Validation Report

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Author(s)	Tom Davies Matthew Banham Dominic Gallagher
Product Name	OMNISIM
Product Version & Compile Date	Version: 1.2.1, Compiled: 4th Jan 2005
Reference Files	[1]C. Manolatou et al, "*Coupling of Modes Analysis of Resonant Channel Add-Drop Filters*", IEE Journal of Quantum Electronics, *vol. 35, No. 9, September 1999*. [2] AddDropFilter.pdf
External Files	ValidationData/AddDropFilter/AddDrop Validation.prj

A Resonant Add-Drop Filter Comparison

1. Report Summary

The aim of this study was to compare results obtained from OMNISIM and those obtained in [1] and [2] (a validation document for the Photon Design product FIMMWAVE) for a resonant add-drop filter device described in Figure 1 and Figure 2 below.

It was shown in [1] that the resonant add-drop filter had an extremely high Q and reasonably good power output, thus these two qualities had to be reproduced in the OMNISIM simulations.

1.1 Validation Test - Brief Description

There were two devices that were tested. These devices shall be referred to as the *single resonator* and the

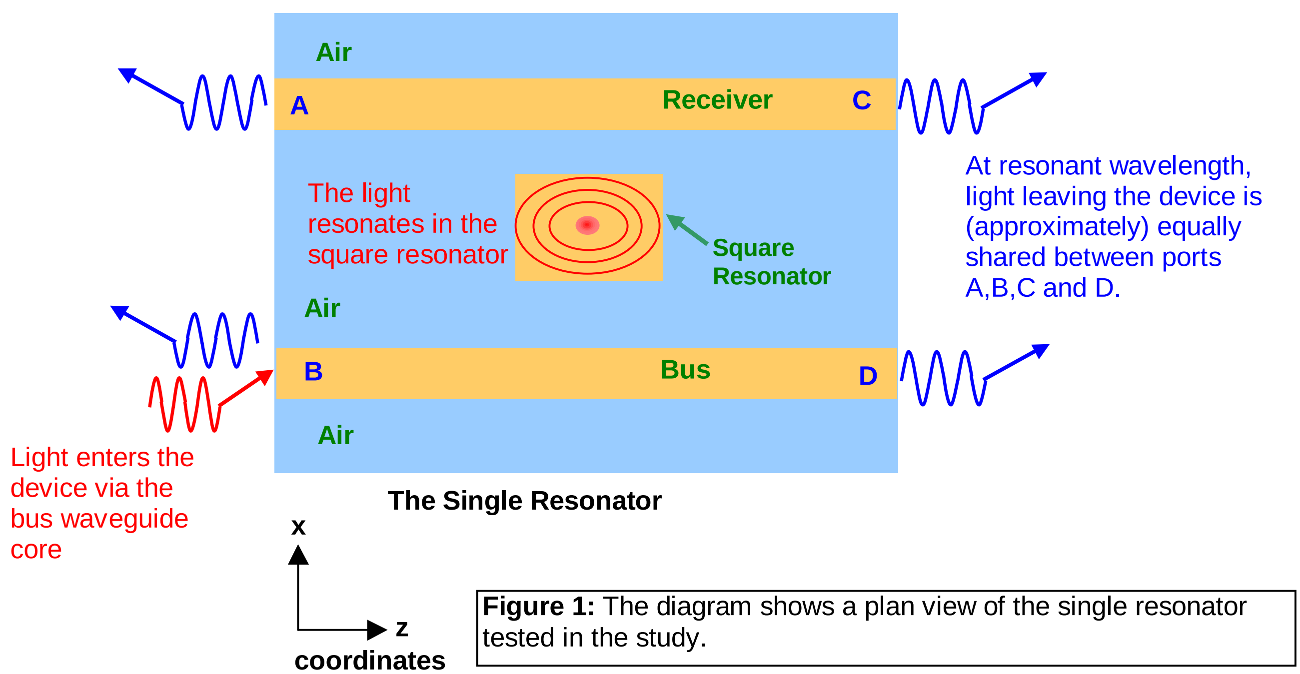


Figure 1: The diagram shows a plan view of the single resonator tested in the study.

double resonator.

1. Single Resonator

A plan-view showing the operation of the single resonator is given in Figure 1 above. The refractive index only varies in the x and z-directions.

From Figure 1, it can be seen that the single resonator consists of three components separated and surrounded by air. These components are:

The Bus	This is a single-moded waveguide core of a high refractive index. Light is initially injected into this core.
The Receiver	This is a single-moded waveguide core of the *same* refractive index and dimensions as the bus. When the correct wavelength of light is injected into the bus, a large amount of light of this wavelength (only) is coupled (or *dropped*) into the receiver and so leaves the device via ports A or C.
The Square Resonator	This is a square piece of material of the *same* refractive index as the bus. It is symmetrically placed between receiver and bus such that it is within the 'evanescent tails' of their common guided mode.

The dimensions and refractive indices of the structure to be simulated are given in Figure 2a.

2. Double Resonator

The double resonator is almost identical to the single resonator with the addition of an extra square resonator. The two square resonators are perfectly aligned in the x-direction and are slightly separated in the z-direction. The dimensions and refractive indices of the structure to be simulated are given in Figure 2B. The distance marked **L** in Figure 2b was calculated from

$$L + a = (n + 3/4)\lambda_g$$

Where

- ***n*** is an integer (chosen in this case to equal 3)
- '***a***' is side length of the square resonator (i.e. 1.54 microns)
- λ_g is the wavelength in the guided region of either the bus or the receiver.

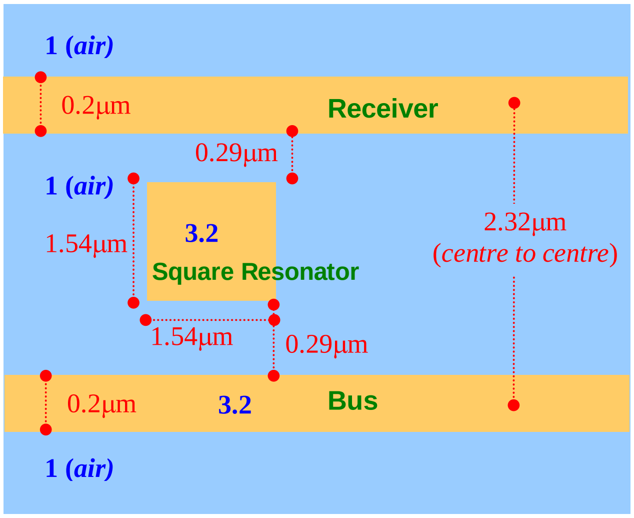
The distance marked **L** was set to 0.788771μm.

Notes.

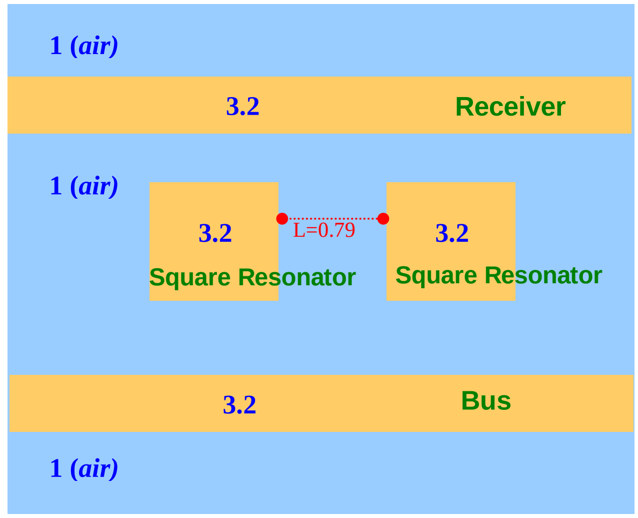
1) The port labelling convention will be maintained throughout this report. Therefore, if power is leaving the device from the receiver and is travelling in the positive z-direction, then the light leaves via port C.

2) As both devices had refractive indices that only varied in the x and z-directions, then figure 2 gives a complete description of both devices.

3) These devices have been stored as two components in the OMNISIM project file *AddDrop Validation.prj*.



A. The Single Resonator



B. The Double Resonator **–** All distance measurements are the same as the *Single Resonator*.

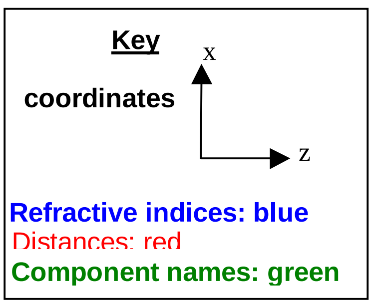


Figure 2: The diagram the dimensions of the single resonator and the double resonator.

1.2 Results Summary – Single Resonator

Using OMNISIM, plots of output power (port C) against wavelength were obtained and compared to the resonance curves published in [1] and [2].

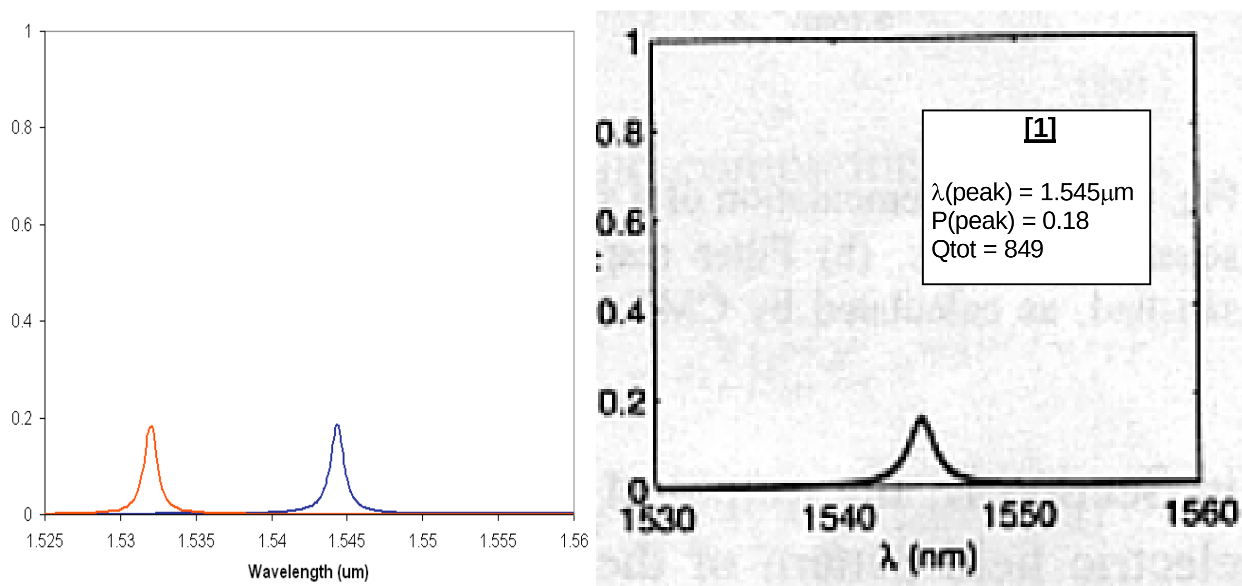


Figure 3: A comparison of wavelength spectra for the single resonator

Figure 3 shows graphs of the power output from port C of the single resonator against the wavelength, λ, as measured by OMNISIM and published in [1] and [2]. It is observed that OMNISIM predicts a resonance at just over 1.544 um. This is in good agreement with [1] which predicts 1.545 um. FIMMWAVE – [2] predicts a resonance when λ = 1.532 um which is slightly different.

However, the peak power coefficients measured in in all three cases are in good agreement with each other (within 1%). OMNISIM predicts 18.6%, while [1] predicts 18% and [2] predicts 18.5%.

The Q of the resonance is given by the following formula.

$$Q_{tot} = f_0 / (f_{+1/2} - f_{-1/2})$$

- where f_0 is the frequency at which the peak power is observed
- $f_{-1/2} - f_{+1/2}$ are the frequencies either side of the peak, where the power drops to half its peak value.

The Q predicted by OMNISIM is taken to be approximately 1500. This value is 1.8 times that measured in [1] which was ~849, but is in good agreement with [2].

Note that in [1] the authors actually quote Q_0 in their publication

1/Qtot = 1/Qo + 1/Qe + 1/Qe'

where Q_0 is associated with radiation or other loss mechanisms of the uncoupled resonator(s) and Qe and Qe' are associated with the coupling to the bus and receiver waveguides.

A summary of these values are given in the table below.

	OMNISIM	[1]	[2]
Peak Wavelength (um)	1.544	1.545	1.532
Power at Peak Wavelength	0.186	0.18	0.185
Q	1500	849	1530

1.3 Results Summary – Double Resonator

Figure 4 shows graphs of the power output from port C of the double resonator against wavelength as measured by OMNISIM and FIMMWAVE - [2] along with the data published in [1].

As in the single resonator case, the peak wavelength is slightly shifted in FIMMWAVE to a value of λ = 1.532μm. The peak power in FIMMWAVE is slightly less than that measured in [1] and again the Q_{tot} is 1.4 times that of [1].

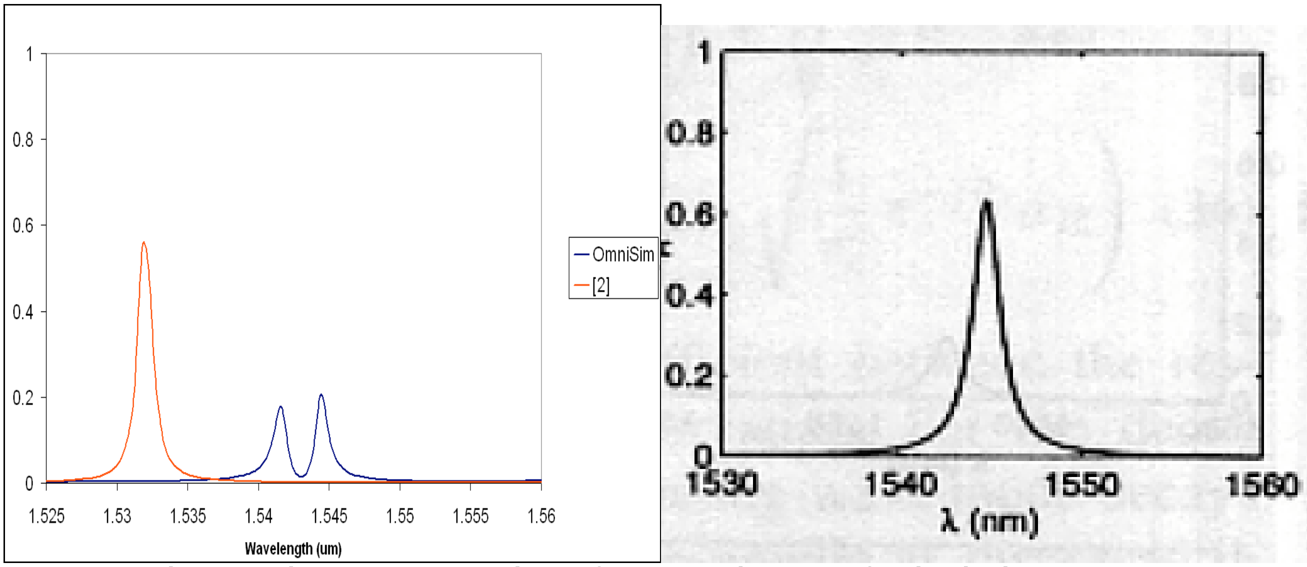


Figure 4: Figure 3: A comparison of wavelength spectra for the double resonator.

Notice that the OMNISIM results show a double peak. This is because the grid size was chosen to be 0.05um. This is not a common denominator for all the dimensions given in Figure 2. Thus the evaluated structure is not symmetric, hence the two resonance peaks. One solution would be to reduce the grid size to be 0.01um, however to accommodate this, the number of time steps will have to be increased by at least a factor of 4 to preserve the spectral resolution. This would result in an increase in computation time of a factor of approx. 100. This is unobtainable.

For this example, the dimensions of the structure have been changed slightly to allow us to use a grid spacing of 0.05um. The new dimensions are shown in Figure 5 below. The results are shown in Figure 6 along with the results obtained with FIMMWAVE (The EME method used in [2]).

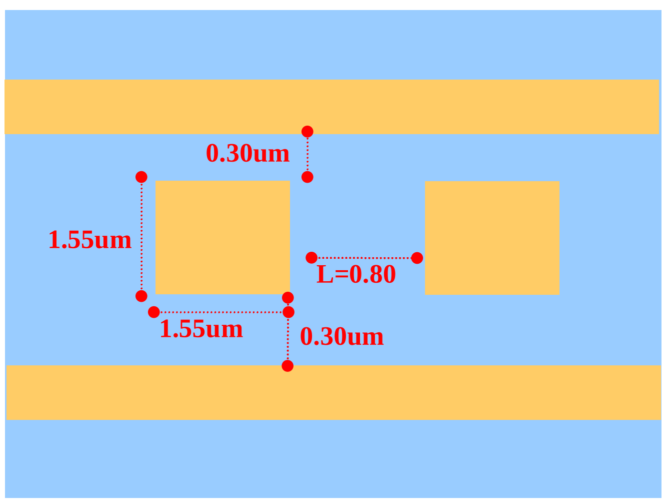


Figure 5: The diagram the dimensions of the adjusted double resonator.

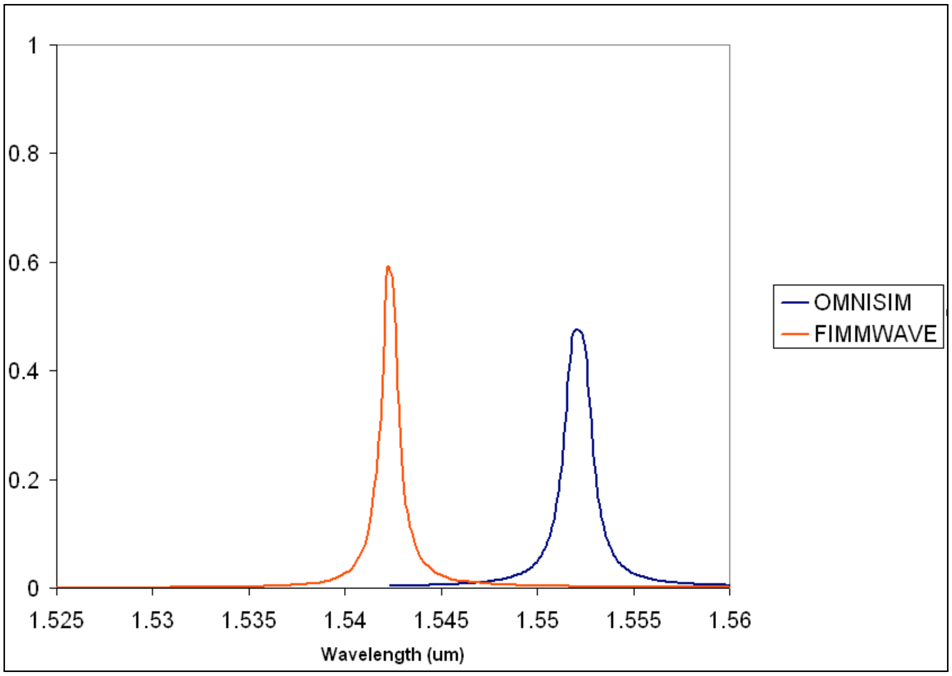


Figure 6: Wavelength spectra for the adjusted double resonator.

Figure 6 shows graphs of the power output from port C of the double resonator against the wavelength, λ, as measured by OMNISIM and FIMMWAVE. From Figure 6, it is observed that OMNISIM predicts a resonance at just over 1.552 um, while FIMMWAVE predicts a resonance at λ = 1.542 um which is slightly different. However, this difference is consistent with the results for the single resonator.

The peak power coefficient measured with FIMMWAVE is similar to the data from [1] (for the non-adjusted device). However, the OMNISIM results show a peak power approx. 20% less.

The Q predicted by OMNISIM is taken to be approximately 920. This value is approx. 0.65 times that predicted by FIMMWAVE which is around 1420, but is in good agreement with that obtained (for the original structure) in [1].

A summary of these values are given in the table below.

	OMNISIM	FIMMWAVE	[1] – original structure
Peak Wavelength (um)	1.552	1.542	1.545
Power at Peak Wavelength	0.475	0.588	0.62
Q	920	1420	804

1.4 Discussion and Conclusions

Overall, the results obtained from OMNISIM are in good agreement with [1] and [2]. For the single resonator, the peak wavelength is well within 1% of the published results. Although for the case of the adjusted double resonator, it differs from the FIMMWAVE results by 20%. It is not possible to conclude which values are more accurate, though the authors of [1] note that their algorithm may introduce some error due to the discretisation scheme that they used. These errors may be apparent in the discretisation in OMNISIM.

There were more significant discrepancies in the measured value of Q and the value of the peak power. In the case of the single resonator, OMNISIM agrees with FIMMWAVE, but not in the case of the double resonator. In discussions with the authors of [1], the authors note that there may be reasons why their values of Q are lower than they should be. However, the observations alone are not sufficient to determine which result is the more accurate.

The Q of the resonators are reasonably large, thus many time steps are needed to resolve this correctly in FDTD. Thus the computation time is actually much longer than when using EME (frequency domain).

In modelling the double resonator, the need to describe the two resonator boxes identically is essential to avoid a spurious double peak in the wavelength response. In this case this requires a much finer mesh (computationally intense), or a slight adjustment in the structure. FIMMWAVE does not have this limitation, as in the case of rectangular structures, the modes of the exact structure are found.

2. References

[1] C. Manolatou et al, "*Coupling of Modes Analysis of Resonant Channel Add-Drop Filters*", IEEE Journal of Quantum Electronics, *vol. 35, No. 9, September 1999*.

[2] D. Gallagher et al, "fimmwave\Documents\ValidationDocs \AddDropFilter.pdf"