International Conference on Antenna Theory and Techniques, 6-9 October, 2009, Lviv, Ukraine pp. 334-336

A NOVEL BROADBAND COAXIAL ORTHOMODE TRANSDUCER WITH HIGH PORT ISOLATION

Dubrovka F. F. and Vasylenko D. O.

National Technical University of Ukraine "Kyiv Polytechnic Institute",
Department of Theoretical Foundations of Radioengineering
E-mail: fedor.dubrovka@gmail.com, dmitry.vasylenko@gmail.com

Abstract

A novel compact design of a broadband orthomode transducer with circular coaxial waveguide input and two orthogonal highly isolated rectangular waveguide outputs is presented. A neural-genetic algorithm is used to optimize the inner architecture of the OMT. Within the operational frequency band 3.4–4.2 GHz input return loss is less than –20 dB and isolation between ports is better than 30 dB. The TEM mode in coaxial structure is not excited due to the special design of the OMT.

Keywords: coaxial orthomode transducer, dual-band, neural-genetic algorithm, neural networks.

1. INTRODUCTION

Feed systems for reflector antennas used in radio astronomy and satellite communications have permanent demands placed upon them to improve the operational efficiency of the antennas. The problem can be solved by using dual-band or multi-band and dual-polarization systems. When frequency bands are widely separated it is the most reasonable to use a coaxial feed system: the coaxial structure propagates lower frequency band and interior hollow waveguide of coaxial feeding is dimensioned to propagate electromagnetic waves within upper frequency band. Orthomode transducers (OMT) that separates orthogonal polarizations within the same frequency band are often realized as turnstile junction [1] that uses a pair of orthogonally polarized ports, each with a pair of oppositely positioned launching ports. It is an effective way to launch the coaxial TE_{11} mode avoiding the fundamental TEM mode and the higher order modes. A major shortcoming of a turnstile configured approach is the significant size, weight and complexity. It is also known a compact coaxial OMT design [2] that uses a junction of T-septum coaxial waveguides and four T-septum sectoral waveguides. This OMT needs phasers, hybrids and power dividers that are built on the surface of the inner conductor. Such kind of OMT has the isolation 23 dB within the bandwidth of 4.4%.

In this paper we present a navel design of broadband coaxial OMT for the C-band (3.4 – 4.2 GHz) that has only two ports and relatively simple inner matching system and provides isolation between orthogonal ports better than 30 dB.

2. TRANSDUCER DESIGN

The OMT comprises an input coaxial waveguide of circular cross-section and two output rectangular waveguides that are radially coupled to the outer section of the coaxial waveguide (see fig.1). The axes of these three waveguides are orthogonal to each other. Output waveguides are axially displaced and spatially rotated (by 90°) about the longitudinal axis of the coaxial waveguide. In order to reflect a wave having a vertical plane of polarization a thin metallic plate is placed diametrically in the coaxial waveguide exactly perpendicular to the first output waveguide. The metallic plate is set partly in the interaction region of the coaxial and first output waveguide and has a part that short-circuits the coaxial waveguide for coaxial TE_{11} mode with polarization parallel to the plate and a part with linear tapering for better impedance matching. The length of the short-circuiting part is chosen to suppress the wave with the vertical polarization for 50 dB and more. Additionally, a good impedance matching is achieved by two pairs of tuning stubs: one in the coaxial waveguide in the same plane as the mentioned above metallic plate and one in the output rectangular waveguide (in the middle of the wide side of the waveguide). The metallic plate does not disturb the propagation of a wave having a horizontal plane of polarization. On the contrary a first output waveguide is a large discontinuity for this wave. To minimize the discontinuity influence on the wave propagation two septums are placed in the origin of the output rectangular waveguide in planes that are parallel to the wide side of the waveguide. The septums are also aligned with the inside surface of the coaxial waveguide completing the conducting path for longitudinal currents of the horizontally polarized wave and eliminating substantially the reactance discontinuity introduced by the first output waveguide. The architecture of the second output port for the horizontal polarization is the same except that metallic septums in the second output waveguide are not necessary. At the end the coaxial waveguide is short-circuited. Due to the metallic plates there is no need in dielectric ring supports of the inner conductor.

3. Optimization algorithm and numerical results

Optimization of the OMT is realized by the neural-genetic algorithm proposed in [3, 4] and efficiently applied to UWB antennas design. The microwave device to be optimized is realized as a “global” artificial neural network (ANN) model that consists of different modules representing the mapping from geometry parameters to device characteristics. A neural-genetic algorithm performs inversion of the neural network model using a genetic algorithm (GA) [5].

Each port of the OMT has been optimized separately. The parameters selected by the GA to find an optimum design are position and length of the tuning stubs in the coaxial and rectangular waveguide, position of the metallic plate relative to rectangular waveguide and the length of the linear tapering. Return loss of the OMT has been modeled at 21 frequencies uniformly distributed within a frequency range of 3.2 – 4.4 GHz that is slightly broader than an operational frequency range 3.4 – 4.2 GHz. OMT characteristics for the given geometry are obtained from the FDTD based full-wave simulation program CST Microwave Studio by using mesh of λ/10. A multi-layer perceptron as an efficient complex function approximator [6] is chosen to build up the neural network. To control complexity the ANN is trained to represent the mapping from geometry to the performance values of S11 at only one frequency. It is necessary 21 ANNs with a topology set according to experience as acquired from computer simulations: 6 input neurons corresponding to 6 optimization parameters, 3 hidden layers with 10 neurons and logistic sigmoid transfer functions in each of them and only 1 output neuron. Input and output minimum and maximum values were preliminary mapped to [0; 1]. Multilayer perceptrons were trained with a Levenberg-Marquardt backpropagation algorithm with Bayesian regularization. This approach minimizes a linear combination of squared errors and weights for better generalization. An early stopping in the algorithm prevents the activation values from becoming too large and the occurrence of neuron saturation during training, and, consequently, improves a quality of ANN training. By using 2000 and 1000 randomly selected combinations of the optimization parameters to train and verify the average error of the trained neural networks turned out to be less than 5% (or 0.022 in a linear scale).

For the inversion the fitness function is constructed as follows:

$$fitness = \sum_{n=1}^{21} |S11 - S11\_spec| \qquad (1)$$

where $S11\_spec$ is a specified value of the return loss at each of 21 frequencies; $S11$ is a return loss obtained from the ANNs for each combination of the optimization parameters. Due attention, however, should be given to the physical realizability of the device parameters required. In this investigation $S11\_spec$ is chosen to be 0.05 at all frequency points.

The GA used for the inversion is binary and of steady state type with a replacement rate of 0.5 using a random roulette wheel selection and double point crossover. This implies that half of the population is carried on from one generation to the next. GA is initialized by starting from a randomly generated population. Each optimization parameter is coded by 10 bits. Double point crossover is efficiently executed on randomly selected chromosomes and mutation changes the value of a random gene with a very small mutation probability of 0.01. A large population size of 6000 is used in the GA based inversion in order to ensure that an opti-

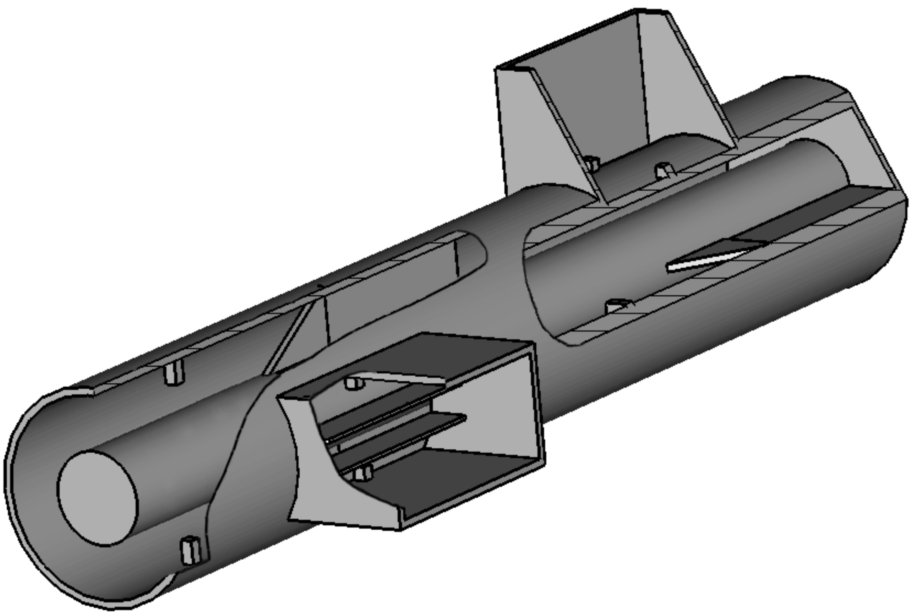

Fig. 1. A three-dimensional view of the OMT optimized design.

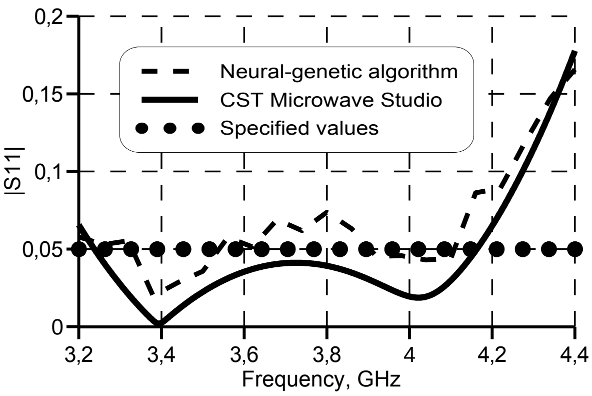

Fig. 2. Return loss of the OMT 2nd port obtained using neural-genetic algorithm.

mum solution is found. The GA optimization is stopped when the cost of the best chromosome differ from an average of the 50% best chromosomes in a population not more than 1% for minimum 5 generation. It means that optimization is stopped when the probability of an appearance of new information in chromosomes is negligible.

A three-dimensional view of the optimized OMT architecture is shown in Fig.1. The thin metallic plate begins approximately from the axis of the output rectangular waveguides. The optimization of the linear tapering and position of the metallic plate ensures the return loss less than 0.3. For a better matching the tuning stubs in the rectangular waveguide are placed exactly at the boundary with the outer conductor of the coaxial waveguide.

Optimization takes 76 hours: 75 hours for the training data generation, 1 hour for ANN training and less than 1 minute for GA inversion. Since OMT architecture is relatively simple a powerful computer is not needed. Therefore optimization can be realized by parallel computing (for example in the computer classroom) reducing the optimization time proportionally to the number of computers. The specified values for return loss of the optimized design serve as an average value (Fig. 2) since there is not much flexibility in the geometry of the OMT to fully realize the specified values of S11. The difference between OMT return loss predicted by the ANN and computed for the optimized design using CST Microwave Studio is on the average 0.02 (Fig. 2) that agrees well with the precision of the trained ANNs.

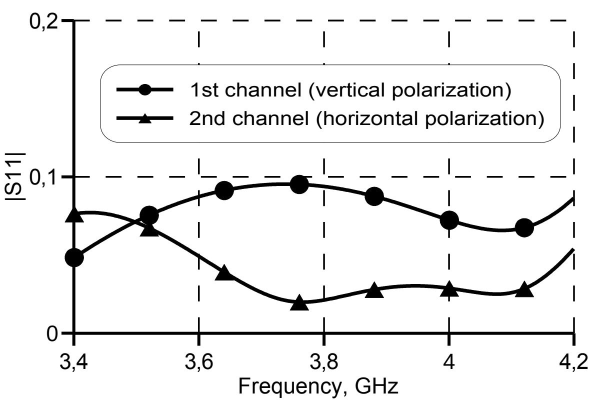

Fig. 3. Return loss of the OMT ports obtained by final inspection with the mesh size of λ/50.

In this paper, only the port without septums in the rectangular waveguide (horizontal polarization) is optimized. Return loss of the OMT ports obtained by final inspection with the mesh size of λ/50, as shown in Fig. 3, is better than 0.1, the computed isolation between ports is better than 50 dB. Measured isolation between ports (in combination with a dual-band horn) is within 30–40 dB. If better characteristics are needed optimization should be held using a smaller mesh size and taking in account metallic septums of the first output port.

4. Conclusion

A broadband coaxial orthomode transducer design is proposed in this paper. It is superior to the turnstile design in such parameters as size, weight and complexity. OMT with the optimized geometry has the isolation between ports more than 30 dB and return loss less than 0.1.

A neural genetic algorithm previously used for the optimization of UWB antennas has shown its effectiveness for the optimization of the microwave devices as well.

References

1. A. Navarrini and R. L. Plambeck, “A turnstile junction waveguide orthomode transducer,” *IEEE Trans. Microw. Theory Tech.*, vol. MTT-54, no. 1, pp. 272–277, 2006.
2. H.Z. Zhang, “Dual-band coaxial feed system with ridged and T-septum sectoral waveguides,” *IEE Proc.-Microw. Antennas Propag.*, Vol. 152, No. 5, pp. 305-310, 2005.
3. F.F. Dubrovka, D.O. Vasylenko, “ Synthesis of UWB planar antennas by means of natural optimization algorithms,” *Radioelectronics and Communications Systems*, Vol. 52, Issue 4, pp. 167-178, 2009.
4. D.O. Vasylenko, P. Edenhofer and F.F. Dubrovka, “Genetic algorithm based inversion of neural networks applied to the optimized design of UWB planar antennas,” *Electronics Letters*, Vol. 44, Issue 3, pp. 177 – 179, 2008.
5. Y. Rahmat-Samii and E. Michielssen, *Electromagnetic optimization by genetic algorithms*. New York: J. Wiley, 1999.
6. S. Haykin, *Neural Networks: A Comprehensive Foundation*. Prentice Hall, NJ, USA, 1994.