Waveguide DC breaks for TE$_{01}$ and HE$_{11}$ microwave transmission lines

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Introduction

Oversized waveguide are widely used in high power and high frequency microwave setups. Low modes in such waveguides have relatively low losses in gaps several wavelengths long [1], which make it possible to use waveguide gaps for DC insulation. Further optimization of DC breaks is possible by introducing waveguide taper converters at both sides, which are designed to increase beam quality and increase waveguide radius at its ends. The method of synthesis of such converters developed earlier by authors allowed to decrease the losses by an order of magnitude or more in comparison to simple break [2], but improvements are possible to make the converters smaller and keep losses near the theoretical minimum limited by diffraction.

Waveguide system synthesis with multi-region field analysis

The optimized DC break consists of two waveguide converters separated with air or vacuum gap and some other components, which may be exposed to high-power electromagnetic field, e.g. insulated box around the gap and some parts of cooling system. Direct analysis of fields in the whole system may take quite a long time, and synthesis usually requires several tens of calculations. To increase the speed, we separated the calculations into several parts (Fig. 1). Fields in region II can be calculated by fast methods like coupled modes or mode-matching, but region III of arbitrary shape requires slow direct methods. In low-loss DC break, only a few low modes are present inside the waveguide converters, therefore we can calculate the radiation of each of these mode from transmitting waveguide cross-section into region III once and then decompose the results into several waveguide modes at the receiving end to form a low-dimension transmission matrix. In general case, this approach has very low precision, but in a special case where transmission efficiency is very high, it produces good results and allows us to skip slow direct field calculations within the iteration loop.
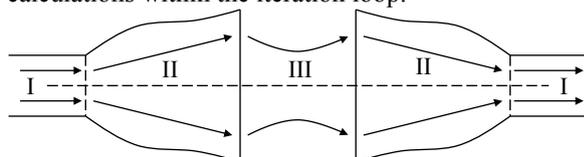
Fig. 1. Waveguide break parts: I – regular waveguides of transmission line, II – waveguide converters, III – interior of insulated box.

The synthesis of converters is based on the previous work made by authors [3]. At the beginning of every iteration step the system (Fig. 2) consists of the given input cross-section S_1, given output cross-section S_2 and initial conducting wall surface S_0. If we consider only one orientation, then conversion efficiency can be is increased after iteration by calculating two field distributions inside the waveguide. The first one is calculated using the given $\mathbf{E}_1$ and $\mathbf{H}_1$ fields at the input as a boundary condition, the second one by using the spatially reversed desired $\mathbf{E}_2$ and $\mathbf{H}_2$ fields at the output. Small and smooth deformation l orthogonal to waveguide wall affects the efficiency (mutual power) P according to formulas

$$\Delta P = \int_{S_0} l F\, dS, \quad F = -ik\left(\mathbf{H}_{\tau 1}\mathbf{H}_{\tau -2} + \mathbf{E}_{n1}\mathbf{E}_{n-2}\right) \quad (1)$$

where τ and n means tangential and normal field components, respectively. We can minimize the average square of deformation (i.e. norm) using real and imaginary parts of (1) as equality constraints with given ΔP, and in this simple case the deformation takes the form

$$l = \alpha \operatorname{Re} F + \beta \operatorname{Im} F \quad (2)$$

where constants α and β are expressed by ΔP and surface integrals of function F [4].
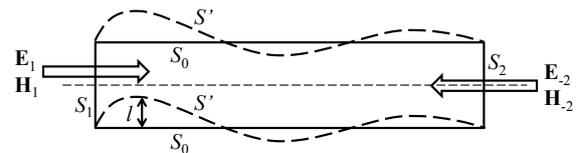
Fig. 2. Waveguide synthesis notations: two given waveguide cross-sections S_1 and S_2 (input and output, respectively), the waveguide surface before iteration S_0 and the surface after iteration S', the deformation value l at some point of the surface, the specified input fields $\mathbf{E}_1$ and $\mathbf{H}_1$, and the reversed desired output fields $\mathbf{E}_{-2}$ and $\mathbf{H}_{-2}$.

At the first iteration the fields in the simplified representation are far from the real ones, but as the synthesis converges the accuracy increases.

DC break for TE$_{01}$ mode

The break for TE$_{01}$ transmission line have to be able to withstand 80 kV voltage, the operating frequency of the setup is 28 GHz, and the radius of the transmission line is 16.27 mm. The gap length equal to 100 mm is enough withstand the required voltage with allowed static field strength 30 kV/cm, as the field bigger near the waveguide ends. The waveguide radius at its ends have to be 50 mm to transmit the wave beam with very low losses. The length of each synthesized waveguide converter is 318 mm, and the total calculated efficiency is 99.8% at the central frequency (Fig. 3). The DC break passed the tests at voltages up to 85 kV limited by the voltage source available, and low power microwave tests which show the transmission efficiency 99%±1%.
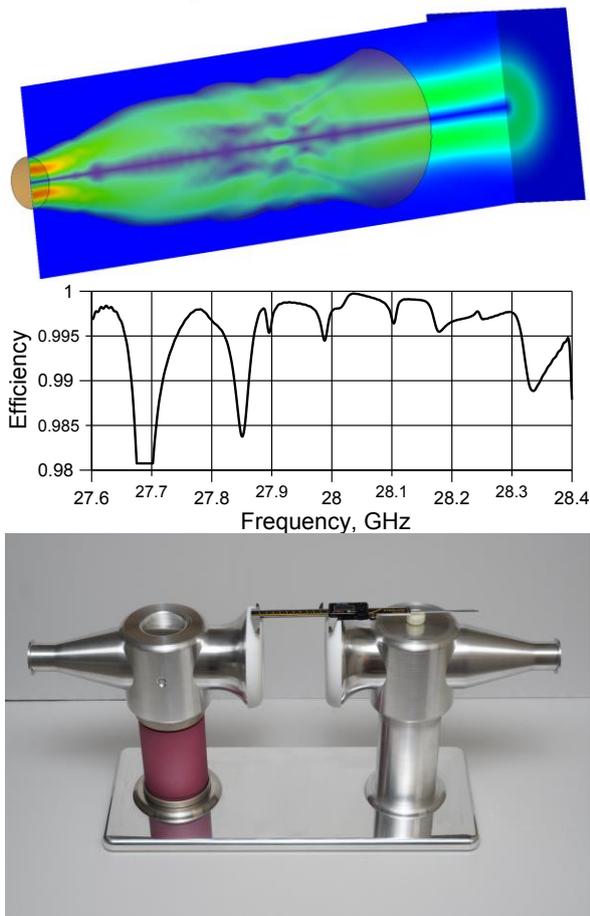
Fig. 3. Top – waveguide converter for TE_{01} mode break and cross-section of the electric field; middle – calculated transmission efficiency (FDTD); bottom – DC break in configuration used for high voltage tests.

Wideband DC break for HE$_{11}$ mode

Special wideband version of DC break was synthesized and tested for HE_{11} mode. Able to withstand 50 kV, this break has waveguide converters 270 mm length each with radius changing from 20 mm to 31.75 mm, gap length 63.5 mm and was designed to work in frequency band 28.5-31.5 GHz. Calculated efficiency is at least 97.5% in 5% frequency band and at least 95% in 10% frequency band. Measured efficiency agrees well with calculations in 5% band, but drops in 10% band (Fig. 4), which may be the result of the limited precision of low-dimension transmission matrix.
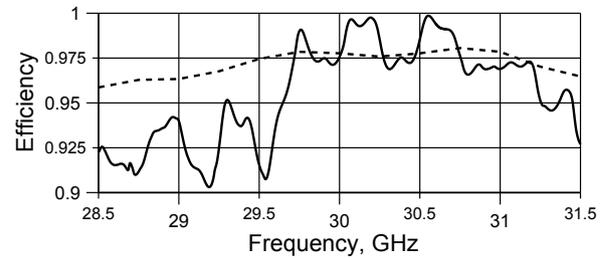
Fig. 4. Wideband DC break for HE_{11} mode: dashed line – calculated transmission efficiency, solid line – measured transmission efficiency.

References

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