**Title**
Ultralow-loss compact silicon photonic waveguide spirals and delay lines



**Journal**
Photonics Research, 10(1)

**ISSN**
2327-9125

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**Publication Date**
2021-12-09

**DOI**
10.1364/PRJ.437726

Peer reviewed

# Optimized Spiral Waveguides with Ultralow-Loss)

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*Abstract* – **First and foremost, waveguides allow for light propagating waves to be concentrated into a specific pathway to reduce the amount of attenuation as it travels along. Although spiral waveguides have become commonplace in realizing photonic integrated circuits, a new structure for these spiral waveguides which includes a Euler Curve S-Bend and optimized radius and width could decrease propagation loss to .28 dB/cm. These Euler S-Bend waveguides use the same machinery and production process as the standardized spiral waveguides, negating the cost of requiring new machinery and increasing the validity of using the Euler S-Bend waveguides in standard practice.**

## I. INTRODUCTION

Standard spiral waveguides have limitations in its ability to provide long delays lines while also exhibiting low losses. Standard practices to reduce these losses requires the usage of processes that go beyond multi-project wafer, MPW, practices and therefore are not realistic to implement. Thus, the introduction of this new Euler-S Bend spiral waveguide offers a solution to reducing loss in propagating waveforms.

This summary paper will discuss the development and design of an ultralow-loss high delay spiral waveguide using standardized production practices such that the waveguides can be used in photonic integrated circuit design.

## II. STRUCTURE AND DESIGN

The distance between two waveguides plays an important role in the loss of the light being propagated. There is an inherent understanding that when two waveguides are placed near each other, coupling can occur. The most basic form of coupling that has been discussed is two-mode coupling in which two modes are coupled within the same structure or two parallel structures close to each other. The interaction of these two modes plays an integral role in whether or not light will be propagated along or not depending on if the modes are constructive or destructive. Using this same logic, a spiral waveguide has the same mode running throughout it; however, because they begin to loop around, some form of coupling occurs. In order to minimize the loss, the Euler S-curve bend and radius of the core is adjusted.

One of the major areas of loss for a wave propagating along is at the waveguide interface. Although the best way to reduce the waveguide interface loss is to reduce the roughness of the sides of the waveguide, that is almost entirely a fabrication variable with very little that we can do to fix it. As a result, the width of the core can also be enlarged to reduce the waveguide interface loss. By widening the core, "the loss due to the scattering at the sidewalls can be reduced exponentially as the core width increases, which is due to the significant decrease in field amplitudes at the sidewalls" (Hong, Zhang, Wang, Zhang, Xie, and Dai).

In order to reduce the amount of cross talk, which occurs because the spiral shape of the waveguide is similar to the two mode coupling discussed earlier, the radius of the Euler Curve S-Bend is maximized. When comparing the excess loss of a Euler S-Bend with a regular curve, the Euler S-Bend was 147.5 times smaller.

## III. RESULTS

### *A. Figure 1*

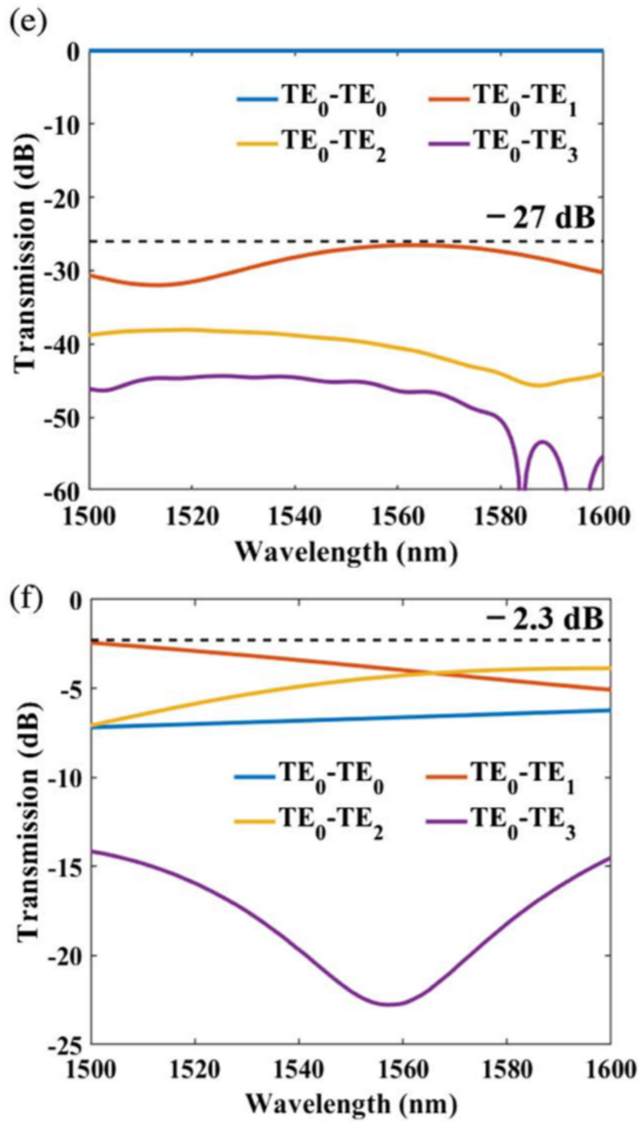


Fig. 1. Intermode crosstalk and excess loss of Euler curve S-Bend (e) and regular curve S-Bend (f).)

In order to determine the efficiency of a new spiral waveguide in comparison to the standardized spiral waveguide, a simulated light wave propagates along both waveguides and the outputs measured. Both the Euler Curve S-Bend and standard spiral waveguide have the same footprint, ordering on the magnitude of micrometers so there is no worry about needing to increase the size of the Euler Curve S-Bend. In Figure 1 above, graph E measures the different waves in different modes propagating along the Euler Curve S-Bend. Graph F measures the same thing except for a regularly curved S-Bend. In the lowest mode propagation, the blue line, the Euler Curve S-Bend has little to no excess loss, measuring at a loss of .016 dB. Meanwhile, the regular S-Bend curve has a loss of 2.3 dB. This indicates that the optimized radius of the Euler curve and core of the waveguide have reduced the excess loss of light propagation by 143.75%. Furthermore, the intersection between two modes, measured with the orange curve, is measured to be -27 dB for the Euler curve and -2.3 dB for the standard curve. This means that for any mode cross talk to occur, the transmission has to dip a certain amount. The lower that value is, the better the waveguide is because it requires the transmission of the wave propagating to drop an incredibly low amount before any sort of interference occurs. From Figure 1, the Euler Curve S-Bend waveguide has a significantly lower crosstalk threshold than the standard spiral waveguide.

In terms of low losses and minimal crosstalk, the Euler Curve S-bend waveguide is significantly superior to the standard S-Bend waveguide because of its optimized radius and core width.

## IV. CONCLUSIONS

The findings in this paper could revolutionize the way in which spiral waveguides are produced. Not only are these waveguides also produced using similar MPW processes, but they are also far better than standard waveguides at producing low losses and high delay lines. These low losses are actualized by optimizing the core width of the waveguide as well as the radius of the Euler curve itself. Continuing on, the proposed Euler Curve S-Bend waveguide is just as compact as standard S-Bend waveguides, using the same footprint so there is no loss in compactness when applying these to integrated photonic circuits.

## V. ACKNOWLEDGEMENTS

This paper was written per the UCLA Electrical Engineering curriculum under the guidance of Assistant Professor Dr. Sergio Carbajo.

## VI. References

Hong, S. et al. Ultralow-loss compact silicon photonic waveguide spirals and delay lines. Photonics Research 10, 1–7 (2021).