New Compact Mode Converters for SLAC RF Pulse Power Compression System*

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Abstract

A RF pulse power compression scheme has been developed at SLAC (Stanford Linear Accelerator Center) where they adopt a method of a long delay line, in an overmoded circular waveguide, to rephase the transmission mode. A low loss mode, TE_{01} in a circular waveguide is required. However, the output mode of a megawatts klystron is a TE_{10} mode in rectangular waveguide. A transition and mode conversion system needs to be developed. Conventional mode conversion sequence of TE_{10}, in rectangular waveguide, to TE_{01} mode, in circular waveguide, is using Marie' Transition which requires very long transition length and very complicated structure. We have developed several mode converters with very compact length and high efficiency. The proposed conversion sequence is TE_{10}-TE_{11}-TE_{01}. In this sequence, our main interests are in developing the TE_{11} and TE_{01} uptaper, and TE_{11}-TE_{01} serpentine mode converter at 11.4 GHz.

I. INTRODUCTION

High-power microwave tubes producing output power from several kilowatts up to many megawatts often generate modes which are not suitable for long distance transmission, plasma heating and radar applications. To obtain a more desirable mode, a sequence of mode converters is often used with various high-power microwave sources such as gyrotrons, and klystrons.

In order to produce high-gradient linear accelerators (Linac) for next generation linear collider, it is required several hundreds of megawatts of peak power per unit length. Binary Pulse Compression (BPC) is a promising technique to deliver, at least, a five-fold peak power output compared to the input peak power [1]. This technique increases peak power at the expense of reducing the pulse width which was still long enough to fill the accelerator section.

The delay line, which was used at the BPC system, has the freedom to operate the propagation mode, such as TE_{01} mode, in an overmoded circular waveguide. The TE_{01} mode was operated at considerably above cutoff frequency, for example, 11.4 GHz with 3.57 cm of waveguide radius. We can have negligible ohmic loss even with a small diameter pipe. With the consideration of available pulse klystron and Linac, an X-band microwave frequency, 11.4 GHz, has been chosen as operating frequency at current stage.

The proposed transmission and conversion sequence was shown in Fig.1 [2]. In the following sections, we will use these conversion sequence and waveguide radius to design our mode converters and tapers at 11.4 GHz.

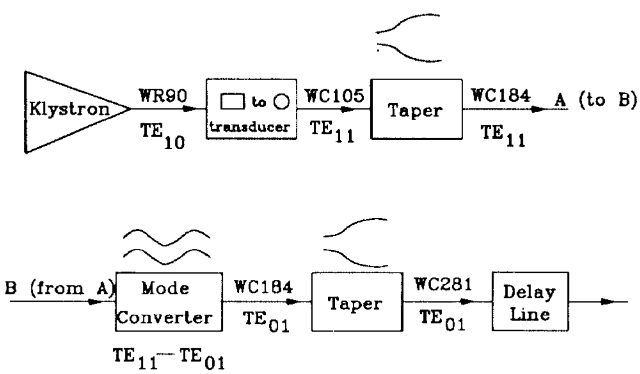

Figure 1. The purposed transmission modes, waveguide size, and conversion sequence for binary pulse compression system at 11.4 GHz operating frequency.

II. VARYING-RADIUS MODE CONVERTERS

A. Coupled Mode Equations

For varying-radius mode converters, the coupled mode equations for the TE_{0n} modes can be written in the form of [3]

$$\frac{dA_n}{dz} = \beta_n(z)A_n(z) + \sum_{j\neq n} C_{nj}(z)A_j(z)$$

where $\beta_n(z)$ is the propagation constant of mode n at location z. $|A_n|^2$ is the power that transported in positive z direction by mode n. C_{nj}, as function of z, is the coupling coefficient between mode n and mode j.

For quasi-periodic varying radius mode converters following Kovalev [4], we used a radial variation of the form

$$a(z) = a_0 + \varepsilon_1[1 - \cos(H(z))]$$

where a_0 is the input waveguide radius, ε_1 is the perturbation amplitude of waveguide taper. $H(z)$ is a harmonic function of the beat wavelength between the transmission mode and the strongest coupled nearby-mode. A multi-dimension

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optimization scheme has been used to optimize the tapers such that we will get the best conversion efficiency with very compact structure. The backward traveling modes, calculated by shooting method to match the two points boundary condition, have been shown to be negligible in all the cases considered here.

B. The Designs of TE_{01} and TE_{11} Uptaper

A TE_{01} uptaper has been designed from the waveguide radius of 2.34 to 3.57 cm. For the varying-radius mode converter, TE_{0n} modes will couple with TE_{01} mode. The taper length is 15 cm with 99.9% of transmission efficiency and 0.05% of ohmic loss. The waveguide profile can be expressed as following

a(z) = .0234 + .00615(1 - cos(20.94z - .1sin(20.94z))].

As shown in Fig. 2, a TE_{11} uptaper with input diameter of 2.67 cm and output diameter of 4.67 cm has been designed. The coupled TE_{1n} and TM_{1m} modes families were considered for the case of TE_{11} uptaper. The overall length of the taper is 13.1 cm with 99.8% of transmission efficiency and 0.13% of ohmic loss. The profile of the mode transducer can be written as

a(z)=.0133 + .00503[1 - cos(23.98z - .06sin(23.98z))].

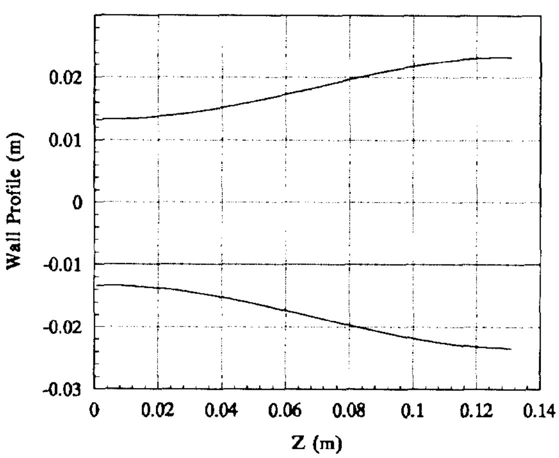

Figure 2. The waveguide profile of an optimized 11.4 GHz TE_{11} uptaper with input and output diameter of 2.67 and 4.67 cm respectively.

IV. TE_{11}-TE_{01} SERPENTINE MODE CONVERTER

A similar coupled mode equations can be found by using Morgan's [5] method for a constant-radius serpentine-type mode converter. The coupled mode equations can be written as

$$\frac{dA_n}{dz} = \beta_n A_n + \sum_{j\neq n} C_{nj} A_j$$

where A_n is the amplitude of mode n, β_n is the propagation constant of mode n at waveguide radius a_0. C_{nj} is the coupling coefficient between mode n and mode j, which is independent on z.

The coupling coefficients for the modes that we are interested in can be derived by applying perturbation theory and solving the Maxwell's equations for the waveguide surface deformation.

We only consider the first and second order coupling. The third order coupling is too small to be included as we try to optimize the conversion efficiency. A very strong coupling between TE_{11} and TE_{21}, and TE_{01} and TE_{12} has been found during solving the coupled mode equations.

From conventional design philosophy, it would be possible to design a mode converter using a large number of perturbation periods to suppressed spurious modes. However, it is not a practical solution while we consider the ohmic loss, frequency response, and the available space to accommodate the mode converter. A quasi-periodic structure has been used to optimize the structure of the serpentine mode converter.

It is very difficulty to find a high efficiency mode converter with perturbation period less than 3-periods. The coupling diagram is shown in Fig. 3. The mode contents of the TE_{11}-TE_{01} serpentine mode converter along the waveguide axis is shown in Fig. 4. The detail waveguide profile can be expressed as following:

For the first section,
a(z) = .0234 + .391*10^{-2}{1 - cos[62.33z + .829sin(62.33z) + .028sin(124.7z)]} where $0 \leq z \leq .1008$ m.
For the second section,
a(z) = .0234 + .665*10^{-2}{1 - cos[42.89z - .101sin(42.89z) + .350sin(85.78z)]} where $0 \leq z \leq .1465$ m.
For the third section,
a(z) = .0234 + .405*10^{-2}{1 - cos[55.65z + .114sin(55.65z) + .179sin(111.3z)]} where $0 \leq z \leq .1129$ m.

The waveguide profile of the optimized mode converter was shown in Fig. 5. The conversion efficiency is 98.9% with .19% of ohmic loss. The output mode purity is 99.1% with overall length of 36.02 cm.

V. CONCLUSION

A series of compact mode converters have been designed which can be used as a substitution of current Marie' Launcher and the tapers at current BPC system. The mode purity of the designed serpentine-type mode converters and tapers were above 99%. A similar computer codes has been used to design a single-period TM_{01}-TE_{11} serpentine mode converter at 8.6 GHz [6]. The measurement results of previous designed mode converter, TM_{01}-TE_{11}, were in excellent agreement with the computer simulation.

VI. ACKNOWLEDGEMENT

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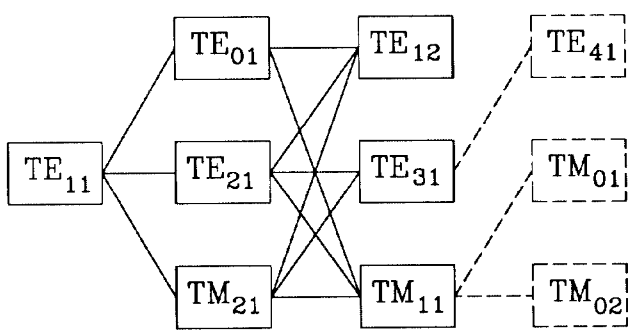

Figure 3. Coupling diagram of a TE_{11}-TE_{01} single plane serpentine mode converter at 11.4 GHz with a diameter of 4.67 cm.

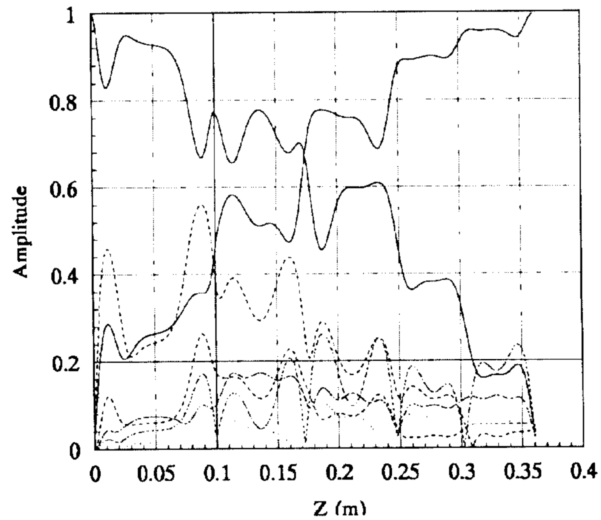

Figure 4. The mode contents along an optimized 11.4 GHz TE_{11}-TE_{01} serpentine mode converter with 4.68 cm of diameter. The TE_{01} output mode purity is 99.1%.

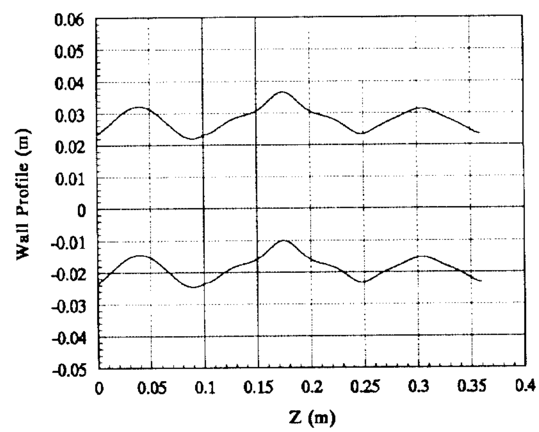

Figure 5. The waveguide profile of an optimized 11.4 GHz TE_{11}-TE_{01} serpentine mode converter with waveguide radius of 2.34 cm.