CLAIMS

What is claimed is:

1. An apparatus, comprising an arrayed waveguide grating (AWG) that comprises:

a substrate having a planar surface;

a first optical star coupler being along said surface and having first and second optical inputs and a first spatial array of optical outputs;

a second optical star coupler being along said surface and having a second spatial array of optical inputs and a third spatial array of optical outputs; and

an array of waveguide arms, each waveguide arm connecting one optical output of the first spatial array to a corresponding optical input of the second spatial array, wherein the array of waveguide arms is configured to cause a first set of four optical outputs of the third spatial array to receive four different phase combinations of light received at the first and second optical inputs in response to the light received at the first and second optical inputs being of about the same wavelength.

2. The apparatus of claim 1, wherein the four different phase combinations are combinations of the light from the first and second optical input ports with relative phases of about 0, $\pi/2$ radians, π radians, and $3\pi/2$ radians..

3. The apparatus of claim 1, the array of waveguide arms is configured to cause a separate second set of four optical outputs of the third array to receive four second combinations of the light, the second combinations being a polarization of component of the light that is about orthogonal to a polarization of the light output to the first set of optical outputs of the third array.

4. The apparatus of claim 1, the array of waveguide arms is configured to cause a separate second set of four optical outputs of the third array to receive four second combinations of the light, the second combinations having a wavelength that is different than a wavelength of the light output to the first set of optical outputs of the third array.

5. The apparatus of claim 1,

wherein, for at least some of the waveguide arms, at least a portion of the arm comprises a birefringent waveguide; and

further comprising a polarization-control element configured to change a polarization of the light received at the second optical input so that optical power is partitioned between a first polarization and a second polarization approximately orthogonal to the first polarization.

6. The apparatus of claim 1, wherein:

the AWG is adapted to function as an n-channel wavelength demultiplexer, where n is a positive integer greater than one; and

the third spatial array of optical outputs comprises $4n$ optical outputs, each for receiving a corresponding mixed signal that differs from each of the remaining $(4n\text{-}1)$ mixed signals in at least one of (i) a carrier wavelength and (ii) a value of relative phase shift between the light applied to the first and second optical inputs.

7. The apparatus of claim 1, wherein:

the array of waveguide arms has a periodic chirp pattern with a period of four waveguide arms; and

the chirp pattern consists of:

(i) two zeros, $-\frac{\lambda_c}{8}$, and $\frac{3\lambda_c}{8}$; or

(ii) two zeros, $-\frac{3\lambda_c}{8}$, and $\frac{\lambda_c}{8}$,

arranged in a selected order, where λ_c is a wavelength corresponding to one or more wavelength channels of the AWG.

8. The apparatus of claim 1, wherein the apparatus is an optical receiver further comprising:

an array of photo-detectors, each optically coupled to a corresponding output of the third spatial array of optical outputs and adapted to convert a corresponding optical output signal into an electrical signal;

an analog-to-digital converter adapted to convert the electrical signals produced by the array of photo-detectors into corresponding digital signals; and

a digital signal processor that receives the digital signals, wherein:

an optical input signal applied to the first optical input comprises a plurality of independently modulated components; and

the digital signal processor is adapted to process the digital signals to recover data carried by each of said independently modulated components, wherein the plurality of independently modulated components comprises two or more WDM components.

9. The apparatus of claim 8, wherein the plurality of independently modulated components also comprises two or more PDM components.

10. A method of processing an optical signal, comprising:

(a) providing an arrayed waveguide grating (AWG) comprising:

a substrate having a planar surface;

a first optical star coupler being along said surface and having first and second optical inputs and a first spatial array of optical outputs;

a second optical star coupler being along said surface and having a second spatial array of optical inputs and a third spatial array of optical outputs; and

an array of waveguide arms, each waveguide arm connecting one optical output of the first spatial array to a corresponding optical input of the second spatial array; and

(b) applying (i) an optical input signal to a first optical input waveguide and (ii) a local-oscillator signal to a second optical input waveguide of the AWG to produce four different phase combinations of the optical input signal and the local-oscillator signal at a set of four optical outputs of the third spatial array.

What is claimed is:

1. An apparatus, comprising an arrayed waveguide grating (AWG) that comprises:

a substrate having a planar surface;

a first optical star coupler being along said surface and having first and second optical inputs and a first spatial array of optical outputs;

a second optical star coupler being along said surface and having a second spatial array of optical inputs and a third spatial array of optical outputs; and

an array of waveguide arms, each waveguide arm connecting one optical output of the first spatial array to a corresponding optical input of the second spatial array, wherein the array of waveguide arms is configured to cause a first set of four optical outputs of the third spatial array to receive four different phase combinations of light received at the first and second optical inputs in response to the light received at the first and second optical inputs being of about the same wavelength, wherein the four different phase combinations are combinations of the light from the first and second optical input ports with relative phases of about 0, $\pi/2$ radians, π radians, and $3\pi/2$ radians.

2. The apparatus of claim 1, the array of waveguide arms is configured to cause a separate second set of four optical outputs of the third array to receive four second combinations of the light, the second combinations being a polarization of component of the light that is about orthogonal to a polarization of the light output to the first set of optical outputs of the third array.

3. The apparatus of claim 2 wherein the four second combinations are combinations of the light from the first and second optical input ports with relative phases of about 0, $\pi/2$ radians, π radians, and $3\pi/2$ radians.

4. The apparatus of claim 1, the array of waveguide arms is configured to cause a separate second set of four optical outputs of the third array to receive four second combinations of the light, the second combinations having a wavelength that is different than a wavelength of the light output to the first set of optical outputs of the third array.

5. The apparatus of claim 1, wherein, for at least some of the waveguide arms, at least a portion of the arm comprises a birefringent waveguide.

6. The apparatus of claim **5**, further comprising a polarization-control element configured to change a polarization of the light received at the second optical input so that optical power is partitioned between a first polarization and a second polarization approximately orthogonal to the first polarization.

7. The apparatus of claim **6**, wherein:

the first polarization is a transverse electric (TE) waveguide mode; and

the second polarization is a transverse magnetic (TM) waveguide mode.

8. The apparatus of claim **6**, wherein the polarization-control element is configured to partition the optical power substantially equally between the first and second polarizations.

9. The apparatus of claim **1**, wherein:

the AWG is adapted to function as an n-channel wavelength demultiplexer, where n is a positive integer greater than one; and

the third spatial array of optical outputs comprises 4n optical outputs, each for receiving a corresponding mixed signal that differs from each of the remaining (4n−1) mixed signals in at least one of (i) a carrier wavelength and (ii) a value of relative phase shift between the light applied to the first and second optical inputs.

10. The apparatus of claim **1**, wherein the array of waveguide arms has a periodic chirp pattern with a period of four waveguide arms.

11. The apparatus of claim **10**, wherein the chirp pattern consists of:

(i) two zeros,

$$-\frac{\lambda_c}{8}, \text{ and } \frac{3\lambda_c}{8};$$

or

(ii) two zeros,

$$-\frac{3\lambda_c}{8}, \text{ and } \frac{\lambda_c}{8},$$

arranged in a selected order, where λ_c is a wavelength corresponding to one or more wavelength channels of the AWG.

12. The apparatus of claim **1**, further comprising an array of photo-detectors, each optically coupled to a corresponding output of the third spatial array of optical outputs, wherein the substrate is a common substrate for the AWG and the array of photo-detectors.

13. The apparatus of claim **1**, wherein:

the waveguide arms are arranged on a plane in a non-intersecting manner for the array of waveguide arms to have a first side edge and a second side edge; and

the waveguide arms have lengths that monotonically change from one waveguide arm to a next waveguide arm so that the waveguide arm located at the first side edge has a smallest length and the waveguide arm located at the second side edge has a largest length.

14. The apparatus of claim **1**, wherein the apparatus is an optical receiver further comprising:

an array of photo-detectors, each optically coupled to a corresponding output of the third spatial array of optical outputs and adapted to convert a corresponding optical output signal into an electrical signal;

an analog-to-digital converter adapted to convert the electrical signals produced by the array of photo-detectors into corresponding digital signals; and

a digital signal processor that receives the digital signals, wherein:

an optical input signal applied to the first optical input comprises a plurality of independently modulated components; and

the digital signal processor is adapted to process the digital signals to recover data carried by each of said independently modulated components.

15. The apparatus of claim **14**, wherein the plurality of independently modulated components comprises two or more WDM components.

16. The apparatus of claim **15**, wherein the plurality of independently modulated components also comprises two or more PDM components.

17. The apparatus of claim **14** wherein the plurality of independently modulated components comprises two or more PDM components.

18. A method of processing an optical signal, comprising:

(a) providing an arrayed waveguide grating (AWG) comprising:

a substrate having a planar surface;

a first optical star coupler being along said surface and having first and second optical inputs and a first spatial array of optical outputs;

a second optical star coupler being along said surface and having a second spatial array of optical inputs and a third spatial array of optical outputs; and

an array of waveguide arms, each waveguide arm connecting one optical output of the first spatial array to a corresponding optical input of the second spatial array; and

(b) applying (i) an optical input signal to a first optical input waveguide and (ii) a local-oscillator signal to a second optical input waveguide of the AWG to produce four different phase combinations of the optical input signal and the local-oscillator signal at a set of four optical outputs of the third spatial array.

19. The method of claim 18, further comprising demultiplexing the optical input signal using the AWG, wherein:

the optical input signal has n carrier wavelengths, where n is a positive integer; and

the third spatial array of optical outputs comprises 8n outputs, each receiving a corresponding output signal that differs from each of the other (8n−1) output signals in at least one of (i) a carrier wavelength, (ii) polarization, and (iii) a value of relative phase shift between the optical input signal and the local-oscillator signal.

20. An apparatus, comprising an arrayed waveguide grating (AWG) that comprises:

a substrate having a planar surface;

a first optical star coupler being along said surface and having first and second optical inputs and a first spatial array of optical outputs;

a second optical star coupler being along said surface and having a second spatial array of optical inputs and a third spatial array of optical outputs; and

an array of waveguide arms, each waveguide arm connecting one optical output of the first spatial array to a corresponding optical input of the second spatial array, wherein the array of waveguide arms is configured to

cause a first set of four optical outputs of the third spatial array to receive four different phase combinations of light received at the first and second optical inputs in response to the light received at the first and second optical inputs being of about the same wavelength, wherein:

the AWG is adapted to function as an n-channel wavelength demultiplexer, where n is a positive integer greater than one; and

the third spatial array of optical outputs comprises 4n optical outputs, each for receiving a corresponding mixed signal that differs from each of the remaining (4n−1) mixed signals in at least one of (i) a carrier wavelength and (ii) a value of relative phase shift between the light applied to the first and second optical inputs.

21. An apparatus, comprising an arrayed waveguide grating (AWG) that comprises:

a substrate having a planar surface;

a first optical star coupler being along said surface and having first and second optical inputs and a first spatial array of optical outputs;

a second optical star coupler being along said surface and having a second spatial array of optical inputs and a third spatial array of optical outputs; and

an array of waveguide arms, each waveguide arm connecting one optical output of the first spatial array to a corresponding optical input of the second spatial array, wherein the array of waveguide arms is configured to cause a first set of four optical outputs of the third spatial array to receive four different phase combinations of light received at the first and second optical inputs in response to the light received at the first and second optical inputs being of about the same wavelength, wherein the array of waveguide arms has a periodic chirp pattern with a period of four waveguide arms, wherein the chirp pattern consists of:

(i) two zeros,

$$-\frac{\lambda_c}{8}, \text{ and } \frac{3\lambda_c}{8};$$

or

(ii) two zeros,

$$-\frac{3\lambda_c}{8}, \text{ and } \frac{\lambda_c}{8},$$

arranged in a selected order, where λ_c is a wavelength corresponding to one or more wavelength channels of the AWG.