transmission wavelengths. In this manner, the double pass Mach-Zehnder filter of the present invention reduces the free spectral range and increase the isolation of the filter, while maintaining the frequency periodicity of the filter.

[0070] The filter characteristics of the double pass Mach-Zehnder filter depend upon the length mismatch between the legs of the double pass Mach-Zehnder filter as described by the above transmission and frequency period equations. As such, the length mismatch between the Mach-Zehnder legs **44** can be used to control the filter performance and the desired output port of the filter **40** by varying the relative distribution of the signal between the output ports.

[0071] The Mach-Zehnder interferometer of the present invention can have a fixed path length mismatch or it can be tunable depending upon the particular application for the filter. For example, various tuning methods, such as temperature, strain, electrical field, etc., can be used to maintain, change, and/or otherwise control the filter function.

[0072] **FIG. 6** further shows the use of a tuning element **52** positioned relative to the longer Mach-Zehnder leg $\mathbf{44}_1$. The tuning element **52** can include thermal tuning elements, for example, resistive heaters, heat pipes, thermo-electric coolers ("TEC"), Peltier elements, etc., as well as other types of tuning elements, such as strain, electric, magnetic, etc. The tuning element **52** can be positioned in various locations relative to the Mach-Zehnder legs **44**, as well as the coupling sections **42**. For example, tuning elements **52** can be used to control the individual temperatures of the legs **44**, or a single temperature control element **52** can be used to maintain both legs **44** at the same temperature. One of ordinary skill will appreciate that the selection of input and output ports and the relationship to the longer Mach-Zehnder leg $\mathbf{44}_1$ and the location of isolators, tuning elements, etc. can be made to achieve various filtering objectives.

[0073] **FIG. 7** shows an embodiment incorporating an optical distributor **34**, typically a low ratio, non-wavelength selective splitter. The distributor **34** is used to tap off a portion of the optical energy exiting one or more of the output/input ports **48** as a monitoring signal. Photodiodes **54**, or other optical to electrical converters, can be used to monitor the total optical energy or a wavelength selective distributor **34** or filter can be used to monitor only selected wavelengths.

[0074] As further shown in **FIG. 7, a** filter controller **56** can be employed to control the Mach-Zehnder leg length mismatch and the resulting filter characteristics of the double pass Mach-Zehnder filter **40** based on the monitoring signal. The filter controller **56** can include various combinations of analog and digital controllers, as well as feedback loops, to control one or more of the temperature control elements **52**. The filter controller **56** can control the tuning element **52** based on the monitoring signal provided by the monitoring photodiodes.

[0075] **FIG. 8** shows the use of a circulator **58** in place of the isolator **50** to prevent the optical energy exiting the second output/input port $\mathbf{48}_2$ from passing back through the Mach-Zehnder interferometer. A three port circulator **58** is shown in **FIG. 8**, although circulators **58** with different numbers of ports can be used. In addition, the optical energy that exits the second output/input port $\mathbf{48}_2$ can be monitored as it exits port **3** of the circulator **58**.

[0076] **FIG. 9** shows a double pass Mach-Zehnder filter embodiment in which at least one of the output/input ports **48** are coupled to reflective mirrors **60**, or other non-wavelength selective devices. The mirrors **60** reflect the optical energy exiting the output/input ports **48** back through the Mach-Zehnder interferometer. A circulator **58** can be provided at the input/output port **46** to separate input and output signals.

[0077] Similarly, **FIG. 10** shows the use of fiber Bragg gratings ("FBGs") **62** as wavelength selective reflectors, in lieu of the mirrors depicted in **FIG. 9**. As with the mirrors, it will be appreciated that one or more types of wavelength selective reflectors can be coupled to one or more of the output/input ports **48** depending upon the desired filter characteristics. In addition, tunable wavelength selective reflective devices can be used, for example, by including a tuning element **52**, to provide wavelength tuning capability, in addition to that association with the Mach-Zehnder legs.

[0078] **FIG. 11** is demonstrative of double pass Mach-Zehnder filter **40** embodiments that include concatenated Mach-Zehnder interoferometers. The concatenated Mach-Zehnder embodiments include one or more intermediate coupling sections $\mathbf{42}_I$ disposed along the communication paths **44** between the first and second coupling sections, $\mathbf{42}_1$ and $\mathbf{42}_2$, respectively. In these embodiments, multiple Mach-Zehnder interferometers, usually having different filtering characteristics, e.g. periods, are coupled in series to provide a combined filter function.

[0079] The double pass Mach-Zehnder device **40** of the present invention can be used in various components and subsystems within a system. For example, the device can be used to perform filtering functions in various components, subsystems, and network elements, including transmitters, receivers, multiplexers, demultiplexers, switches, add/drop multiplexers, etc.

[0080] For example, **FIG. 12** shows the double pass Mach-Zehnder filter **40** used in combination with an optical amplifier **24**, a monitoring photodiode **54**, and a receiver **22**. In these embodiments, monitoring signal from the photodiode **54** and/or the receiver **22** can be used by the filter controller to control the double pass Mach-Zehnder filter **40** and/or the optical amplifier. It will be appreciated that the amplifier **24**, double pass Mach-Zehnder filter **40**, and photodiode **54** can be placed on one or more line cards within a subsystem or network element, or in separate network elements in various manners.

[0081] In other embodiments, the double pass Mach-Zehnder filters **40** can be used in a reconfigurable optical networks. For example, in all-optical network or subnetwork embodiments, tunable filter **40** can be used in combination with various optical components, such as transmitters, receivers, and optical switching devices, to provide reconfigurable signal wavelengths transmission paths through the network.

[0082] It will be appreciated that the present invention provides for improved optical filters for use with optical components, subsystems, and systems. Those of ordinary skill in the art will further appreciate that numerous modifications and variations that can be made to specific aspects of the present invention without departing from the scope of the present invention. It is intended that the foregoing specification and the following claims cover such modifications and variations.