

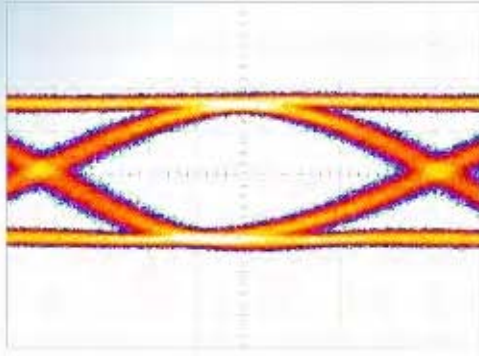


SHF Communication Technologies AG

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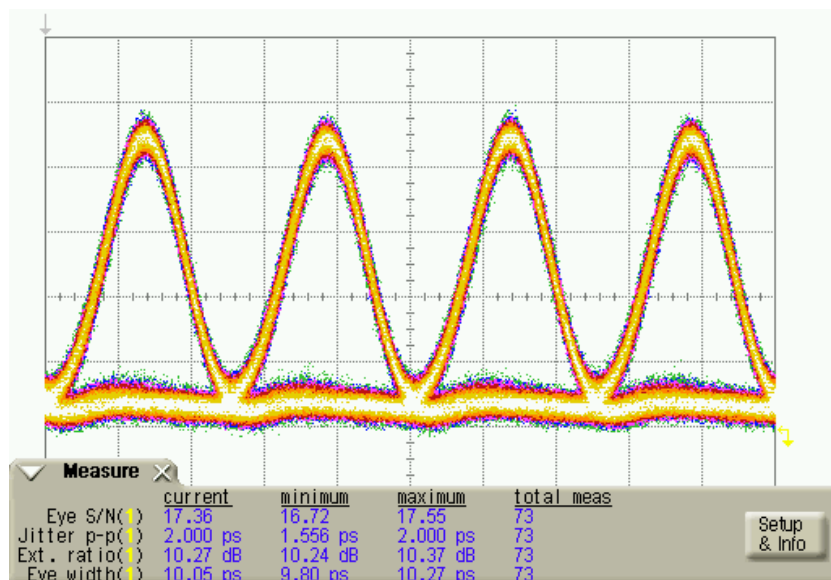
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Tutorial Note #5

Modulation Schemes

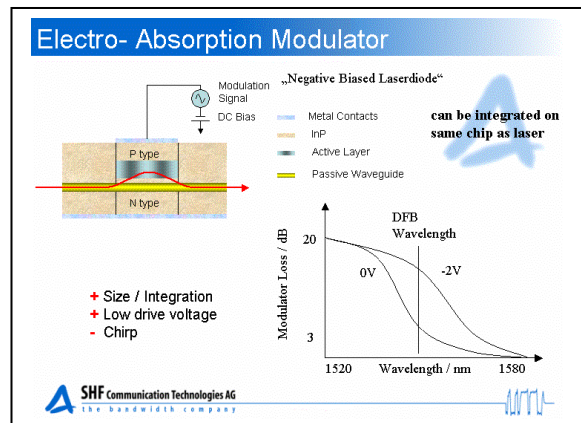


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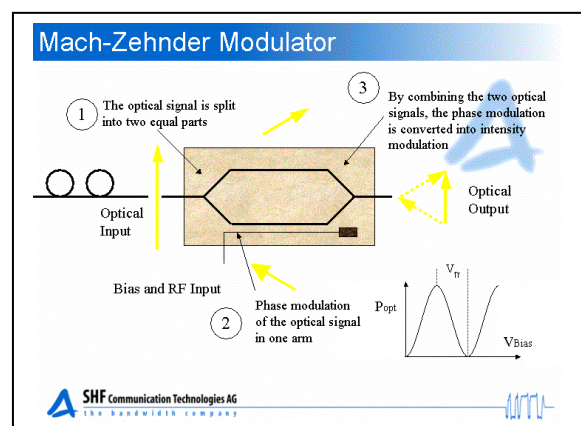
For high-speed communication (10 GBit/s and beyond) it becomes extremely difficult to modulate the laser directly, therefore external optical modulators are used. The electro-absorption modulator is such a modulator. It can be understood as a reverse-biased PIN detector.

Although it improves the chirp performance considerably compared to direct modulation of the laser, there is still enough chirp to make long haul high speed transmission impossible. More importantly, the modulator chirp is dynamic and changes with the actual drive voltage.

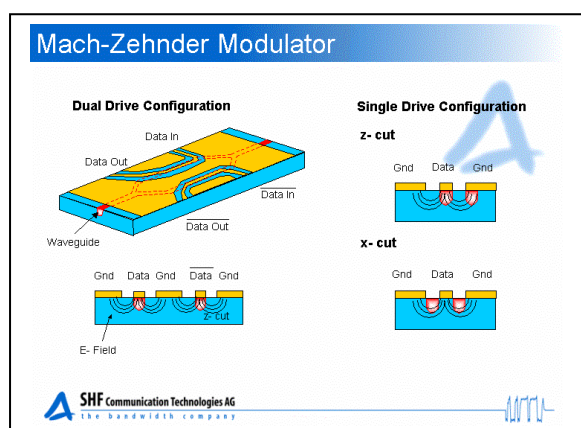


Another possibility to modulate light is a Mach Zehnder structure in a material showing strong electro-optic effect (such as LiNbO_3 or the 3-5 semiconductors such as GaAs and InP). By applying a voltage the optical signal in each path is phase modulated as the optical path length is altered by the electric field. Combining the two paths with different phase modulation converts the phase modulation into intensity modulation.

If the phase modulation is exactly equal in each path but different in sign, the modulator is chirp free, this means the output is only intensity modulated without incidental phase-(or frequency-) modulation.



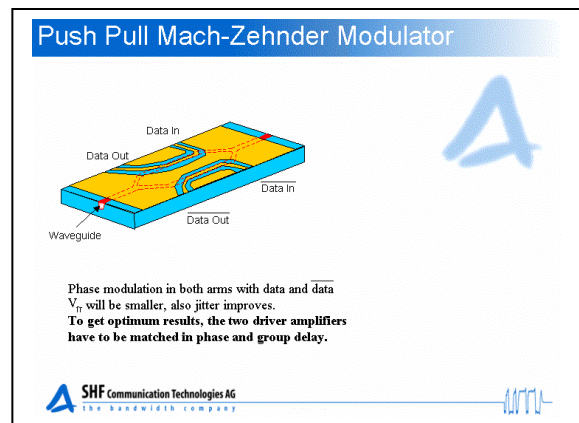
Here you see the schematic of a Mach - Zehnder modulator. MZ modulators are either dual drive or single drive. The dual drive configuration uses data and inverted data to generate the intensity modulation. If the electrical field in both MZ branches is identical the dual drive configuration will be chirp free. The single drive configuration can be either Z-cut or X-cut, since X-cut is intrinsically balanced - this means symmetrical - it is chirp free, whereas the z-cut will exhibit chirp.



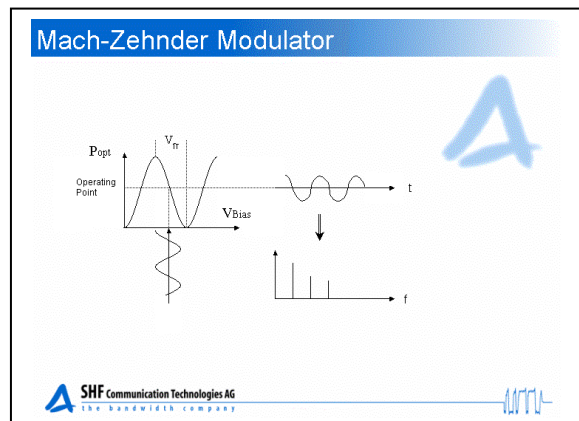
One way of implementing a Mach Zehnder modulator is a dual electrode structure or a push pull modulator: If we apply data and inverted data, the optical output will be chirp free, if we change the amplitudes of the driving signals the chirp can be adjusted.

To obtain a chirp free signal the two drivers have to be very carefully matched (Option matched pairs for SHF amplifiers).

The benefit of a push pull modulator compared to a single electrode modulator is that you need lower driving voltages in each arm. The drawback is that you need two amplifiers that are carefully matched and that it is difficult to quantify the chirp of such a configuration.

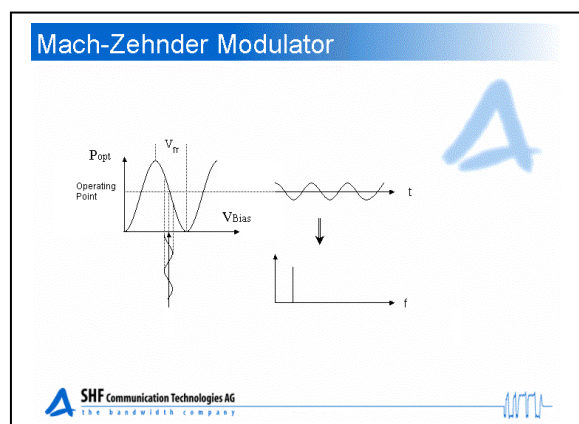


As the electro-optic transfer characteristic of a Mach Zehnder modulator is $\cos^2$ -shaped, the modulator will be biased in the linear range (between the maximum and minimum) and the modulation signal will be superimposed onto the bias voltage. If electrical NRZ data with an amplitude of V_{π} are fed into the modulator, the optical output signal will be NRZ as well. In this application the non-linear characteristic of the modulator will improve the signal quality as overshoot and patterning will be clipped.



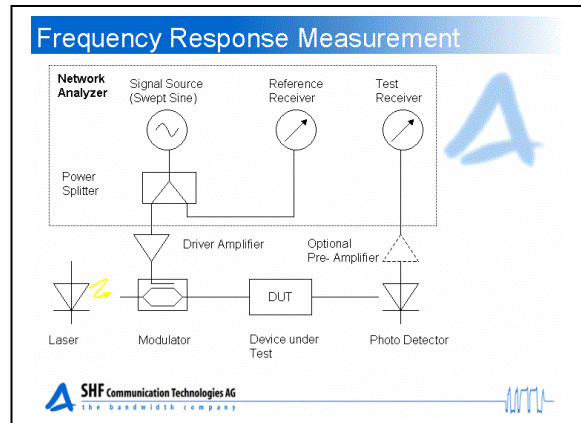
For some applications (mainly analog link applications) the non-linear transfer characteristic of the modulator is a disadvantage, if the modulating signal has an amplitude much less than V_{π} the modulator will operate in its linear range.

Keep in mind that by improving the linearity we have sacrificed the extinction ratio.



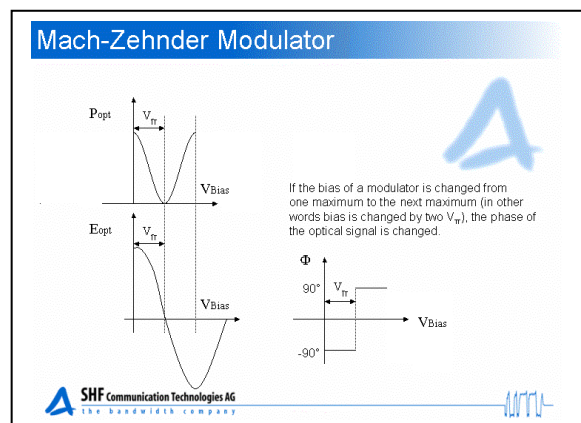
One application where the modulator is operated within its linear range is a frequency response measurement.

To avoid measurement errors due to harmonic signal content, the driving signal is chosen to be small enough not to generate harmonics. The lower extinction ratio doesn't harm as the electrical receiver is narrow band and therefore has a much higher sensitivity than a broadband data receiver.



When a balanced modulator structure (e.g. X-cut or dual-drive Z-cut modulator) is driven by an electrical signal with $2 \cdot V_{\pi}$, the modulator shows interesting behavior:

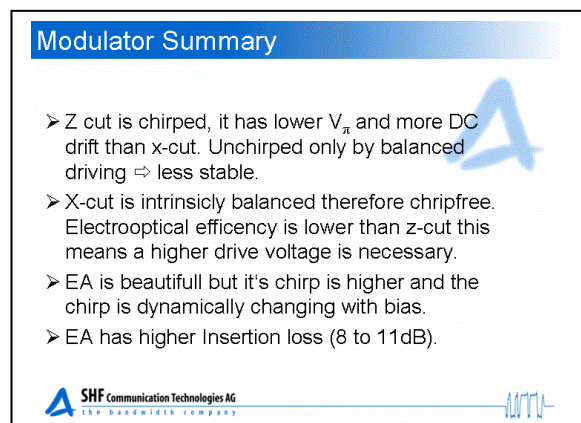
- As the input signal passes through a positive and a negative slope of the transfer characteristic, the output signal will be doubled in frequency.
- When transiting the minimum of the transfer characteristic, the phase of the optical signal will be altered by π .



To summarize:

EA modulators have more chirp than Mach Zehnder modulators and are therefore mainly used in short reach applications.

Z-cut modulators can have lower, and well behaved chirp than EA modulators but still some chirp, whereas X-cut modulators have zero chirp. Z-cut modulators offer lower V_{π} but show higher drift than X-cut modulators.



A lot of research is currently done in the area of novel modulation schemes. Just as radio evolved from basic on/off keying through amplitude modulation to phase- and frequency modulation, optical communication is progressing today – at a much faster speed though.

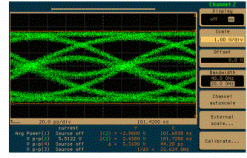
The key driving factor is cost. To reduce cost the following alternatives are investigated:

- Higher spectral efficiency
- Higher robustness and tolerances against fiber non-linearities

Other Modulation Schemes

➤ Driving Factors:

- ✓ Higher spectral efficiency
- ✓ Tolerance against fiber non-linearities

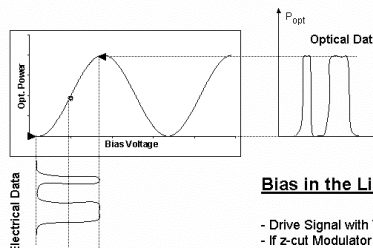


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To understand the new modulation schemes let's review the plain on/off keying called NRZ transmission in optical communication: When biased in the linear region and driven with V_π the LiNbO₃ modulator acts as an intensity (amplitude) modulator.

The non-linear characteristic of the modulator clips the signal; it is therefore sometimes possible to have a better Q factor for the output (optical) signal than for the input (electrical) signal.

Data Modulation – NRZ



Bias in the Linear Region:

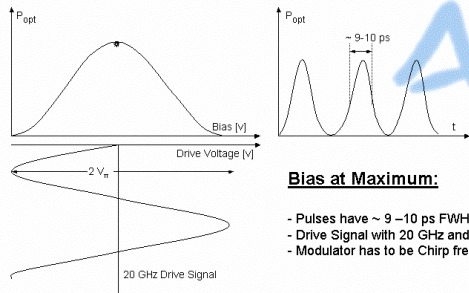
- Drive Signal with V_π
- If z-cut Modulator, optical signal will have chirp

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For generating 40 GHz RZ pulses a LiNbO₃ modulator is also very helpful:

When driven with a 20 GHz sine wave with an amplitude of $2V_\pi$ and biased at the maximum, we will get optical pulses with a width of 9 to 10 ps. Provided that the modulator is chirp free, these pulses are perfectly suited for 40 Gb/s RZ transmission.

Pulse Generation – RZ-Pulses

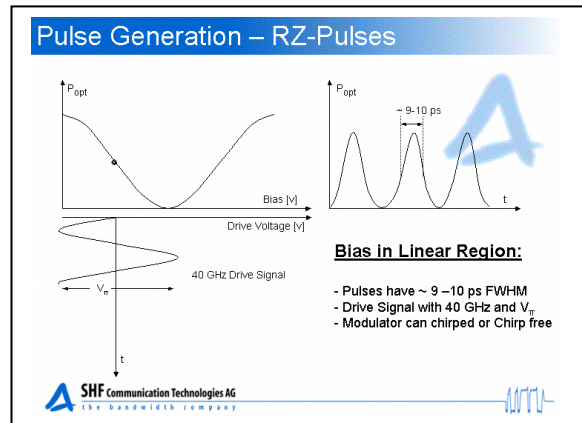


Bias at Maximum:

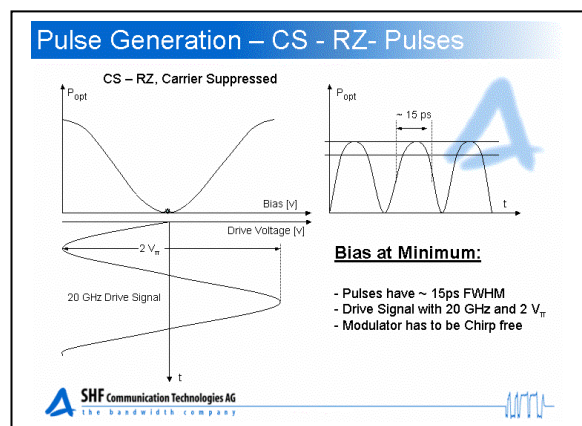
- Pulses have ~ 9 – 10 ps FWHM
- Drive Signal with 20 GHz and $2V_\pi$
- Modulator has to be Chirp free

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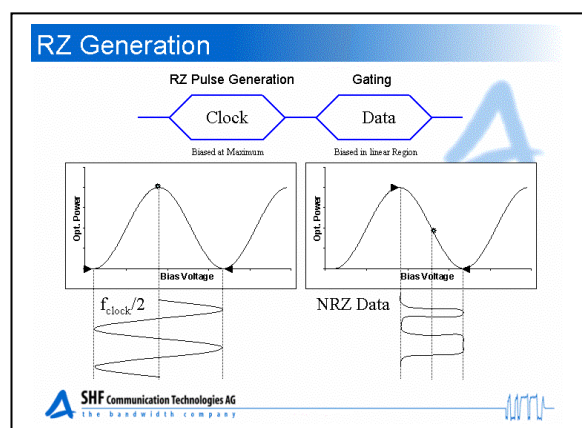
Of course the 40 GHz pulses can also be generated by a 40 GHz sine wave with an amplitude of V_π and a modulator that is biased in its linear region. In this case the modulator does not have to be chirp free.



A third possibility for generating 40 GHz RZ pulses is to bias the modulator at its minimum and to drive it with a 20 GHz sine wave having an amplitude of $2 \cdot V_\pi$. The RZ pulses will be wider, around 15 ps and the modulator has to be chirp free. With carrier suppressed RZ adjacent pulses will have a difference of 180° or π in their optical phase.

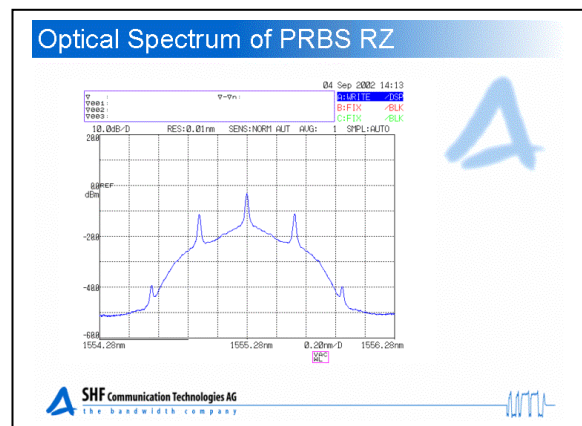


When a stream of RZ pulses has been generated, the data have to be encoded on the stream of equally spaced RZ pulses. A second modulator, the “gating modulator“, commonly does this. The gating modulator is driven with the NRZ data and the output will be an optical RZ signal.

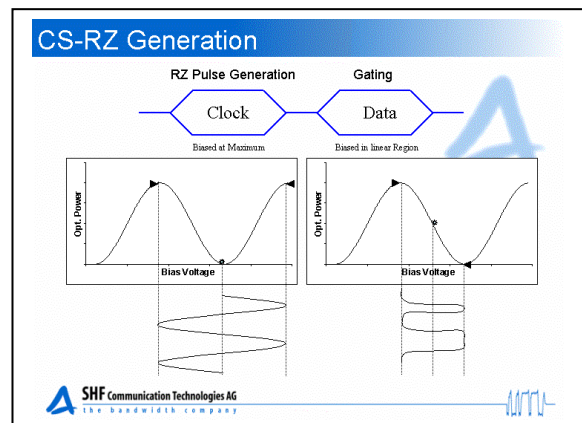


When the modulator is biased in its maximum and driven by a 20 GHz sine wave with $2 \cdot V_\pi$ or if it is biased in its linear region and driven by a 40 GHz sine wave with V_π we get conventional RZ.

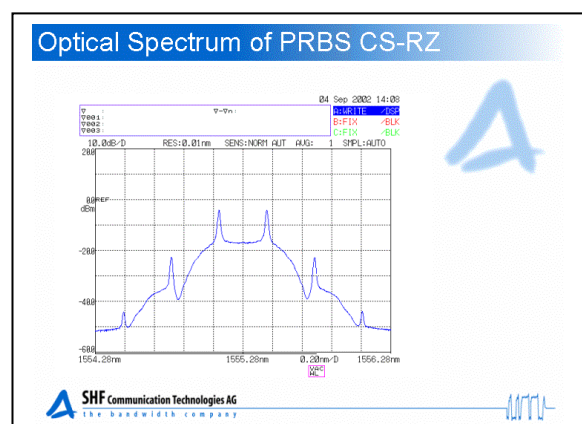
Here you see the spectrum of a PRBS sequence modulated in conventional RZ format.



When the modulator is biased in its minimum and driven by a 20 GHz sine wave with two V_π we have carrier suppressed RZ. (CS-RZ)



Here we show a 40 Gb/s PRBS sequence modulated in CS RZ format. Note that the spectrum shows that the optical carrier is suppressed and that the two modulation sidebands are closer than they are for conventional RZ.



As RZ has some benefits compared to NRZ the higher technical effort in generating RZ signals is justified especially in long-range transmission systems.

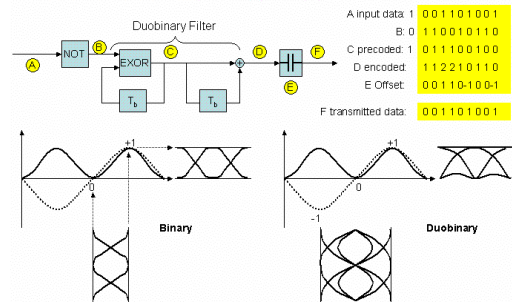
RZ Summary

- Better S/N at the sampling point as higher peak power is transmitted for the same amount of mean power
- Less Intersymbol Interference – therefore more dispersion tolerant
- Less Jitter as RZ pulses are generated from a CW synthesizer

CS-RZ is more spectral efficient than RZ. As with CS-RZ the carrier is suppressed and two consecutive pulses are 180° out of phase it offers more resilience against Self Phase Modulation.

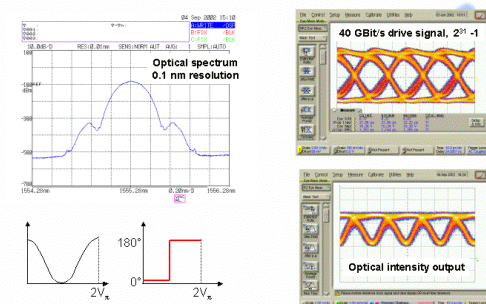
A new modulation scheme that reduces the bandwidth and therefore the vulnerability due to dispersion is duo-binary modulation. The electrical data are precoded and encoded and the modulator is driven with an electrical signal having an amplitude of $2V_\pi$ to obtain modulation of the phase of the optical signal.

Duobinary



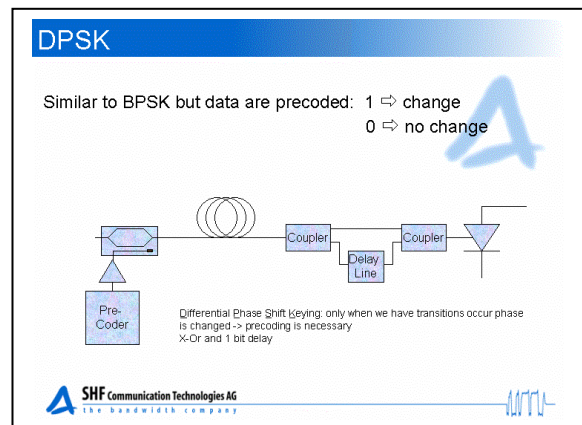
If we modulate the phase of the optical carrier we can potentially improve the sensitivity, as the light will not be “switched off” when a logical 0 is transmitted. A Mach Zehnder modulator is perfectly suited to generate a binary phase shift keyed signal as the phase of the optical carrier is altered by 180 degrees when the bias of the modulator goes through the minimum of the transfer characteristic.

BPSK Modulation

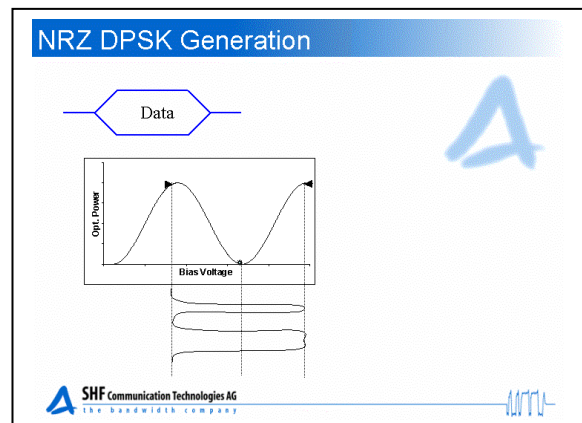


With a BPSK signal a single error would cause all subsequent received bits to be detected wrongly – therefore differential phase shift keying is used. With DPSK the data are precoded in the same way as they are in duo binary, a transmitted “1” means that the data changed whereas a transmitted “0” corresponds to no change of the data.

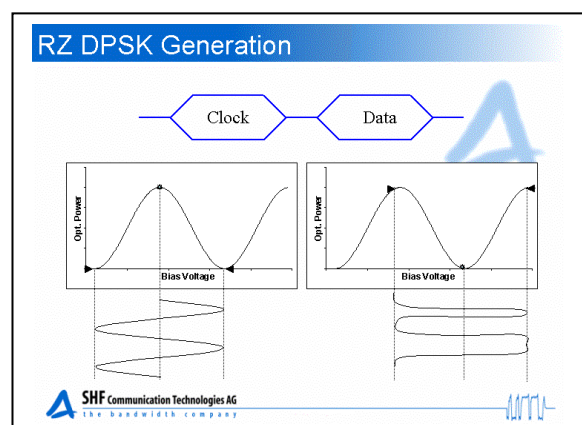
Note: as PRBS signals are not altered by the pre-coding, a pre-coder is not needed in a test transmitter.



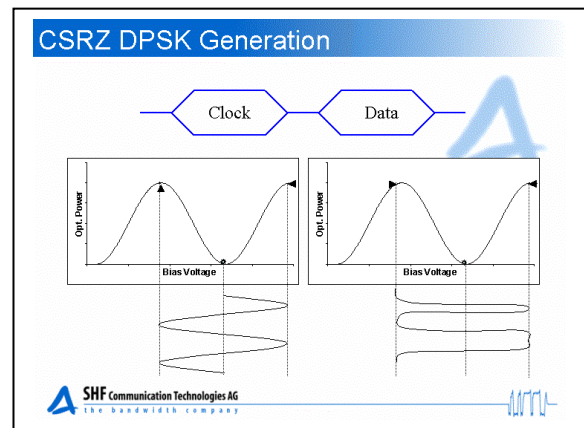
Generating an NRZ-DPSK signal is straightforward, the only difference to NRZ is that the modulator is biased at its minimum and that it is driven with $2 \cdot V_{\pi}$. Each time the data change their logical value the phase of the optical carrier is altered by a 180° . The benefit of using a MZ modulator and not a phase modulator is the limiting characteristic of a MZ modulator and the fact that the phase is altered by exactly a 180° .



If we use the above described phase modulator together with a RZ generating MZ modulator we will have RZ-DPSK.



When CS-RZ pulses are gated with our MZ phase modulator we obtain CS-RZ DPSK.



Phase modulation requires that the modulator is chirp free; therefore electro-absorption modulators and single drive Z-cut LiNbO₃ modulators cannot be used.

Dual drive Z-cut LiNbO₃ modulators – if the two input signals are carefully balanced – and of course X-cut modulators can be employed for phase modulation.

Single drive X-cut modulators have the advantage that you only need one amplifier and you do not have to align the delay (phase) of two input signals.

Modulators for Novel Modulation Formats

- EA modulators can not be used for PSK formats.
- DPSK and BPSK require chirp free signals.
- Z cut LiNbO₃ modulators are traditionally used for RZ and NRZ, they operate chirpfree only if they are balanced driven.
 - Two amplifiers providing V_{π} are necessary.
 - Option Matched Pair is appreciated by customers.
- X-cut LiNbO₃ modulators are chirp free with single drive.
 - One amplifier providing two V_{π} is necessary.

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Each modulation schemes behaves differently regarding spectral efficiency, tolerance against fiber imperfections and implementation complexity.

Relative Performance Merits

Format	Spectral ^[1] efficiency (bit/Hz.s)	Non-linear tolerance	Dispersion tolerance (ps/nm)	PMD ^[2] tolerance (ps)	Implementation complexity
NRZ	0.4	Poor	70	11	Simplest
RZ	0.2	Good	110	12	Moderate ^[3]
Duo-binary	0.4	Poor	100/170	-	Complex ^[4]
VSF	0.4/0.53	Poor	similar to NRZ	-	Moderate ^[5]
CS-RZ	0.4(0.53 max)	Good	112	12	Moderate ^[3]
RZ-DPSK	0.4	Good	60	12	Complex ^[6]

CS-RZ encapsulates all the good features of RZ format, with additional benefit of tolerance to non-linearity due to the anti-phase property of adjacent pulses, and enhanced spectral efficiency

[1] Single polarisation [3] Need 2 modulators + 1 high power narrow band amp
 [2] 1st order PMD only [4] Need high power linear amp + optimum filter
 [5] NRZ + vestigial side band filter
 [6] Need 2 modulators and decoder/balanced detector. But benefit of extra 3 dB in sensitivity compared to ASK count-part

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Here is a summary of the electro-optical and opto-electrical converters we offer.

With these converters you can upgrade our bit error rate testers or our multiplexers and demultiplexers. Depending on your application you can choose between three transmitters: NRZ or NRZ, RZ and CS-RZ or a transmitter that supports six modulation formats: NRZ, RZ and CS-RZ and the three corresponding DPSK versions.

As receivers we offer a photo receiver for NRZ, RZ and CS-RZ as well as a receiver for DPSK with built in decoder and a balanced detector.

Solutions for Novel Modulation Schemes

Generating:	
NRZ:	SHF 5003NRZ
NRZ, RZ & CS-RZ:	SHF 5003RZ
All of the above and DPSK:	SHF 5003 DPSK
Detecting:	
NRZ, RZ & CS-RZ:	SHF 47100A
DPSK:	SHF 5008 DPSK

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