Diffraction Gratings: Theory and Applications

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Outline

- Introduction to Diffraction Gratings
- Principle of Operation
- Applications
What is a diffraction grating?

- It is a device that reflects or refracts light by an amount varying according to the wavelength.

- It works in analogy to the prism.

- Basically, a diffraction grating performs a Fourier Transform, separating a waveform in the time domain into a number of waveforms in the frequency domain.
Planar Diffraction Gratings

There are basically two modes of operation.

1. Transmission: light passes through a material with a grating written on its surface.

2. Reflection: light is reflected from a material with a grating written on its surface. Reflective gratings are of widespread use in optical communication in the context of planar diffraction gratings and hence will be the main focus of this presentation.
   - It consists of very closely spaced set of parallel lines or grooves made in a mirror surface of a solid material.
   - It can be formed in almost any material where the optical properties can be varied in a regular way.
A Simple Case: The Double Slit

where $I_0$ is the intensity of the light in the center of diffraction pattern when only one slit is opened, $b$ is the width of the slit, $d$ is the distance between the slits, $k=2\pi/\lambda$ is the wave factor, $\lambda$ is the wavelength, $\Delta$ is the difference of the optical lengths of the interfering rays (in the case, for example, when the wave is incident
Extension to the Diffraction Grating

\[ l_\phi = l_0 \left( \frac{\sin(kb\varphi/2)}{kb\varphi/2} \right)^2 \left( \frac{\sin(Nkd\varphi/2)}{\sin(kd\varphi/2)} \right)^2 \]

- The first multiplier describes the Fraunhofer diffraction on one slit and the second describes the interference from N point sources.
- \( d \cdot \sin \varphi \) is the path length difference \( \Delta \) between the rays emitted by the slits.
- Therefore, we can write the equation for the main maximums of interference pattern: \( d \cdot \sin \varphi = m\lambda \), where \( m = 0, 1, 2, \ldots \).
Reflective Diffraction Gratings: Principle of Operation

The basic grating equation is shown below:

\[ m\lambda = gs \left( \sin \theta + \sin \phi_m \right) \]

Where:
- \( gs \) = groove spacing
- \( m \) = order of the refracted ray - (integer)
- \( \lambda \) = free space wavelength of the incident ray
- \( \theta \) = angle of incidence (measured against the normal)
- \( \phi_m \) = angle of refraction (measured against the normal)
The shape of the groove has no effect on the angles at which different wavelengths are diffracted.

The groove profile determines the relative strengths of diffracted orders produced. This enables the distribution of powers into different orders to be controlled.
Applications

- Reflective Gratings are wavelength-selective filters. Other examples of filters are Fiber Bragg grating, Fabry-Perot, Mach-Zehnder, etc.

- In optical communications, they are used for

  1. **Wavelength Selection: Splitting and/or combining optical signals**

  2. **Pulse Compression: Normally as reflectors in external cavity DBR lasers**
Wavelength Selection

Figure 162. Wavelength Division Multiplexing with a Littrow Grating. Wavelength routing is bi-directional. Separate wavelengths can be combined onto the same output port or a single mixed input may be split into multiple outputs (one per wavelength).

Figure 163. WDM with a Concave Mirror and a Littrow Grating. The lines showing light paths from the fibre to the mirror and thence to the grating should not be understood as narrow “rays” of light. When light arrives on a fibre it diffuses outward and the divergent wave forms a cone. The mirror focuses this divergent beam onto a spot on the grating. The grating reflects at an angle determined by the wavelength of the light. The reflected light is now refocused by the mirror onto a different fibre.
**Pulse Compression**

*Figure 164. Double-Pass Grating Compressor*

*Figure 165. Pulse Compression with Grating Compressor*
References


- [http://physics.nad.ru/Physics/English/DG10/theory.htm](http://physics.nad.ru/Physics/English/DG10/theory.htm)