



HAL
open science

Hybrid numerical calculation method for bend waveguides

Lucas Garnier, C. Saavedra, Rigoberto Castro-Beltran, José Luis Lucio,
Bruno Bêche

► **To cite this version:**

Lucas Garnier, C. Saavedra, Rigoberto Castro-Beltran, José Luis Lucio, Bruno Bêche. Hybrid numerical calculation method for bend waveguides. Journée Projets Master Photonique et Programmation Matlab, Jan 2017, Rennes, France. 2017. hal-01445934

HAL Id: hal-01445934

<https://hal.science/hal-01445934>

Submitted on 25 Jan 2017

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Abstract

The knowledge of how the light will behave in a waveguide with a radius of curvature becomes more and more important because of the development of integrated photonics, which include ring micro-resonators, phasars, and other devices with a radius of curvature. This work presents a numerical calculation method to determine the eigenvalues and eigenvectors of curved waveguides. This method is a hybrid method which uses at first conformal transformation of the complex plane generating a new and modified index profile that represent the curvature. Then, on this modified index profile, we use a matrix multilayer formalism; we divide the profile in virtual layers of various indices to calculate both the propagation constants (eigenvalues) and the optical field (eigenvectors) into each of such virtual layers.

Conformal Transformation

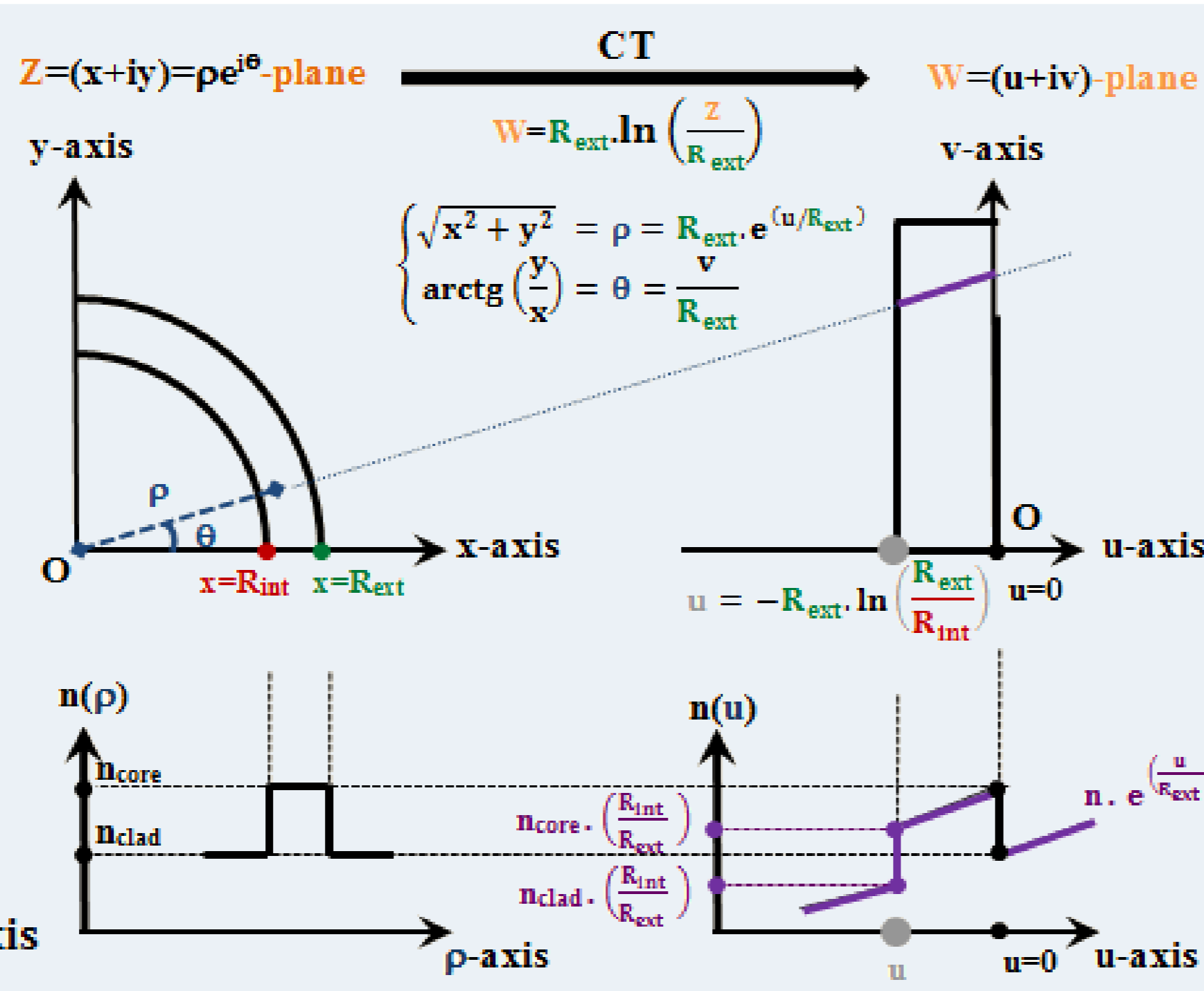


Figure 1 : Conformal transformation of the complex plane used in the calculations onto non-bended waveguides generating new modified index profiles ; the wave equation becomes :

$$\left\{ \Delta_{u,v} + k_0^2 n^2(u) e^{\frac{2u}{R_2}} \right\} \psi(u,v) = 0$$

Multilayer Matrix Formalism

Matrix M_i are associated to each virtual layer, then the matrix associated to the whole structure is defined by :

$$\bar{M} = \prod_{i=1}^n M_i = \begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix}$$

The eigenvalue $\beta = k_0 n_{\text{eff}}$ of such a structure is given by :

$$\begin{cases} m_{11} - jr m_{12} + \frac{j}{p} m_{21} + \frac{r}{p} m_{22} = 0 & \text{TE mode} \\ \frac{p}{n_p^2} m_{11} - j \frac{r}{n_f^2} \frac{p}{n_p^2} m_{12} - j m_{21} + \frac{r}{n_f^2} m_{22} = 0 & \text{TM mode} \end{cases} \quad \text{with: } \begin{cases} p = \sqrt{\beta^2 - k_0^2 n_p^2} \\ r = \sqrt{\beta^2 - k_0^2 n_r^2} \end{cases}$$

(The terms m_{ij} are function of the effective propagation constant β)

Results

By using this method to compute the optical field in each layer, we can draw the shape of the mode in the waveguide.

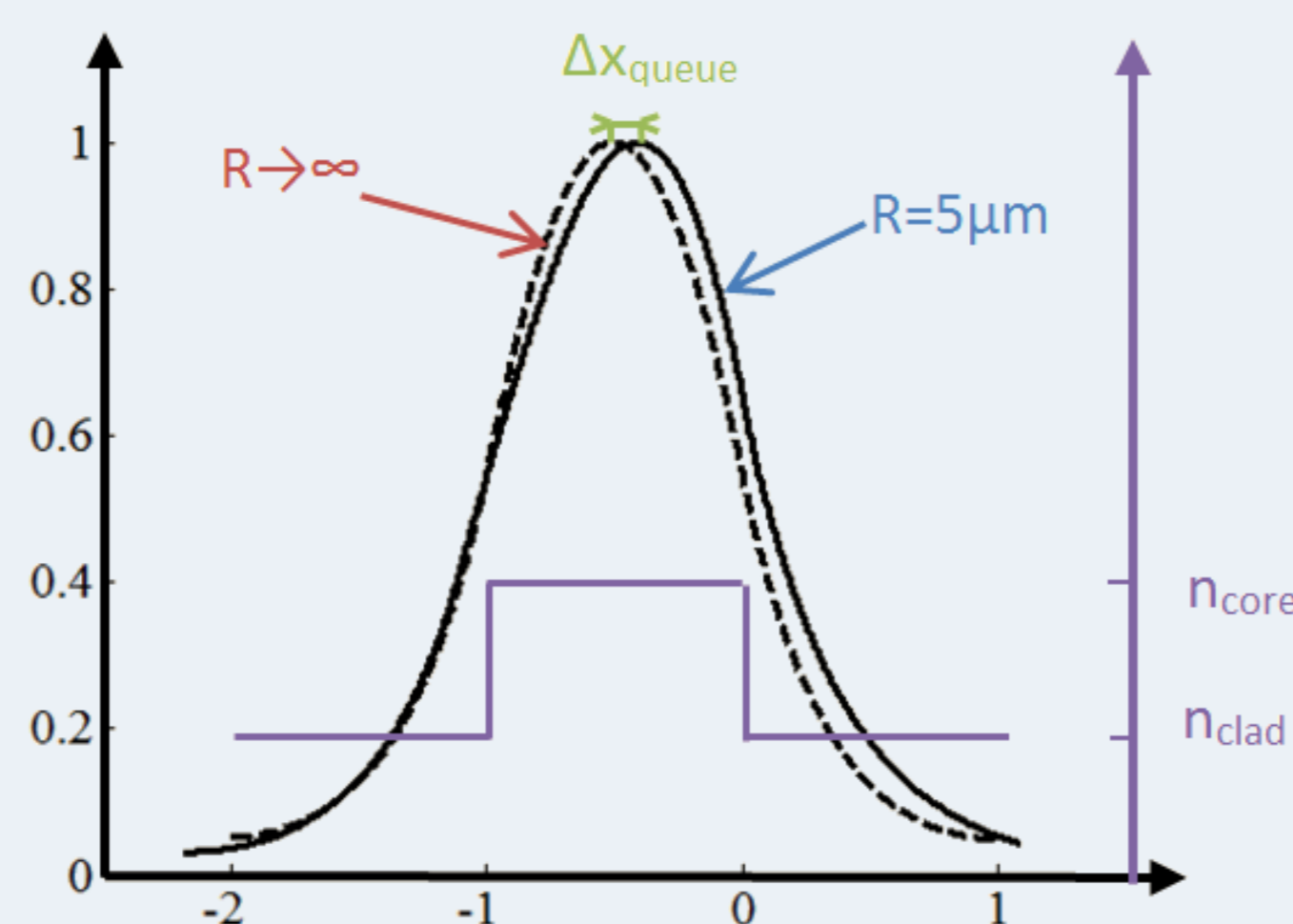


Figure 2 : The dashed line represents the field in a non-bended waveguide ($R \rightarrow \infty$) and the continuous one represents the field in a bended waveguide with a radius of curvature of $5\mu\text{m}$.

These tables represent the eigenvalues of the modes for various width (W) of the guide and different indices concerning the cladding (n_{clad}) and the core (n_{core}). These values can be compared to those given by COMSOL-3D software respectively for $R=10\mu\text{m}$ and $R \rightarrow \infty$.

R (μm)	W ($\lambda_0=1\mu\text{m}$)	($n_{\text{core}} ; n_{\text{clad}}$)	$n_{\text{eff-TE}}$ (programm)	$n_{\text{eff-TE}}$ (COMSOL3D)
10	1	(2 ; 1)	1.68439	1.9529
		(2.5 ; 1.5)	2.19253	2.0021
		(2 ; 1.5)	1.74436	1.9571
	2	(2 ; 1)	1.77214	1.9850
		(2.5 ; 1.5)	2.25812	1.9938
		(2 ; 1.5)	1.79303	1.9856

R (μm)	W ($\lambda_0=1\mu\text{m}$)	($n_{\text{core}} ; n_{\text{clad}}$)	$n_{\text{eff-TE}}$ (programm)	$n_{\text{eff-TE}}$ (Analytic)
∞	1	(2 ; 1)	1.76183	1.81055
		(2.5 ; 1.5)	2.29139	2.34775
		(2 ; 1.5)	1.81608	1.83543
	2	(2 ; 1)	1.91241	1.94671
		(2.5 ; 1.5)	2.42604	2.45654
		(2 ; 1.5)	1.92386	1.94978

Conclusion

This method of calculation associating conformal transformation of the complex plane and multilayer matrix formalism provides a good approximation of the effective index in a bended waveguide without requiring a long time of calculation on a personal computer, unlike the other methods already existing. The values of the effective indices determined by this method give a good approximation of the actual values, and their general evolution in function of the radius of curvature and the indices is conform to COMSOL3D simulation, and analytical case for $R \rightarrow \infty$.

References

- Snyder, Allan W., Love, John D., "Optical waveguide theory", Kluwer Academic Publishers, London, 2000
- Spiegel, Murray R., "Variables complexes", Série Schaum – MacGraw-Hill, New-York, 1973
- Tamir, T., "Guided-wave optoelectronics", Springer-Verlag, Berlin London New-York, 1990
- Yeh, P., Yariv, A., Hong, C-S, "Electromagnetic propagation in periodic stratified media. I. General theory", Opt; Soc. Am., Vol.67, 423-438, 1977
- www.comsol.com