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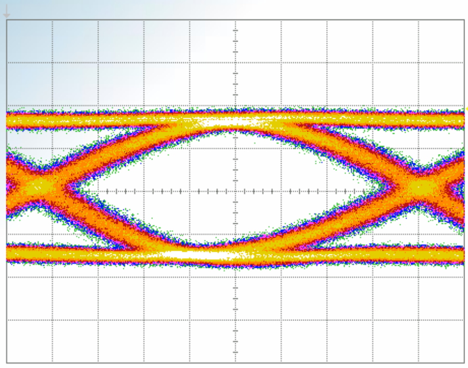
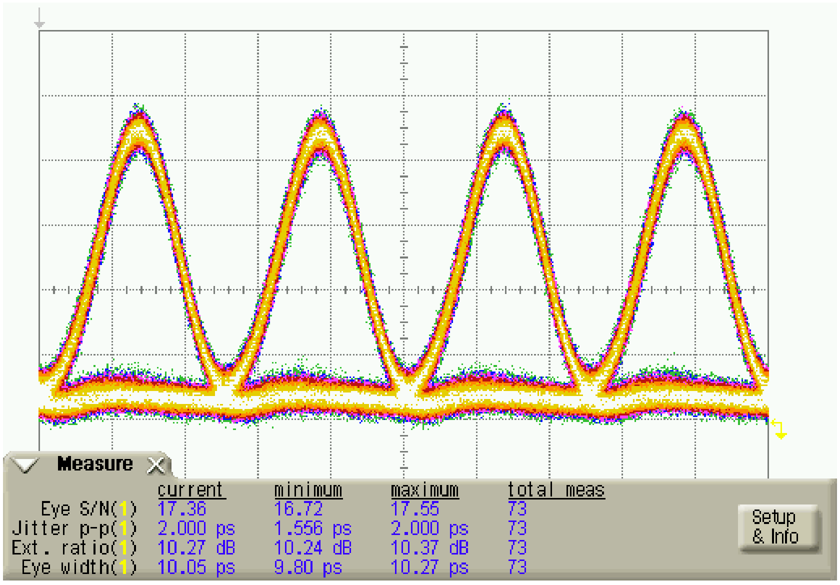


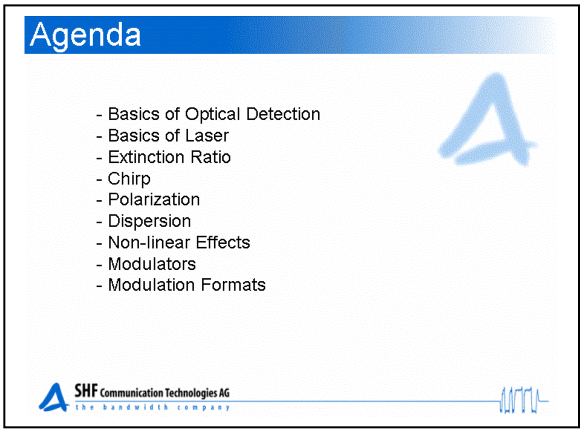
Tutorial Note #4

Basics of Optical Communication

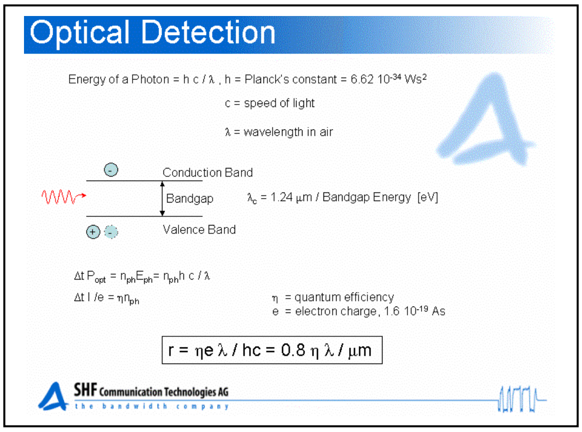


Basics of Optical Communication – V002 – 12/NOV/2003 (edited 11/04/2019)

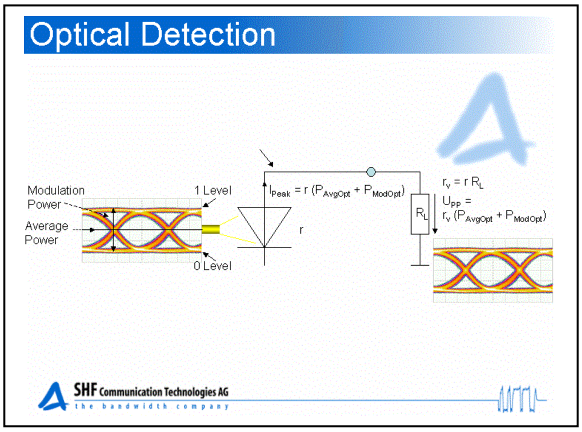
This Application note describes the basics of optical communication. A brief overview about generating and detecting optical signals is given. Important parameters of a high-speed optical transmission system are introduced, followed by an overview of the different modulation formats.



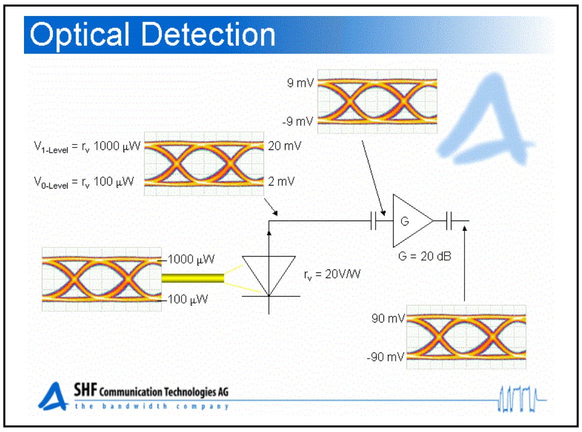
In a PIN diode an electron–hole pair is generated when a photon with an energy above the bandgap energy is absorbed.
For an ideal PIN diode each photon would generate one electron–hole pair.
Real world PIN diodes have less efficiency; the quantum efficiency takes this into account. A common detector parameter is known as responsivity, r, in terms of photocurrent per optical power (A/W).



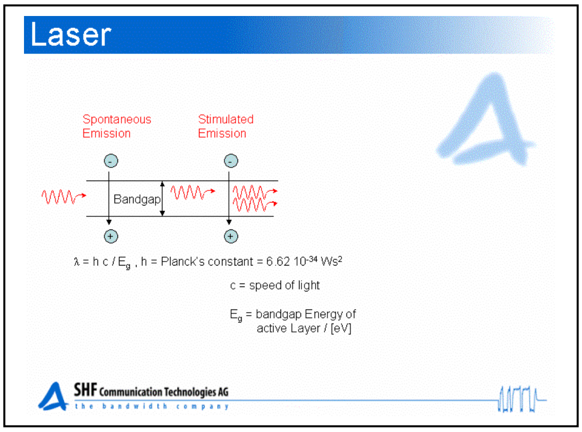
A photodetector generates a photocurrent according to the amount of incoming light and its responsivity. The photocurrent is converted into a voltage by a amplifier or a resistor.
It is important to point out that the optical input power is the sum of the optical average power and the optical modulation power.



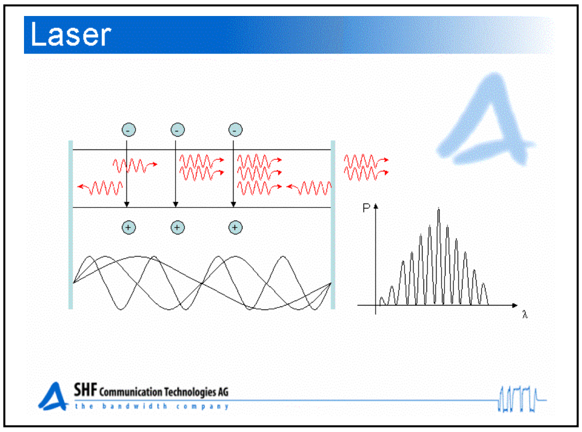
This example explains why the optical average power and the optical modulation power are of interest:
An optical signal with an optical power of 100 µW when a "0" is transmitted and an optical power of 1000 µW when a "1" is transmitted are detected by a detector with a responsivity of 20 V/W. The electrical signal will therefore be between 2 mV (for "0") and 20 mV (for "1"). If this signal is AC coupled, the DC term (corresponding to the optical average power) will be filtered off.
The remaining signal corresponds to the detected optical modulation power.



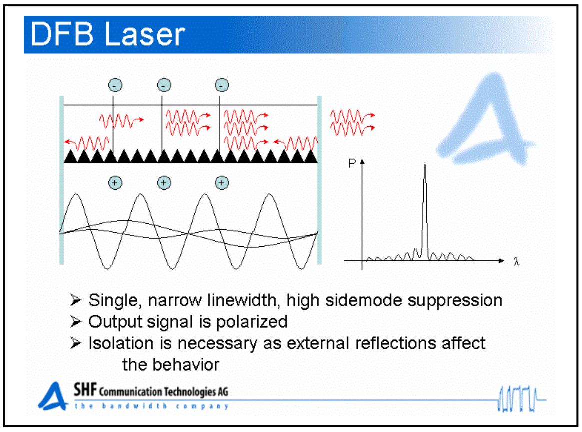
Laser is the abbreviation for:
Light Amplification by Stimulated Emission of Radiation
There are two mechanisms for producing photons:
1) Spontaneous Emission:
Stochastic recombinations of electron – hole pairs generate photons, this is the principle of an LED
2) Stimulated Emission:
A photon can cause further electron-hole recombinations, and thereby produce more photons. These photons have the same phase and wavelength as the stimulating photon. This mechanism is the basis of the laser.



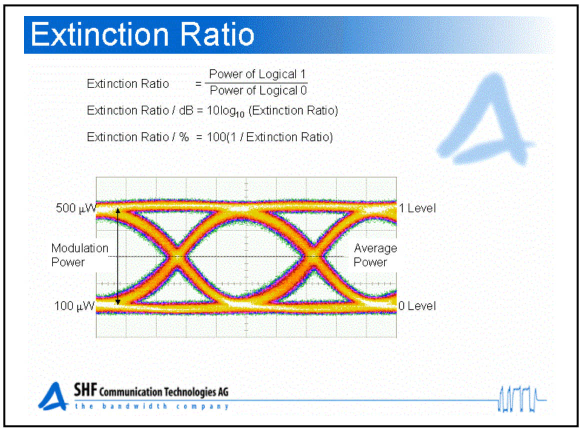
In a laser diode, two semi-transparent mirrors form an optical resonator.
As the resonator length is large compared to the wavelength several modes (integers of a wavelength) are generated.



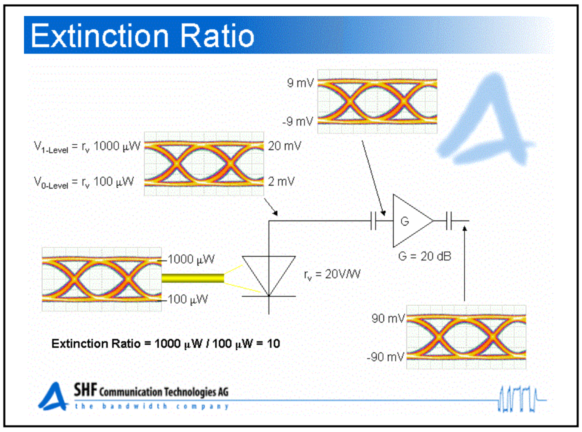
In a Distributed Feedback laser, distributed feedbacks (reflections) inside the resonator suppress all possible modes but one.
As the good side mode suppression is achieved by internal reflections that are carefully designed, the DFB laser is very sensitive to external reflections; this means a high optical isolation is necessary.



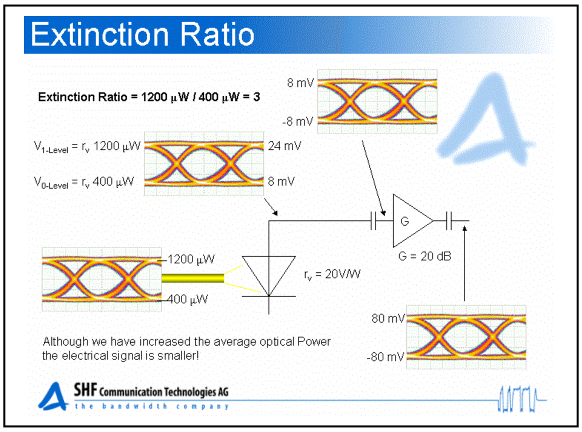
As we have already seen, the quality of an optical transmission is not only given by the received power but also by the ratio in power of the on/off state.
The extinction ratio is the parameter describing this ratio.
The ER can be expressed in linear terms (without any unit), logarithmic (in dB) or in percent.



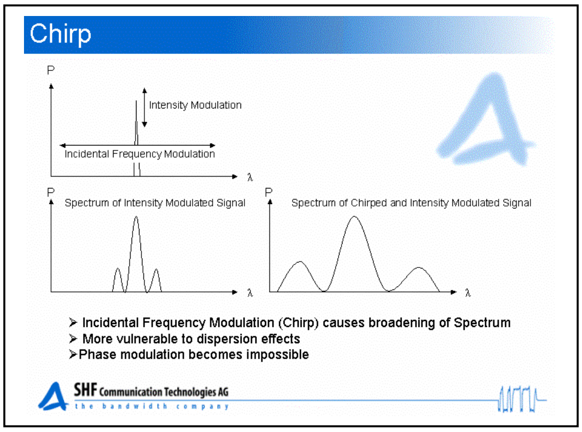
Lets go back to the example on page 3:
The optical signal had an optical power of 100 µW when a “0” was transmitted and an optical power of 1000 µW when a “1” was transmitted, this translates to an extinction ratio of 10.



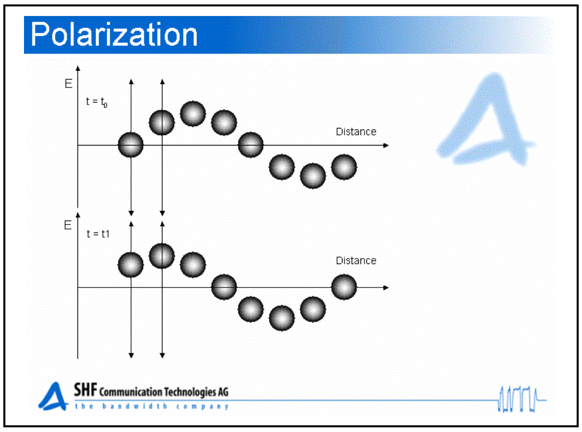
What will happen to the electrical output signal if we increase the average optical power?
The answer is: We don’t know ………
unless we don’t specify the extinction ratio as well.
In this example we have increased the average optical power but degraded the extinction ratio, therefore the electrical signal is smaller than before.



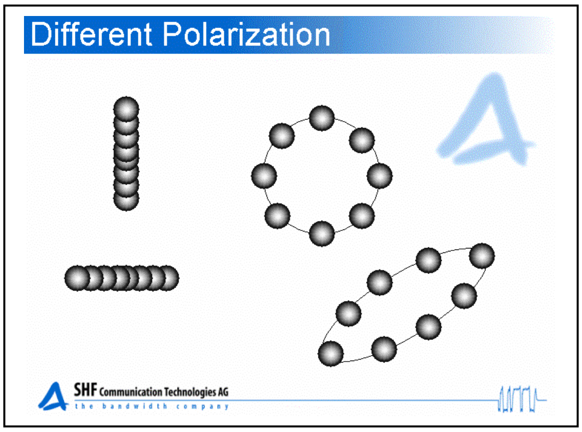
When an optical signal is intensity modulated an unwanted incidental frequency or phase modulation often occurs. This angular modulation causes a significant broadening of the spectrum and therefore possible problems due to chromatic dispersion.
Chirp can also make phase modulation impossible.



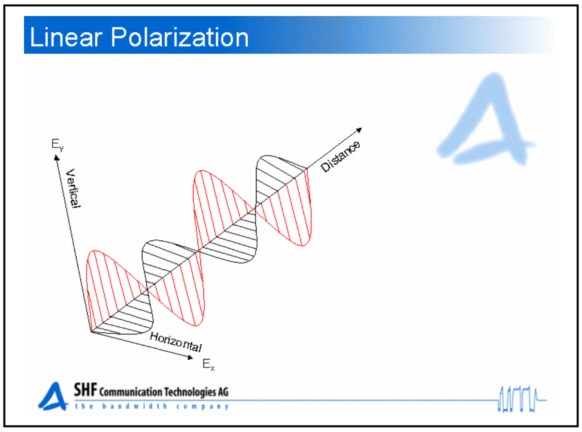
The orientation of the electromagnetic field along the propagation is described by the polarization:
There are unpolarized and polarized waves.
For polarized waves the state of polarization can be defined.



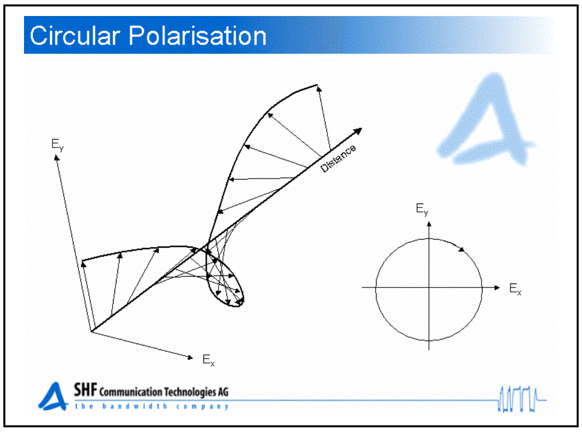
Polarized waves can be linear or elliptical polarized.
Linear polarization can be horizontal, vertical or of any angle in between.
Elliptical polarization can be left handed or right handed.



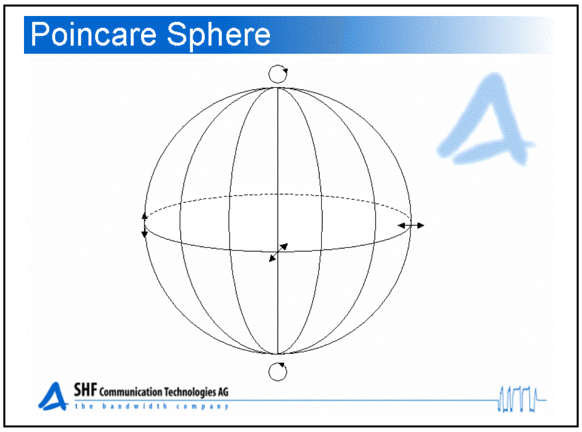
Linear Polarization is shown here: Note that the amplitude of Ex and Ey can vary, the polarization will stay linear.
If the phase relation of Ex and Ey is changed we will get elliptical polarization.



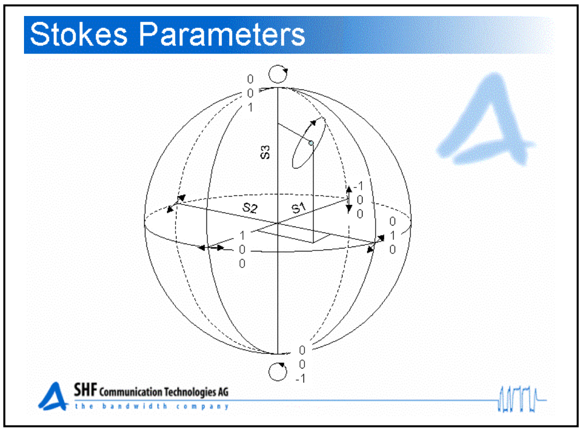
Here you see circular polarization (a special case of elliptical polarization). We have to admit, this is a diagram of artistic merit, but to judge the state of polarization it is not very helpful.
Therefore to display the state of polarization the Poincare sphere is used.



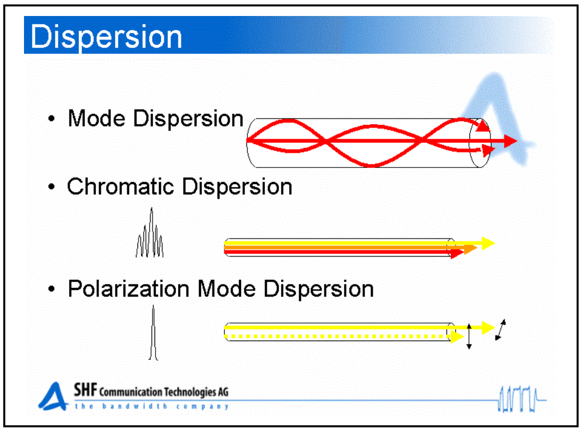
At the Poincare Sphere the equator represents all possible linear polarizations.
The northern hemisphere represents all right hand elliptical polarizations and the southern hemisphere represents all left-hand elliptical polarizations.
South and North Pole represent circular polarization.



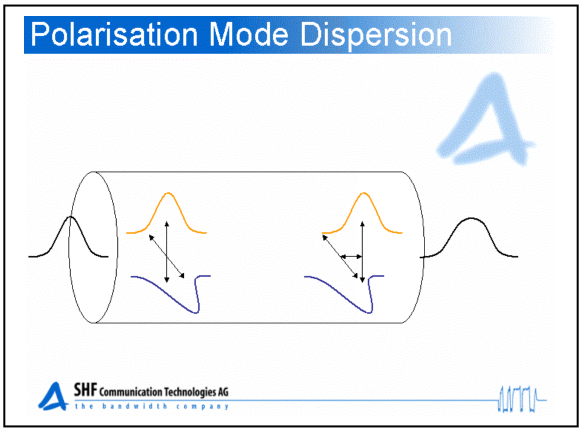
The state of polarization is described by the Stokes parameter:
(1,0,0) is horizontal polarization; (-1,0,0) is vertical polarization
(0,1,0) is +45° linear polarization; (-1,0,0) is - 45° linear polarization
(0,0,1) is right hand circular and (0,0,-1) is left hand circular



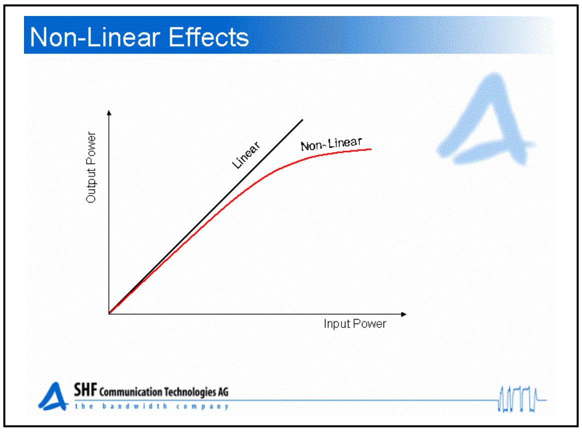
Dispersion means the velocity of propagation is not constant; dispersion causes pulse broadening.
Within a multimode fiber the different modes travel with different speeds causing mode dispersion.
In a single mode fiber two dispersion effects occur:
Chromatic dispersion and polarization mode dispersion.
Chromatic dispersion means that different colors (wavelengths) of the optical signal travel at different speeds.



Due to birefringence different states of polarization travel with different speed, this causes pulse broadening.

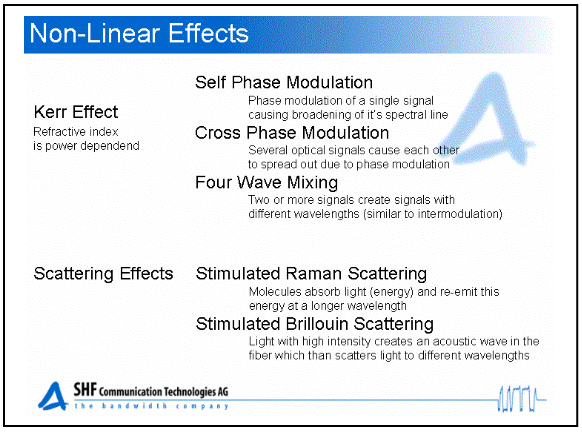


Non-linear effects are sometimes helpful but mostly unwanted.
It is beyond the scope of this seminar to give a detailed overview on non-linear effects in fibers, but as the tolerance against non-linearity is one reason why new modulation schemes are evaluated, we will cover some buzzwords.



The two principal effects causing non-linear behavior are:

- Kerr Effect
- Scattering Effects



We now know the limiting factors for optical high-speed data transmission:

- Dispersion
- Fiber non- linearity
- Polarization mode dispersion

New fibers - like dispersion-shifted fibers or large effective area fibers - are beeing developed to improve the characteristic of the transmission channel.
Another research area is the development of novel modulation formats that are more robust against transmission imperfections.