for radiocommunication systems, *XVIII International Conf. on Electromagnetic Disturbances,* Vilnius, Lithuania, (2008), September 25-26, 79-84
[14] Czawka G., Litwinczuk N., Analysis of multiport broadband amplifiers with antenna arrays, *XXI International Conference on Electromagnetic Disturbances*, Białystok, (2011), September 28-30, 46-50