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Wideband TEM-TE11 mode convertor for HPM applications.

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Abstract. The mode convertor design of fundamental coaxial TEM to the lowest asymmetric TE11-mode of a circular waveguide was proposed and optimized with ANSYS HFSS software. It includes axially aligned parts: the input coaxial line with the high voltage insulator, conical coaxial matching line, wave-coax transition section and output circular waveguide. The most losses in this type of convertor caused by the wave of coaxial TE11-mode running back to the microwave source. To minimize these losses, there is the matching conical coaxial line with the cut-off insertion for coaxial TE11-mode. Characteristics of the convertor are as follows: the maximum input peak power – 3GW, the input impedance – 28Ohm, the central operating frequency – 1.14GHz. The power conversion efficiency to the output mode is from 90% upto 100% in the frequency band of 20%.

1. Introduction

The interest in wide-band transformers of the principal coaxial wave (TEM) to a low asymmetric mode (TE11) of the circular waveguide is kept up by the development of generators of the high-power microwave pulses with the subnanosecond and nanosecond duration, where the microwave pulse is formed in coaxial lines: the generators of the ultra wide band (UWB) pulses, sources based on Non-linear transmission line (NLTL), coaxial vircators and etc.[1-3]. Other devices that needed the wideband output section are generators with wideband frequency tuning [4].

The short pulse duration as well as the basic principles of operation result in HPM pulses with the frequency band of about 10% or more. There is a number of patents and papers devoted to the coax-to-waveguide transitions where axes of the waveguide and the coaxial are orthogonally placed. Among them the “door knob” type is the only that meets HPM requirements.

The closest structural analogue of the transformer proposed had been developed more than fifty years ago [5]. There are the coaxial and the rectangular waveguide sections that placed axially. They are electromagnetically coupled by the coaxial inner conductor extended into the waveguide and angled to the axis. Sometimes, the axial coaxial-to-waveguide transition is preferable to develop a compact design of an assembly. This paper stated the high quality of the matching the transmission lines with the power reflection level of about 1% in the frequency band of 2.6-3.6GHz. That corresponds to the operating band width of about 35%. However, the device is not intended for the high power operation because of the step-like coax-to-waveguide junction and the sharp edges of the matching elements.

As opposed to the converter described [5], the paper proposed the structure with a circular waveguide instead of the rectangular one. The axial geometry of the elements simplifies their production with the increased mechanical and electric strength. Another big difference is the matching coaxial – conical line used to eliminate the step-like coaxial-waveguide junction. These distinguishing features are the reasons of the significant increase in the converter's breakdown level.

The aimed maximal peak power of 3GW was calculated under condition of the 300kV/cm upper limit for electric field strength at regular sections. This value matches the value of the static breakdown for most dielectrics including the insulating oil used in a high voltage equipment. The structure requires the output section filling with SF6 up to 5atm of overpressure. The vacuum insulation is allowed as well.

ANSYS HFSS software [6] was used to analyze the wave modes presented in the structure. It was revealed that the key factor which impacted the efficiency and the band width of the converter was the excitation level of the lowest coaxial non-symmetrical wave TE_{11coax}. To minimize the power fraction transformed into the TE_{11coax} mode, a short rejecting line was provided in the converter. That enabled us to essentially increase the efficiency of the frequency wideband conversion into the operating mode TE_{11}. In numerical simulation, the power conversion into the TE_{11} mode from 0.9 upto 1.0 was obtained within the 20% band with the central frequency of 1.14GHz.

The structure, which is similar to the proposed one excluding the rejecting line, was used with the horn antenna for emission of the microwave radiation in the work [2]. As the simulation proved, the use of the structure without the rejection line decreased the conversion efficiency of the TEM wave power into the operating mode for about 20%. The experiments demonstrated the breakdown in the gas filled section of the converter. Using the SF_6 under the overpressure of 2-3atm helped eliminate the breakdown at the output power level of 260MW.

2. The Converter Structure

The structure of the proposed converter presented in figure 1 includes the following sections.

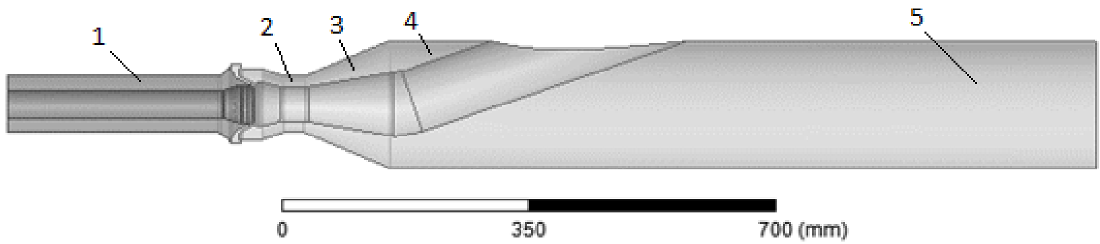

Figure 1. The view of the mode convertor: 1 - oil filled input line, 2 – TEM_{11coax} rejecting line, 3 – conical coaxial matching line, 4 – coax-to-waveguide transition, 5 – output waveguide.

Input section (1) is the coaxial line with the impedance of 28Ohm filled with insulation oil. The inner diameter of the outer conductor is 8 cm. The input line is separated from the gas filled sections by a high-voltage Nylon6 insulator. The rejecting coaxial line (2) has the impedance of 28Ohm. The inner diameter of its outer conductor is 8cm. The conical coaxial matching line (3) has the length of 12cm. The angular aperture is of 45^0. The impedance at the larger base crossection is about 41.5Ohm. The coax-to-waveguide transition (4) was designed as the prolongation of the inner conductor of the matching line angled at 20 degrees from the axis. The output section (5) is the circular waveguide with the inner diameter of 18cm.

3. Numerical Simulation

The proposed structure (figure 1) is the result of modifying the axis coaxial waveguide transition, where the coaxial outer diameter is equal to the diameter of the circular waveguide (see figure 2). The coaxial and waveguide are coupled by the junction, designed as the prolongation of the inner coaxial

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conductor angled to the axis and electrically linked to the common outer conductor. This configuration was numerically simulated with the discrete variations of the inner conductor diameter and of the junction slope angle. The junction slope angle was varied within the range of 10-90 degrees, the coaxial impedance was within the range of 20-60Ohm. The research was aimed at the achievement of the maximal band width with the highest conversion coefficient of the TEM wave to the circular waveguide mode TE_{11}.

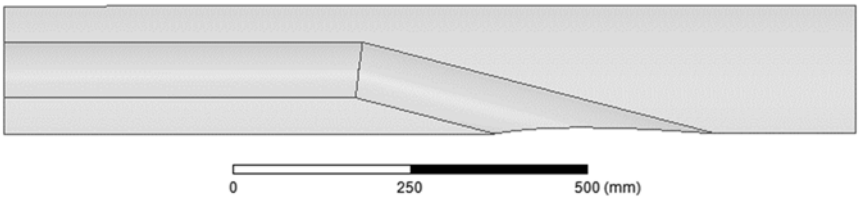


Figure 2. The coaxial-to-waveguide transition with the common outer conductor.

The most successful results in this configuration were obtained when the coaxial impedance ρ was within 30-50 Ohm and the junction slope angle β was 15 – 20 degree. It was revealed that the conversion coefficient K_{conv} approximate to 1.0 was hardly possible to be obtained under various ρ and β combinations even at the narrow frequency band. The typical value of K_{conv} was 0.8.

The simulation results for the instance with the ρ = 50Ohm and β = 15^0 are presented in figure 3. The power conversion coefficient K_{conv} to the output TE_{11} mode is about 0.8 in the band of 1-1.4GHz (figure 3a). The rest power fraction of 0.2 is transformed to the reflected TEM and TE_{11coax} modes (figure 3b). In this case, the most losses are attributed to the TE_{11coax} mode, while the fraction of reflected TEM mode is of few percent near the central frequency. Any changes in the coaxial impedance and the junction slope angle result in the reproportioning between the reflected modes and irregularity for the output power dependence on frequency.

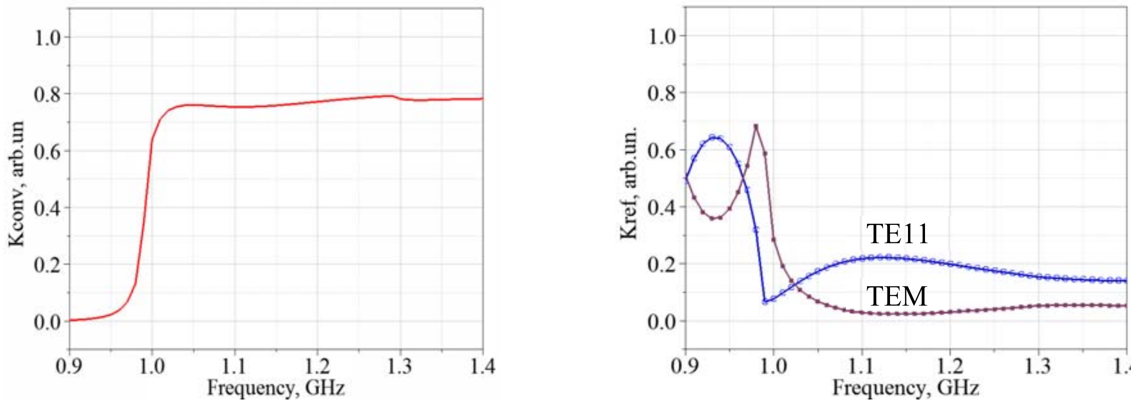
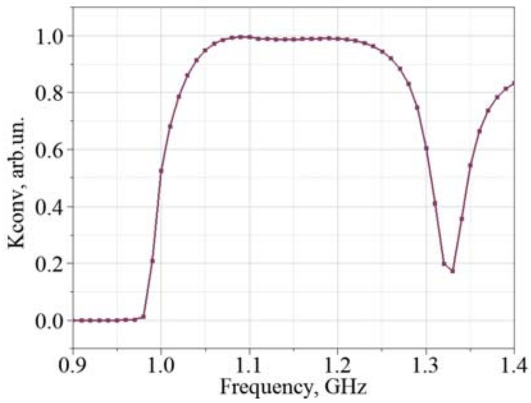
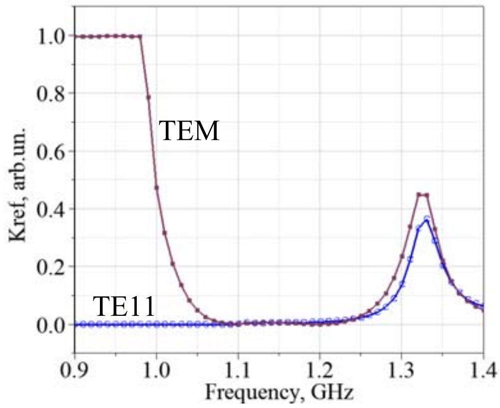


Figure 3. Simulation results for the coaxial-to-waveguide transition with the common outer conductor: a – conversion power coefficient to the TE_{11} output mode, b – reflected power coefficients for TEM and TE_{11coax} modes.

The numerical simulation results of the optimized construction of the mode convertor are presented in figure 4. The dependence of power conversion coefficient Kconv to the output mode on frequency is shown in figure 4a. The operating bandwidth determined by the level Kconv = 0.90 is of 20% with the central frequency of 1.14GHz. The reflected power coefficients for coaxial TEM and TE_{11} modes are presented in figure 4b.



a)



b)

Figure 4. Simulation results for the proposed convertor: a – conversion power coefficient to the TE_{11} output mode, b – reflected power coefficients for TEM and TE_{11coax} modes.

4. Conclusion

The mode convertor from the coaxial TEM mode to the fundamental TE_{11} mode of circular waveguide with axially aligned input and output was proposed and numerically simulated. The power conversion efficiency obtained was 0.90 – 1.00 within the 20% band and the central frequency was 1.14 GHz. The maximum operating power is supposed to be about 3GW using SF_6 gas with about 5atm overpressure in the output section. The main effect constraining the operating band is the exciting of the coaxial TE_{11} mode. The recent experiments [2] proved that such type of mode convertor is capable to operate with the microwave pulse of a few nanosecond duration with GW power level in the L band.

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