Application of higher-order wave modes filter for measurement of phased antenna array elements

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***Abstract.* The paper presents the results of the development and application of higher-order modes filter for measurement of phased antenna array elements with circular polarization. Comparative results of main electrical parameters measurement with and without a filter are presented.**

Keywords: septum polarizer; polarization selector; microwave filter; microwave absorber; phase shifter; phased array antenna element;

I. INTRODUCTION

One of the most important production stages of phased array antenna elements is the measurement of main electrical parameters. The task of developing a measurement bench, including its parts, is comparable in complexity to the development of the antenna elements themselves.

To measure the parameters of phased array antenna elements, they are placed in a simulated antenna or measurements are taken directly in phased antenna array. However, such methods are laborious and do not allow to estimate some parameters with the required accuracy. A common technique is the development of special test fixtures or measurement benches connected to standard coaxial or waveguide transmission lines with standard connectors / flanges. However, in some cases, resonance phenomena occur that are inherent directly to test system and causes measurement errors, which not showing actual behavior of elements in phased antenna array. For example, if measurement results show high insertion loss caused by resonance phenomena in such test facility, this element can be unreasonably rejected. It can only pass the test when statistical apparatus of modern measuring technology such as smoothing is used to obtain a suitable result, or Insertion Loss peaks are ignored by agreement. To obtain the most correct measurement results, it is possible to use special techniques of microwave paths constructing (for example choke flanges) and functional units such as filters, rejection or absorbing plates, tuning elements of the microwave path, etc.

II. MEASUREMENT BENCHES

To measure the main electrical parameters of phased antenna array elements with circular polarization, benches based on 2 typical units of the microwave path are mostly used: 1) a polarizer based on a dielectric plate in a circular waveguide (Fig. 1), 2) a septum polarizer (Fig. 2).

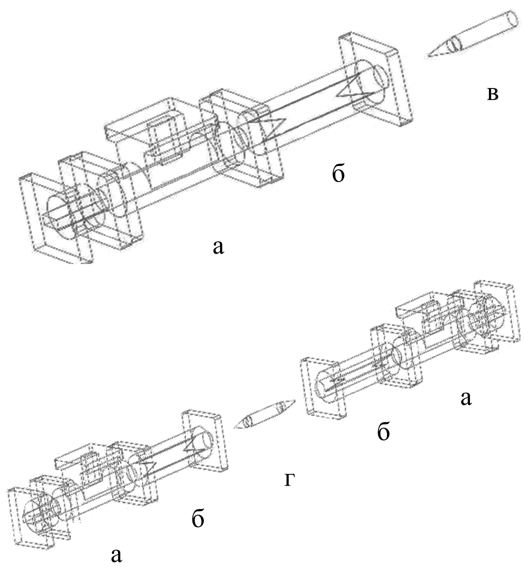

Fig. 1 – Measurement benches based on the dielectric plate polarizer. a – polarization selector, b – dielectric plate polarizer, c –reflective or combined feed (coaxial, waveguide, etc) phased array antenna element, d – transmissive phased array antenna element

Today, the most popular and modern test benches are based on septum polarizers. There are two main reasons for such popularity: simplicity of its calculation and simulation in modeling software like Keysight EMPro and high manufacturability. The last reason lies in the possibility of manufacturing a waveguide path with a polarization element in one setup on a CNC machine. In this case, the maximum possible accuracy of manufacturing achievable[1].

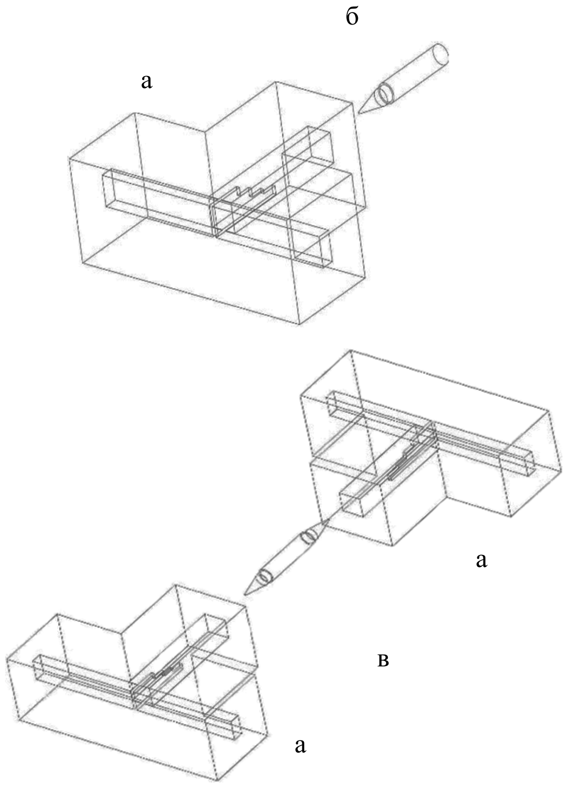

Fig. 2 - Measurement benches based on the septum polarizer. a – septum, b – reflective or combined feed phased array antenna element, c – transmissive phased array antenna element

III. MEASUREMENT SPECIFICS

The main electrical parameters include insertion loss. One specific of insertion loss measurement is different conditions for the propagation of electromagnetic waves in test fixture and real phased array antenna. An analysis of the typical insertion loss curves during production of elements shows that loss increase at certain phase states or insertion loss peak travelling over the frequency range depending of phase state have a different nature: components defect, assembly defect or caused by measurement bench. Sorting of insertion loss errors can significantly increase the output of quality products. One of the unpredictable floating defects is the appearance of a narrow 3..10 dB insertion loss peak, which level and frequency differently and unpredictably depend on phase state and significantly varies with small movement of measured element inside of test fixture or changing its alignment relative to the center axis of the measuring path, and sometimes affected by replacing the test fixture. The reason for its occurrence is the excitation of higher-order modes of waves in the microwave path: septum polarizer - adapter - measured element, due to many reasons: incomplete galvanic contact between element and test fixture, misaligned positioning of element in test fixture, etc. To overcome this phenomenon, the following solutions were tested: development of an adapter with a waveguide choke connection, development of a polarizer with a smaller cross-section that does not allow excitation of higher-order modes, etc. However, the most effective method was the use of a higher-order modes filter.

IV. HIGHER-ORDER MODES FILTER IN CIRCULAR WAVEGUIDE

In a circular waveguide, the main mode is considered to be H11.[2] The theory of the higher-order modes filter in circular waveguides is already known. Unlike H11, other modes contain a longitudinal component of the electric field. A long absorbing element (resistive element) is placed in the center of the waveguide channel. When various wave modes pass through, they are either reflected or attenuated in the section with the absorbing element, except of the H11 mode.

In our case, this simple task was complicated by the fact that it was necessary to make a filter in the Ka-band (26-40 GHz). It should have the lowest possible utilization factor for H11 mode and minimum effect on ellipticity factor when H11 propagates in a waveguide.

To implement this filter, we used a material with a low dielectric constant ($\varepsilon<4$) and a resistive element with a diameter of D <0.5 mm and a length of $\sim\lambda$ (Fig. 3). The resistance of this element was selected close to the characteristic impedance E01.

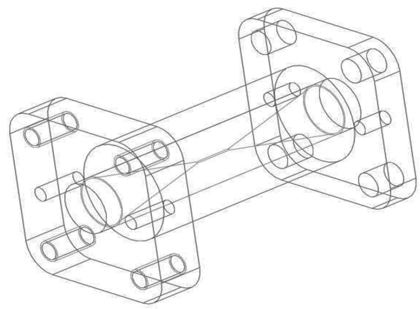

Fig.3 – Higher-order modes filter design

V. MEASUREMENT RESULTS

To estimate the efficiency of using the higher-order modes filter, comparative measurements of reflective phased array antenna elements were carried out in a bench based on the septum polarizer with and without a filter. It should be noted that the quality factor Q of the "parasitic" loss peaks which occurs with the variation of element positioning in the test fixture is more than 1000. This correlates well with the theory of propagation of electromagnetic waves in a circular waveguide in terms of using the E01 wave for transmitting microwave signals over long distances due to its high Q factor.[2]

During main electrical parameters of phased array antenna element measurement, the insertion loss in the operating frequency range at various phase states were recorded. Fig. 4 shows 2 sets of typical insertion loss without filter and with filter installed.

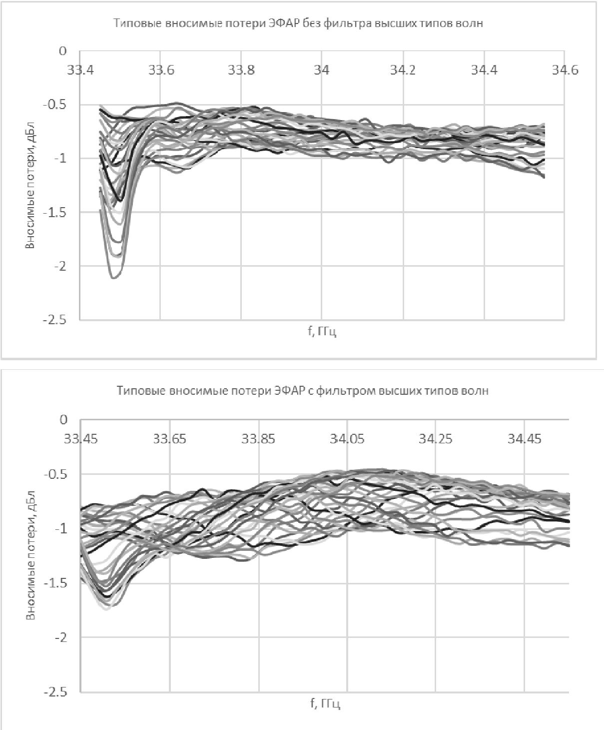

Fig. 4 Typical insertion loss curves at different phase states

In case of the presence of an insertion loss peak in a particular sample, its amplitude significantly reduces with filter. In some cases, there is a complete "cutting out" of such "floating" loss peaks, regardless of the element positioning in test fixture.

It can be noticed that set of insertion loss curves in different phase states becomes “wider” when using a filter. It can be a consequence of a non-zero ellipticity factor of the filter itself.

VI. CONCLUSION

The developed filter with an optimally selected resistive element makes it possible to decrease or even eliminate the resonant effects of the insertion loss. It allows more correctly estimate the insertion loss of phased array antenna elements even in the case of "pumping" the main mode energy into higher-order modes oscillations due to imperfection of test bench. The use of a filter in measuring bench during the production of phased array antenna elements makes it possible to increase the output of quality products due to a selective approach to the assessment of defects.

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