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Design Optical BPF Using Double Clad Fiber MZI for Free Space Optical Communication

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Abstract: A novel design of Mach Zehnder Interferometer (MZI) in terms of using special type of optical fiber that has double clad with graded distribution of the refractive index that can be easily implemented practically was suggested and simulated in this work. The suggested design is compact, rapid, and is simple to be modified and tested. The simulated design contains a MZI of 1546.74 nm of central wavelength that is constructed using special type of double clad optical fiber that has two different numerical apertures. The first aperture will supply single mode propagation via its core, while the second numerical aperture supports a zigzag wave propagation (multimode) in the first clad region. The interferometer's sensing arm (double clad fiber) was etched using 40% Hydro-Fluoric (HF) acid to achieve three different fiber diameters, which are (84, 72, 54) µm with (5) cm length. The simulation programs Optiwave version 15 and Optigrating version 4.2.2 were used to simulate the setup and to acquire the readings for the three durations of etching (10, 20, and 30) min, and also for the case of no etching at all. The obtained results show that the simulated setup can be used efficiently to test which one of the etching cases has the highest effect on the performance of the overall system, specifically when it comes to spectrum bandwidth, signal amplitude, and received power.

Keywords: Mach Zehnder Interferometer – Fiber Interferometer – Etched Double Clad Fiber – Optical Band Pass Filter

1. Introduction:

Novel integrated optics are currently regarded as the fundamental element of processing all types of light waves, where they can be utilized for both transmitting and receiving the data. That's the main cause that most new research directions are aimed at achieving the task of eliminating most electronic components in communication systems, where they are replaced by optical components instead to achieve better results [1, 2].

There are several applications for an optical system, such as implementing a system to produce a narrow laser pulse, which is considered as an important part in many optical setups [3]. There has been an exponentially increasing interest in designing novel photonic setups that can work with fast rates of data communication as well [4, 5].

An optical fiber interferometer is a photonic device that is used in many applications like optical Band Pass Filter (BPF), pulse compressor and super continuum generation optical source. Optical fiber MZI is a simple interferometer to be implemented practically.

Photonic devices group previously worked on designing optical fiber MZI as optical BPF using four different types of optical fibers: In 2018, Hollow Core Photonic Crystal Fiber (HC-PCF) with 7 and 19 cells were used [6], while in 2020 an optical fiber MZI was designed using Large Mode Area fiber (LMA-10) and two types of HC-PCF 7 and 19 cells after filling all their holes with ethanol, acetone, and acetic acid [7].

In 2022, an optical fiber MZI was designed using optical fiber with zero Polarization Mode Dispersion (PMD), which is called Polarization Maintaining Fiber (PMF) [8]. Lastly in 2022,

designed nested optical fiber MZI using three different etching times of Multi-Mode Fiber (MMF) [9].
In this work, the suggested approach covers a design and simulation of an optical system implemented by utilizing an MZI. The system is focused on a Double Clad (DC) optical fiber that is placed between two identical Single Mode Fibers (SMF's), which is different from No Core Fiber (NCF) and Dispersion Compensation Fiber (DCF) in that DC fiber supports single mode wave propagation at the core while simultaneously supports multimode wave propagation in the first cladding at the same time. The measurements are taken when the DC optical fiber is etched for (10, 20, and 30) minutes, and compared to the readings in the case when it is not etched at all as a reference.

2. Theoretical background:

Dispersion phenomena is a negative effect in the wave propagation via optical fibers which cause optical pulse broadening [10].
For the simulated setup, there is an Optical Spectrum Analyzer (OSA) component placed after each other component to check the effect of each stage on the spectrum of the light pulse. It is important to mention that the MZI is produced by the etched DC fiber that is placed between two SMF's, where the etching results in producing a mode misalignment [1, 11].

Interferometers can be used to give information regarding temporal, spatial, and spectral

4. Simulated setup:

The setup that was simulated in this work is as shown below in figure (1)

domains, so the received signal from them can be specified in a set of quantities [12].
This is a proper way in order to detect any changes that occurs to the several parameters of the light pulse, such as frequency, bandwidth, and other parameters [12].
It should be mentioned that the etching process affects the number of propagating modes within the optical fiber, that is because the clad size to core size ratio is affected [13].

3. Method and procedure:

It should be mentioned that the (HF) acid is usually used in optics laboratories since it has strong etching effect, and specifically when used on silica, which is the material most optical fibers are made from. So, the (HF) acid can be used for decreasing the diameter. This procedure is affected by the duration it is performed, which means that etching for a longer time period removes more thickness of the optical fiber layer compared to that removed in shorter time duration [14 – 18].
For the suggested simulated setup in this work, the diameter of the DC fiber is reduced by etching it using HF acid in three steps, where these steps are acquired by changing the etching time durations as (10, 20, 30) minutes. Setup consists of components that are described:

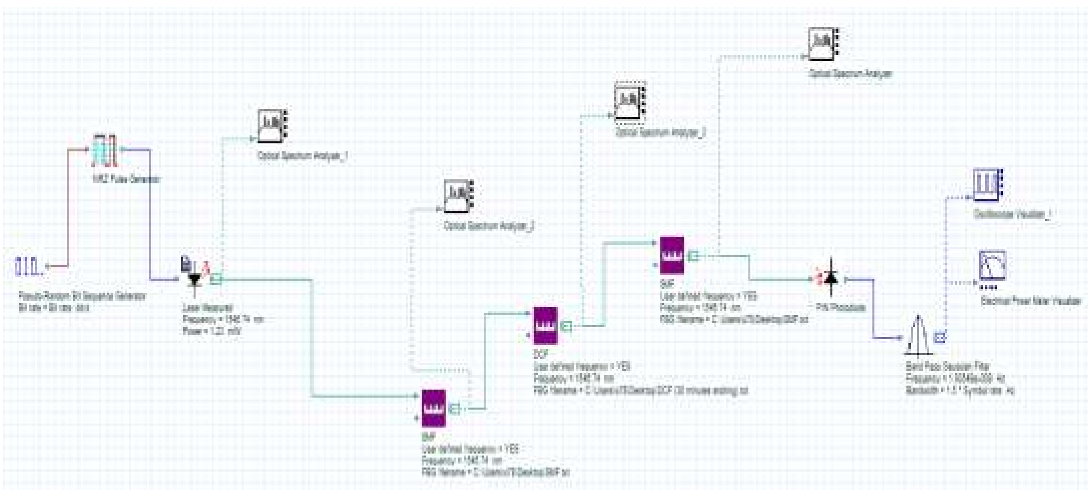

Figure (1): Schematic diagram of simulated setup.

4.1 Pseudo Random Bit Sequence Generator:
This generator is utilized to produce a random sequence of 1's and 0's to act as a power feeder to the laser source, that is because producing a laser is a random process.

4.2 NRZ Pulse Generator:
This generator is used to provide the necessary pulses encryption that is required by the laser source to operate properly

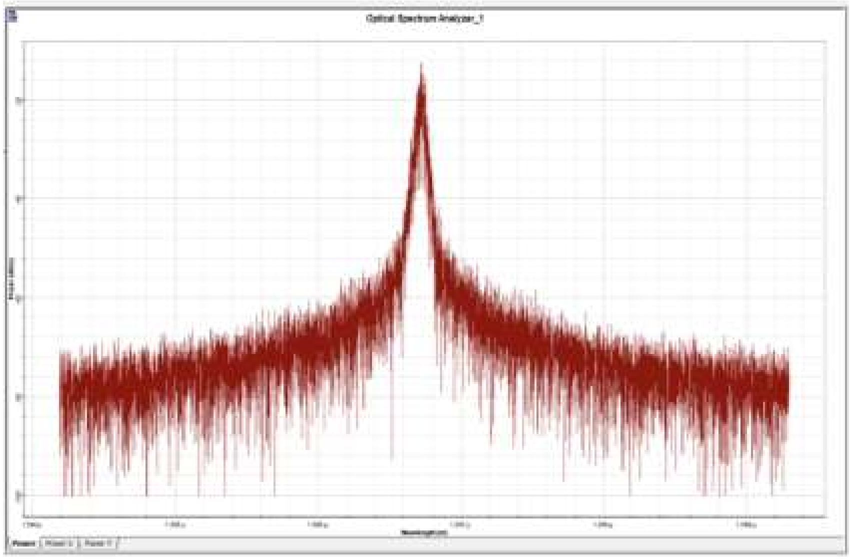

Figure (2): spectrum of laser source

4.3 Laser Measured:
This is the pulsed laser source in the setup, it has a peak power of 1.23 m. W, and a wavelength of 1546.74 nm. Its spectrum is as shown in figure (2)

4.4 SMF:
There are 2 SMF's in the setup, where each one of them is connected to one end of the DC fiber.

4.5 DCF:
This is the main component in the setup, where its diameter is changed 3 times and for each case, the readings are taken to acquire the desired results.

The default DC fiber without etching is as shown in figure (3) below, where it is considered as the first case of four cases. For each case, multiple readings are taken, including:

1- Power at the receiver.
2- Amplitude at the receiver.
3- The optical spectrum at various points.

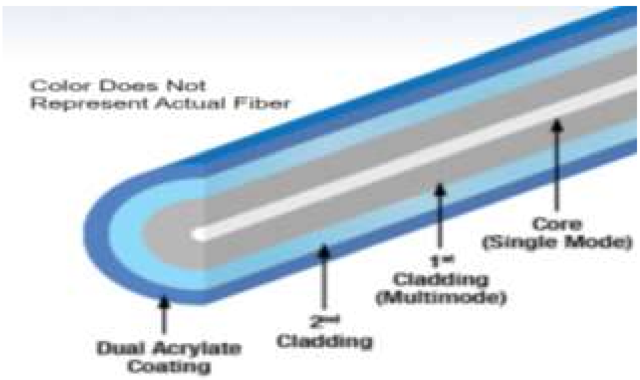

Figure (3): Schematic diagram of DC fiber.

4.6 PIN Photodiode:
Positive – Intrinsic – Negative (PIN) photodiode is used to detect the optical pulse by changing it from optical to electrical form, which means changing it from intensity to amplitude and power.

4.7 Band Pass Gaussian Filter:
This filter is utilized to take only the required spectrum into account, any part of the spectrum outside the frequency response of this filter will be attenuated and filtered out.

4.8 Optical Spectrum Analyzer:
There are several (OSA) components in the setup, where each one of them shows the spectrum of the pulse at a specific point. It is most useful to acquire information about power budget and bandwidth budget.

4.9 Electrical Power Meter Visualizer:
This visualizing component shows a numerical value, which is most useful when the power difference in two cases is rather low such that it is hard to be detected in graphical visualizers.

4.10 Oscilloscope Visualizer:
This component is used to acquire a visual reading of the amplitude of the pulse at the receiver end of the setup.

5. Results and discussion:

The simulated setup shown previously is run 4 times (one for each etching duration), and for each one of those times, the resulting graphs are shown, where figure (4) below shows the spectrum of the pulsed laser after passing through the 1st SMF.

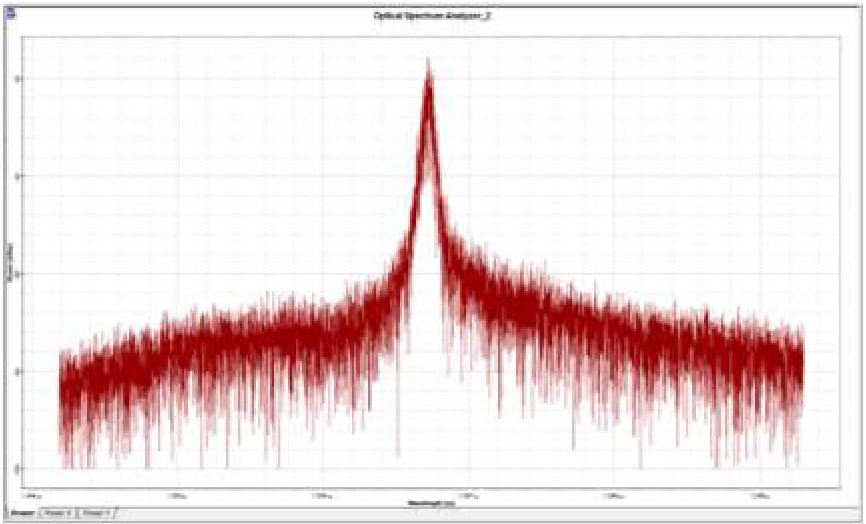

Figure (4): Spectrum of the pulsed laser after passing through first SMF

Figure (5) shown next illustrates that the attenuation of the etched DC fiber is affecting the spectrum of the pulse in a nonlinear fashion, where for example it is shown here that the peak power is reduced. It's important to mention that the spectrum suffers from attenuation in all parts, and not just the peak value.

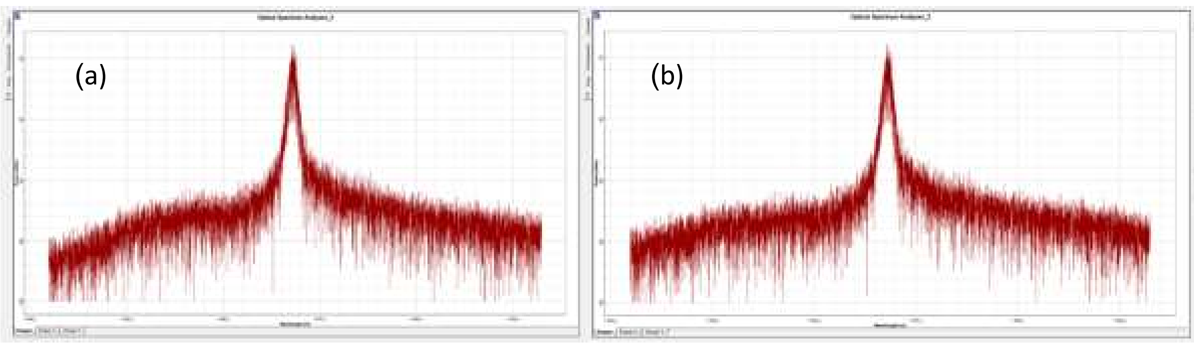

Figure (5 (a and b)): OSA after DC fiber for (a) no etching (b) etching for 10 minutes

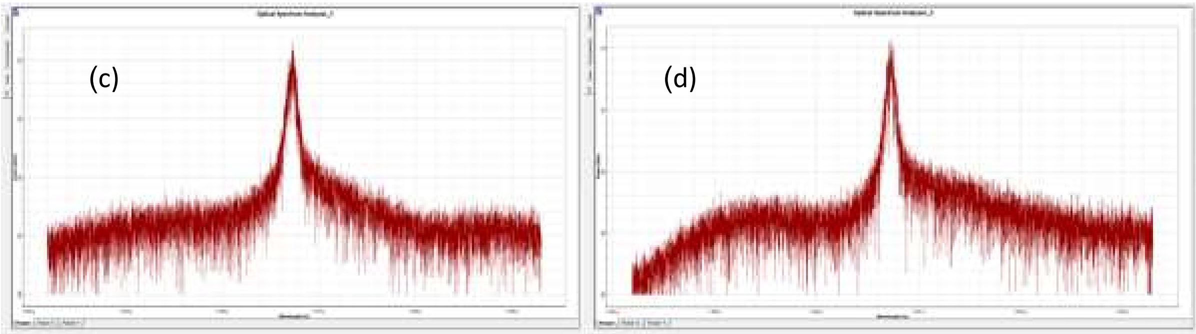

Figure (5 (c and d)): OSA after DC fiber for (c) etching for 20 minutes (d) etching for 30 minutes

Output peak power is an essential parameter for designing the optical BPF, which is affected by the attenuation characteristics of the optical fiber (0.2 dB/km in an SMF) and the other essential parameter in designing is dispersion, where it is (18 ps / nm . km). These two parameters are labelled in the c-band optical communication system. Figure (6) demonstrates that the 2nd SMF offers spectrum attenuation and slight dispersion as well, where the coupler is made from SMF-28 in any optical fiber visualizer.

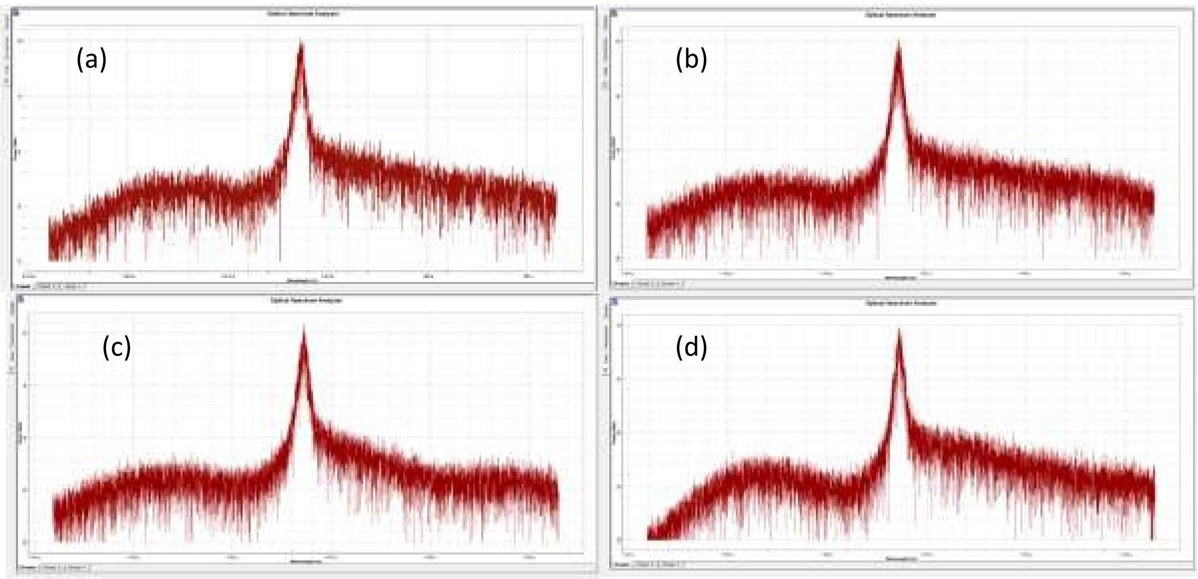

Figure (6): OSA after 2nd SMF for (a) no etching (b) etching for 10 minutes (c) etching for 20 minutes (d) etching for 30 minutes

Figure (7) here shows that the voltage peak to peak value gets affected as well by etching the DC optical fiber, where the lowest value here is for the etching duration of 20 minutes, that is because the effect is nonlinear regarding the etching time.

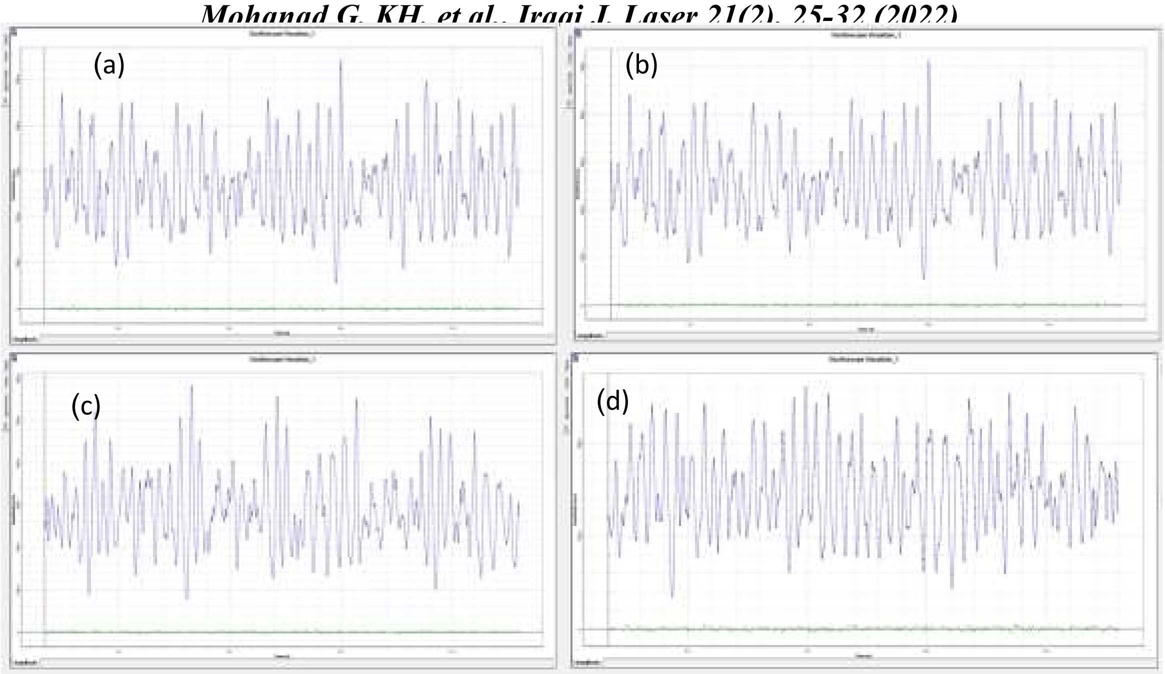

Figure (7): Oscilloscope after receiver for (a) no etching (b) etching for 10 minutes (c) etching for 20 minutes (d) etching for 30 minutes

The average power is altered as well by the effect of etching the DC optical fiber, which can be clearly seen from figure (8) below

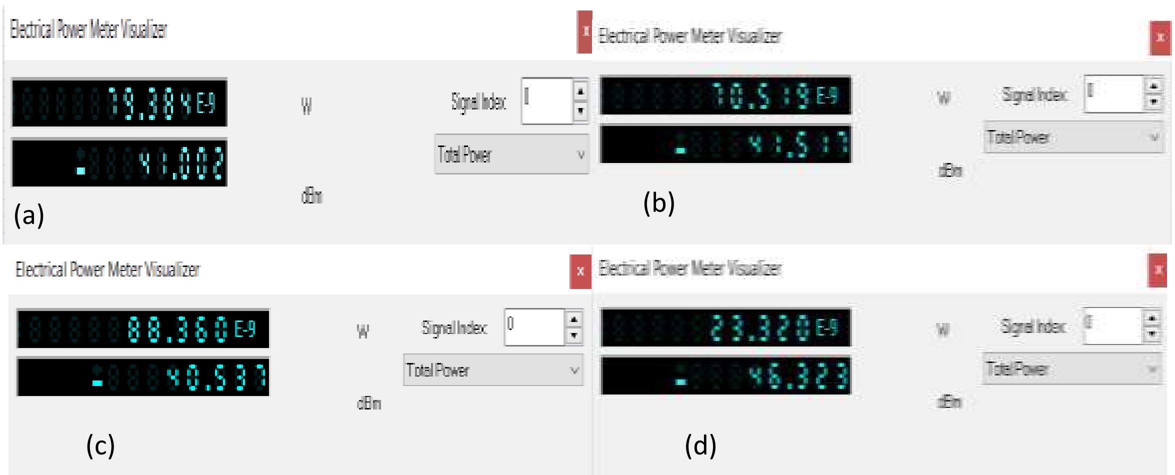

Figure (8): Power meter after receiver for (a) no etching (b) etching for 10 minutes (c) etching for 20 minutes (d) etching for 30 minutes

Table (1): Comparison between the four cases of etching durations

Case	Etching time (minutes)	Remaining diameter (µ. meters)	FWHM (n. meters)	Peak to Peak Voltage (n. Volts)	Peak Power (dBm)	Average power (n. Watts)
1	0	125	0.22	0.480	-18	79.384
2	10	84	0.21	0.460	-18	70.519
3	20	72	0.17	0.500	-17	88.360
4	30	54	0.20	0.225	-20	23.320

6. Conclusions

Narrow optical PBF was obtained from an etched DC fiber MZI that has 170 pm Full Width Half Maximum (FWHM) with highest average power of 88.36 n.W in the case of 20 minutes etching time, and a fiber length of 5 cm because the maximum excitation to the higher order modes in the second cladding region occurred, and the surrounding media is air, so four different refractive index distributions happened gradually from its highest value at core region (n = 1.5247) to its lowest value of surrounding media (which is air n =1)

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تصميم فلتر ضوئي من نوع معبر الحزمة الوسطية بإستخدام مُداخل ماخ زندر من ليف ضوئي ثنائي الغلاف للإتصالات الضوئية في الفضاء الحر

مهند غازي خميس   تحرير صفاء منصور

معهد الليزر للدراسات العليا / جامعة بغداد – بغداد / العراق

الخلاصة: تصميم لمنظومة مُداخل ماخ-زندر ريادي من ناحية إستعمال نوع مميز من الليف الضوئي ذو الغلاف المزدوج يحتوي على توزيع متدرج لمعامل الإنكسار والذي من الممكن تنفيذه ببساطة بشكل عملي تم اقتراحه ومحاكاته في هذا العمل. التصميم المقترح صغير، وسريع، ومن السهل التعديل وإجراء الفحوصات عليه.

التصميم المُحاكى يحتوي على مُداخل ماخ-زندر ذو طول موجي يبلغ مركزه ١٥٤٦.٧٤ نانومتر الذي تم بناؤه من نوع مميز من الليف الضوئي ذو الغشاء المزدوج الذي يحتوي على قيمتان مختلفتان من الفتحات العددية. الفتحة العددية الأولى سوف تدعم إنتشار أحادي الطور بواسطة مركز الليف، أما الفتحة العددية الثانية فتدعم الإنتشار الموجي المتعرج (متعدد الأطوار) في منطقة الغشاء الأول. الذراع المتحسسة الخاصة بالمُداخل (الليف الضوئي ذو الغشاء المزدوج) تم حكها بإستخدام 40% حمض هيدروفلوريد للحصول على ثلاثة قيم مختلفة للأقطار، وتبلغ (٨٤، ٧٢، ٥٤) مايكرومتر بطول قدره 5 سم.

برامج المحاكاة (Optiwave 15 & Optigrating 4.2.2) تم استعمالها لمحاكاة المنظومة والحصول على القراءات للفترات الثلاث من الحك (١٠، ٢٠، ٣٠) دقائق، وأيضاً لحالة عدم الحك إطلاقاً. النتائج التي تم الحصول عليها تظهر بأن المنظومة التي تمت محاكاتها من الممكن استعمالها بكفاءة لفحص أي من حالات الحك لديها التأثير الأكبر على أداء النظام الكامل، وبالذات من ناحية عرض الحزمة، وفولتية الإشارة، والقدرة المستلمة.