Al Imam Mohammad Ibn Saud Islamic University

College of Engineering

Department of Electrical Engineering

Communication 2 Lab –EE 454

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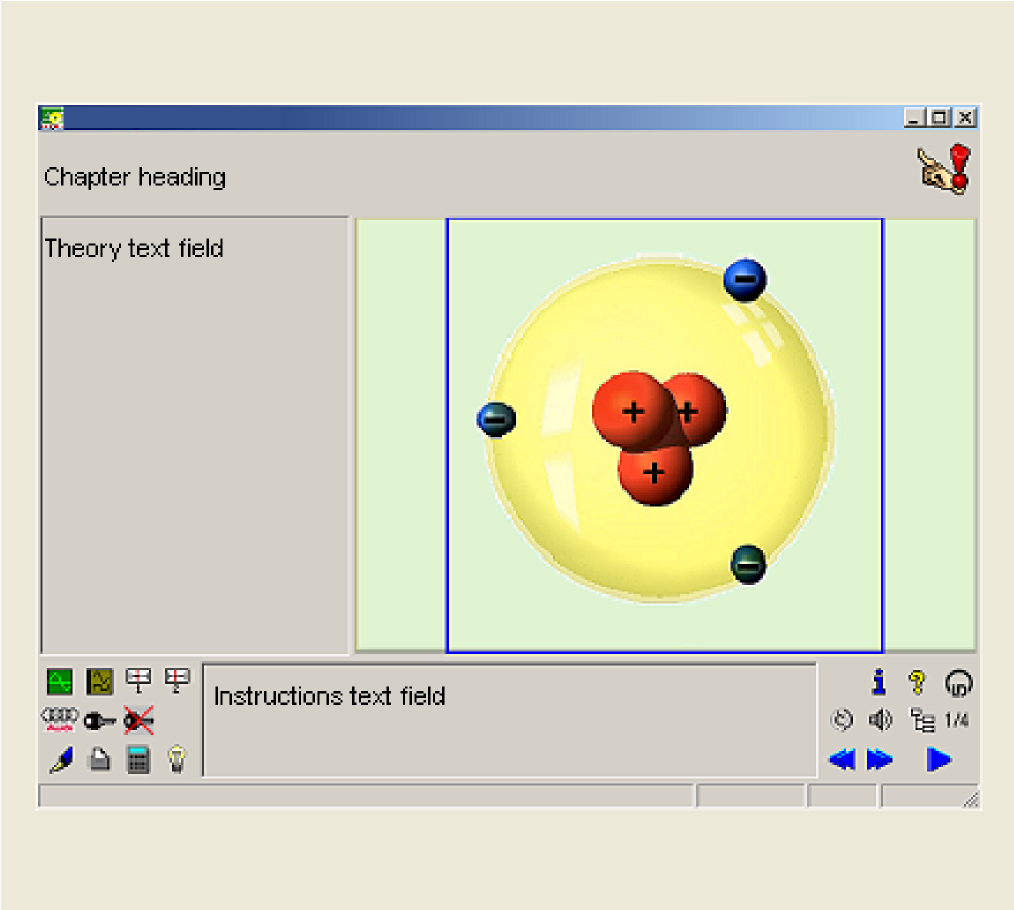
Communication 2 Lab

Introduction to Com3Lab

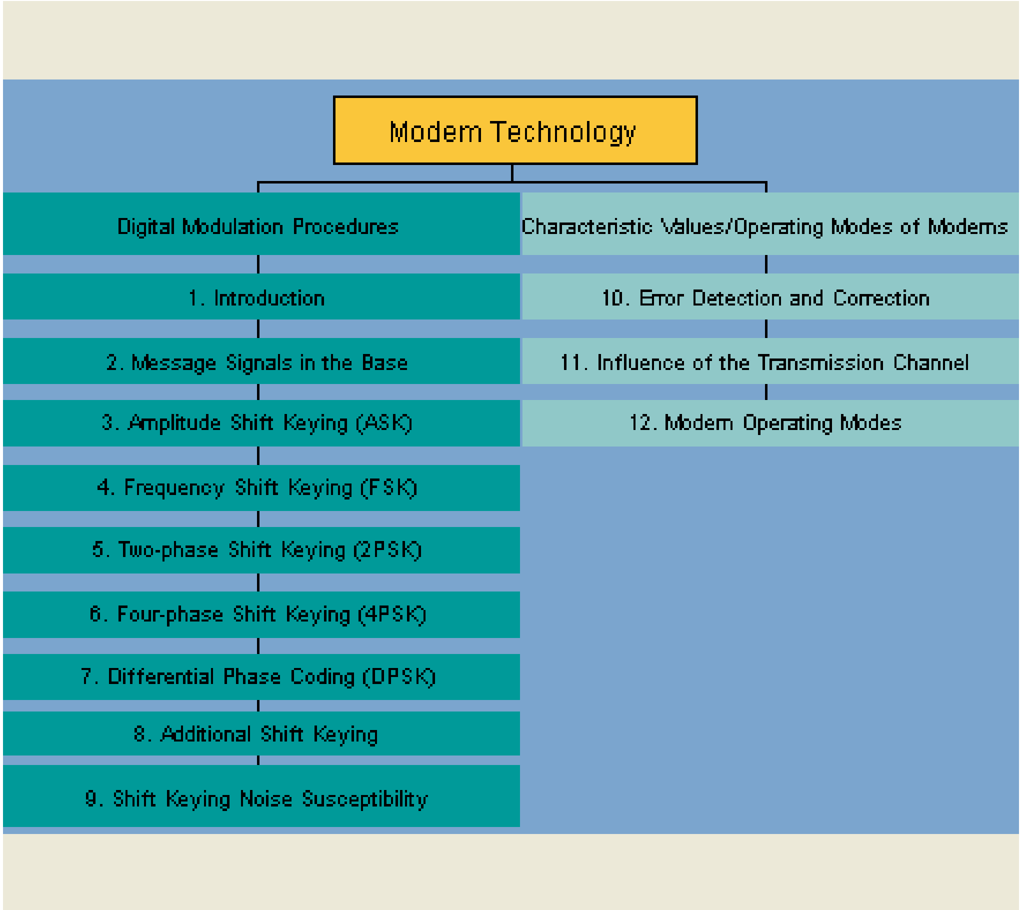
1.1 Using the course



Welcome to the COM3LAB course. Before you begin with the course, you should spend some time on the next pages with the COM3LAB System.

More detailed information can be obtained by clicking in the individual areas in the adjacent image.

1.2 Course Structure



The COM3LAB course "Modem Technology" is divided into two main topics: Modulation procedures (here those with a harmonic carrier and digital modulating signals as they are typically used in modems) on one hand, and characteristic values and operating modes of modems on the other. The adjacent graphic shows a detailed overview of the topics covered in the individual chapters.

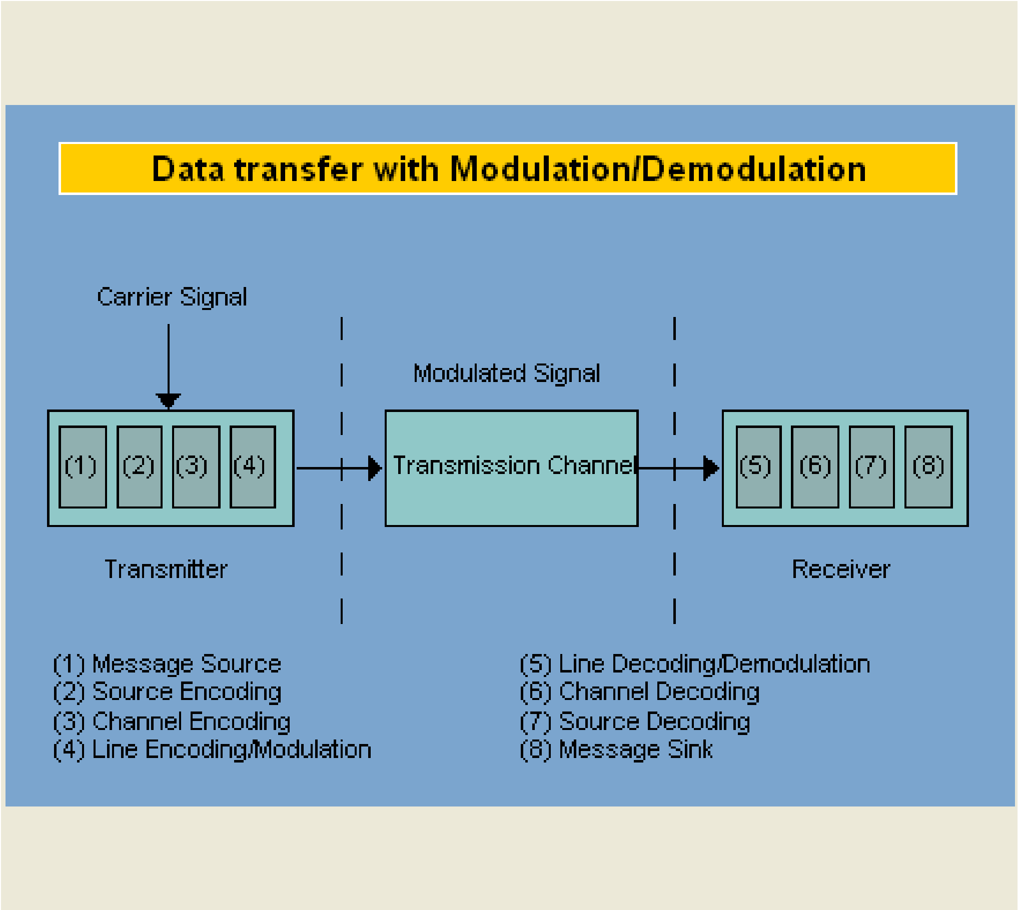
1.3 History

In data communication - whose beginnings go back to Morse telegraphy - digital data are transmitted over direct cable connections, a telephone line or via radio frequency. At the end of the transmission channel are tow communication terminal devices, such as computers. To be transmitted, the data must be adapted to the communication channel by means of modulation[1] .

[1] **Modulation**

A procedure for placing a payload signal on a carrier signal so that the payload signal can be transmitted well. Through modulation the susceptibility to disturbances in the transmission channel is reduced while on the other hand a variety of modulated signals can be sent simultaneously over the channel.

1.4 Principle of Modulation



The principle of modulation is used to adapt to the transmission channel and to use the channel simultaneously for a variety of signals. The payload signal[1] is thereby modulated in the modulator[2] on to a (for example sinusoidal or pulse-shaped) high-frequency carrier[3] and then transmitted. On the receiver side a demodulator[4] then regenerates the original payload signal from the modulated signal. There are various types of modulation. (Note: Output D on the Modem Technology Board is located between units (3) and (4), and Output D' is between units (5) and (6)).

1 **Payload**

The payload is the signal which contains the actual information. It is modulated on to a (generally high-frequency) carrier signal for better transmission over the line.

2 **Modulator**

A modulator modulates the message signal (modulation signal) on to the carrier signal so that it can be better sent over the transmission channel. Through modulation the susceptibility to disturbances in the transmission channel is reduced while on the other hand a variety of modulated signals can be sent simultaneously over the channel. The counterpart to the modulator is the demodulator. A modem contains both components.

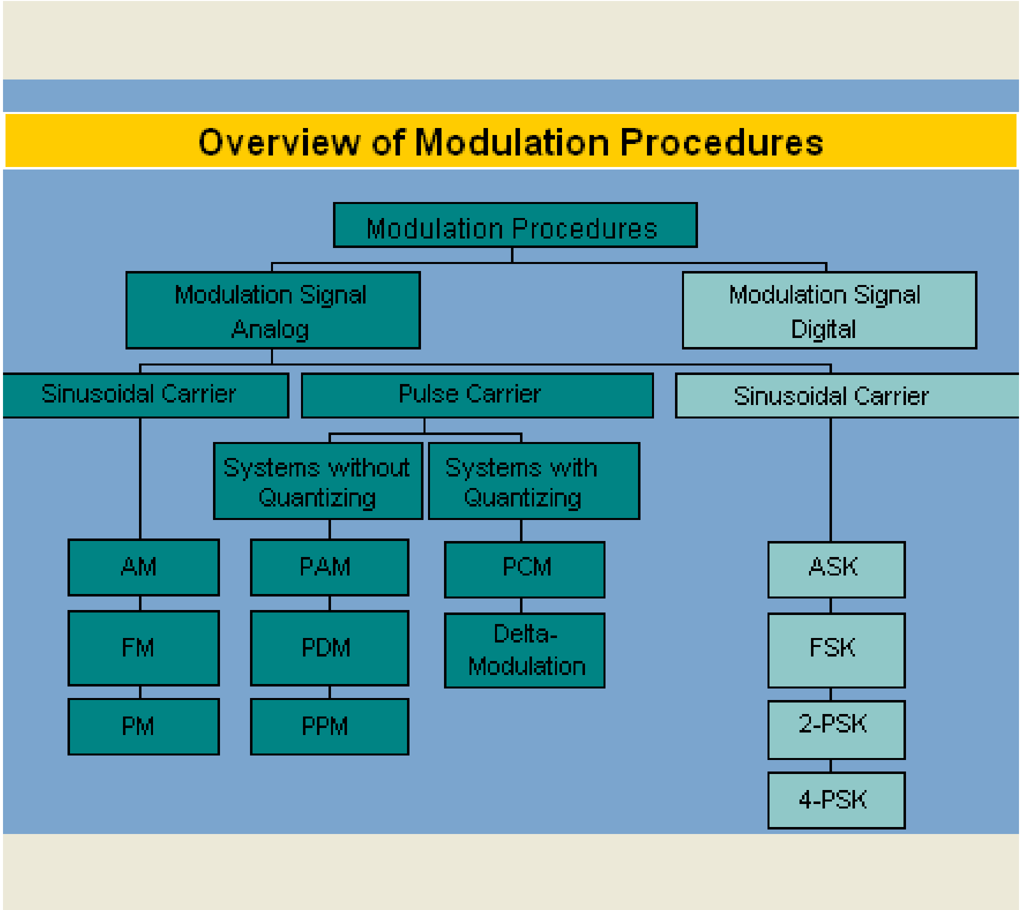
3 **Carrier signal**

The carrier signal is the (e.g. sinusoidal or pulse-shaped) high frequency signal on to which the payload is modulated. The result is better transmission of the payload over the transmission channel in terms of noise immunity and bandwidth use.

4 **Demodulator**

The demodulator extracts the original modulation signal (data signal) from the signal generated by the modulator. A distinction is made between synchronous (coherent) demodulation, in which the phase- and frequency-correct carrier is required, and non-synchronous (incoherent) demodulation (Example: envelope demodulator), in which this carrier is not required. Synchronous demodulation is generally more noise-immune.

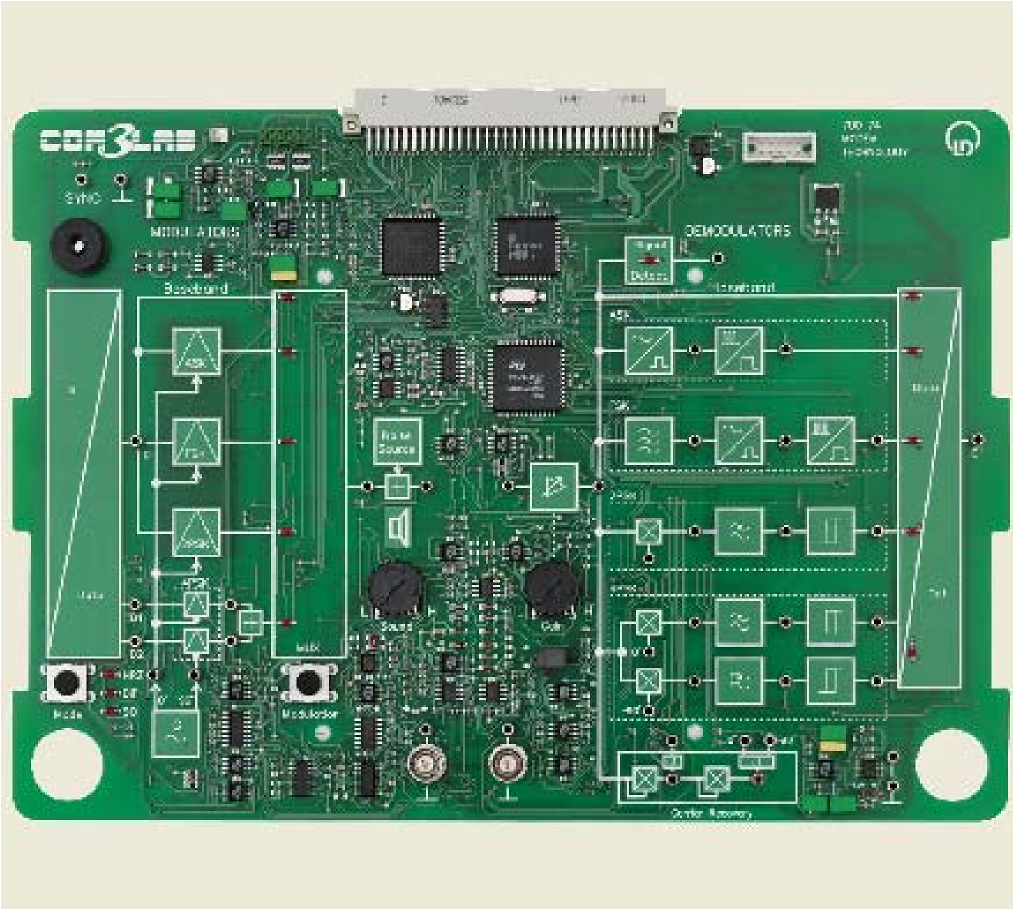
1.5 Modulation Procedures



Modulation procedures are characterized as those having a sinusoidal carrier signal and those with a pulse-shaped carrier signal. On the other hand, the modulation signal representing the message can be analog or digital. This course deals with those modulation procedures in which a digital modulation signal is modulated on to a sinusoidal carrier (shown lighter in the adjacent overview). The basics of the various modulation procedures are provided by the corresponding instructional systems[1] .

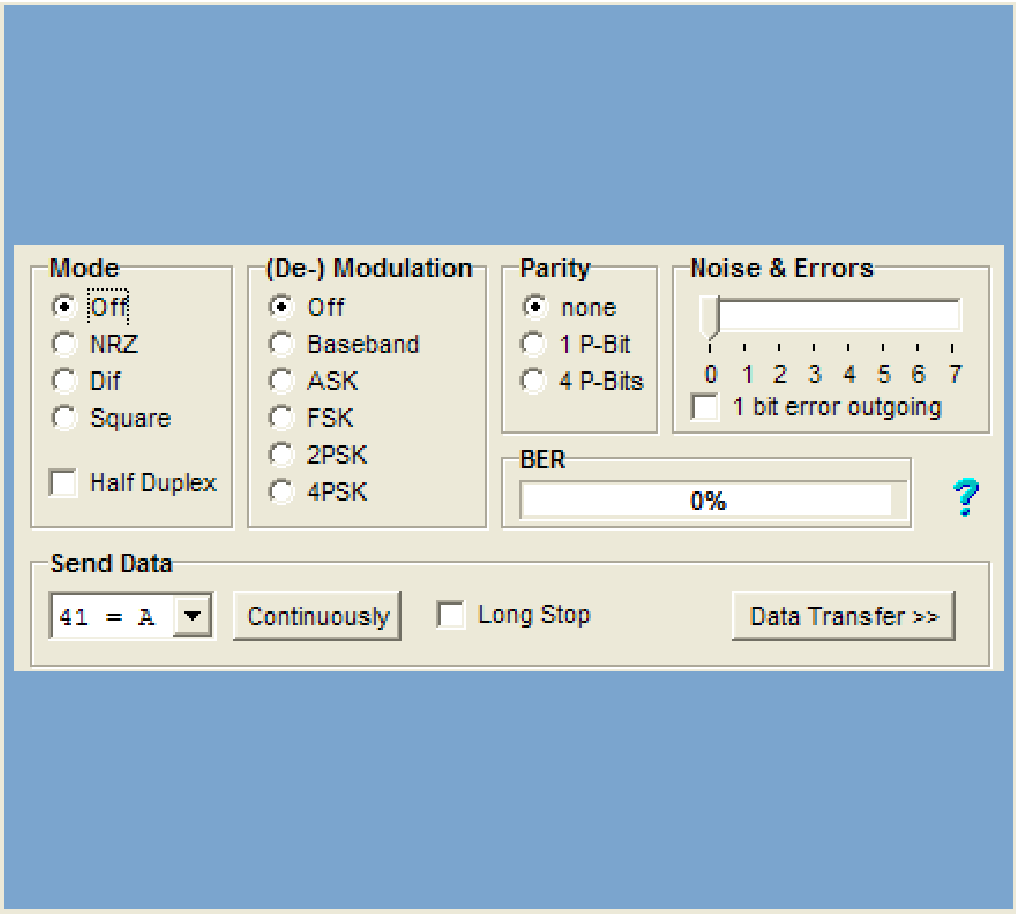
[1]
- T 7.2.1.3 Amplitude Modulation
- T 7.2.1.5 Frequency and Phase modulation
- T 7.2.2.1 Pulse Code Modulation
- 700 71 TX 433 Transmission Technique
- 700 72 RX 433 Receiving Technique

1.6 The COM3LAB-Board 700 74



The COM3LAB-Board 700 74 Modem Technology contains all the components needed for an introduction to digital modulation. This includes especially modulators for amplitude, frequency and two- and four-phase shift keying as well as the corresponding demodulators. Data transfer can be performed over various channels which can be noise induced using an integrated noise generator.

1.7 The Modem Control Panel



The control panel for the Modem Technology course allows you to control all the important board functions such as the data encoding type, modulation/demodulation type as well as the amplitude of the noise source. It also allows you to manually enter the characters for transmitting and enables automatic periodic sending of a settable data byte. The control panel is opened by clicking on the button .

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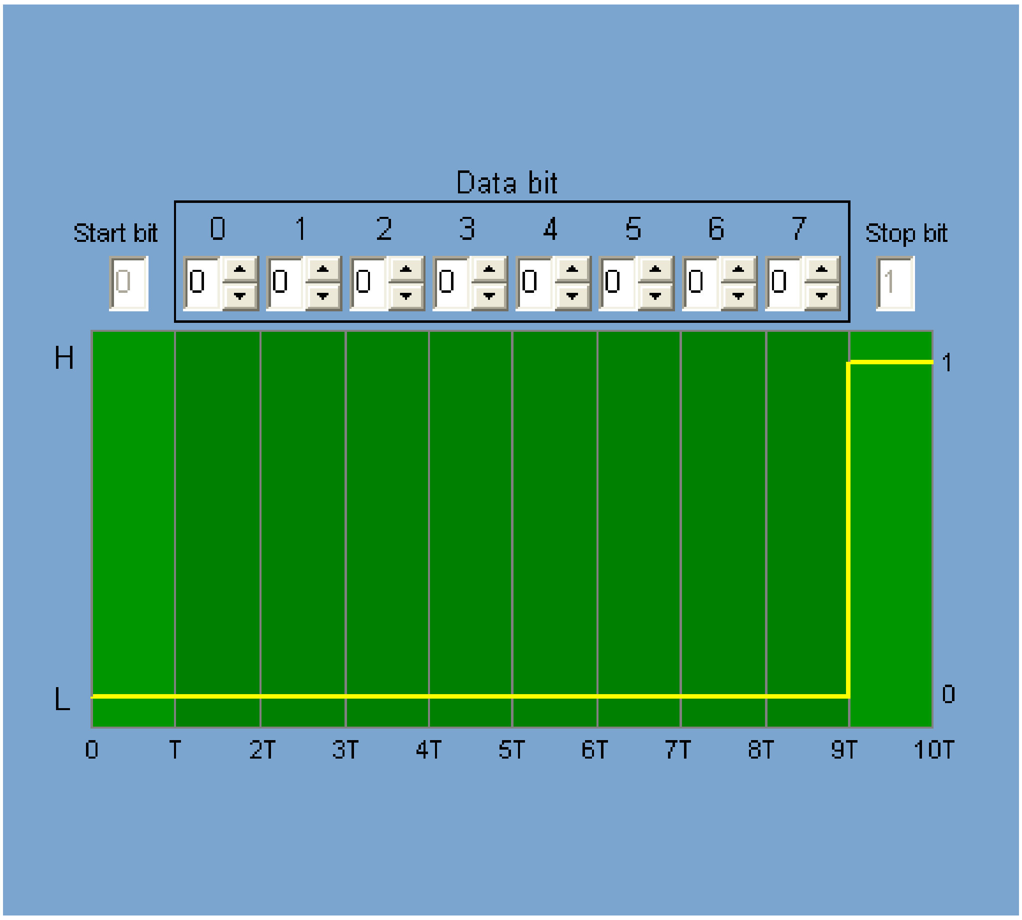
Experiment 1

"Line Encoding"

2.1 NRZ Format



A general distinction can be made between synchronous[1] and asynchronous[2] transmission; only the latter will be considered in context of this course.
In NRZ (nonreturn to zero) format the signal amplitude is constant during the entire duration T of a data bit. Each data byte is introduced by a start bit[3] (logical 0) and ends with a stop bit[4] (logical 1). A data bit of 0 is represented by a LOW level, and a data bit of 1 by a HIGH level.

[1] **Synchronous transmission**

Synchronous transmission is, like asynchronous transmission, a procedure for creating synchronization between the sender and receiver. In this format the synchronization is achieved in contrast to asynchronous transmission not by the start and stop bit(s) for an entire character, but rather by means of clock pulses for each individual bit. Since no start and stop bits are sent, synchronous transmission is faster but technically more complex to implement.

[2] **Asynchronous transmission**

In serial data transfer a procedure for producing synchronism between the sender and receiver is required to allow the receiver to recognize the start and end of a transmitted character. In asynchronous transmission each byte to be sent is marked with a start bit and one or two stop bits (one in the COM3-LAB Board Modem Technology). This start/stop procedure is one of the most often used transmission procedures used especially in the field of microcomputers, since it is technically relatively easy to implement as compared with synchronous transmission .

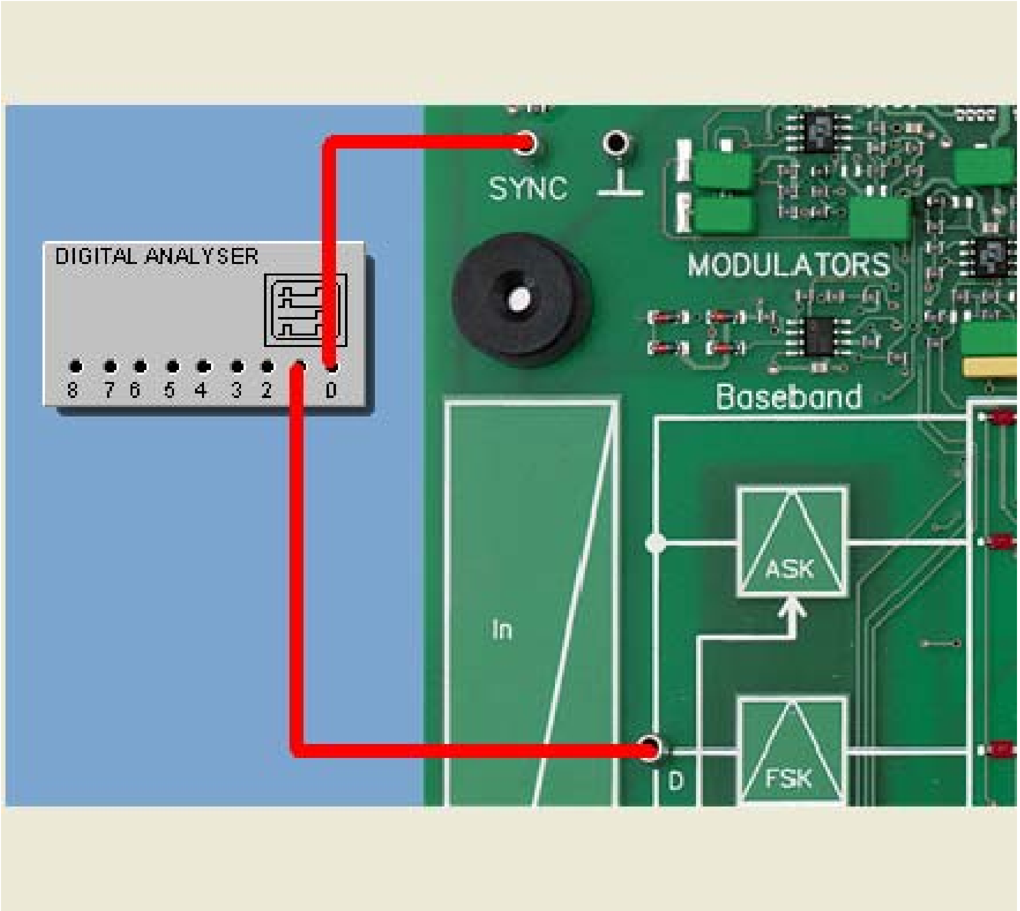
[3] **Start bit**

Bit used in asynchronous transmission to represent the start of a data word. The start bit is generally always zero.

4 **Stop bit**

One, one and a half (!) or two bits in asynchronous transmission which represent(s) the end of a data word. In the COM3LAB Board 700 74 Modem Technology one stop bit is used, but with the 'Long Stop' option for the Modem Control Panel the stop bit can when needed for better recognition be lengthened to 16x the bit duration. The stop bit(s) is/are generally always one.

2.2 Experiment: Time curve of the NRZ signal



In the following experiment you will study the NRZ data format in greater detail. Periodically different data bytes will be transmitted and the curve of the encoded data signal recorded with the digital analyzer. From the recorded curves the bit rate[1] of the data signal will then be determined.

[1] **Bit rate**

The number of bits sent per second (data transfer speed). The bit rate is measured in bits/s or bps. In contrast to the bit rate, the baud rate (also called step speed) gives the number of states of the transmitted signal per second and is measured in units of baud. Multiplying the number of bits per state by the baud rate gives you the bit rate. Multiplying the number of bits per state by the baud rate gives you the bit rate. Only if the number of states is exactly two (in other words exactly one bit is encoded with a state) is the baud rate the same as the bit rate. In general the relationship between data transfer speed v_D and step speed v_S is described by

$$v_D = v_S \text{ ld } N,$$

where N is the number of bits per state.

Procedure:

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2- Select the Experiment which is to be performed
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4- Submit the required answers asked during the experiment on computer screen by performing appropriate calculations and using the theory.
5- Open the appropriate windows for oscilloscope, Spectrum analyzer and other software devices specified on the computer screen.
6- Use appropriate procedures and techniques to get required plots and graphs on the computer screen.
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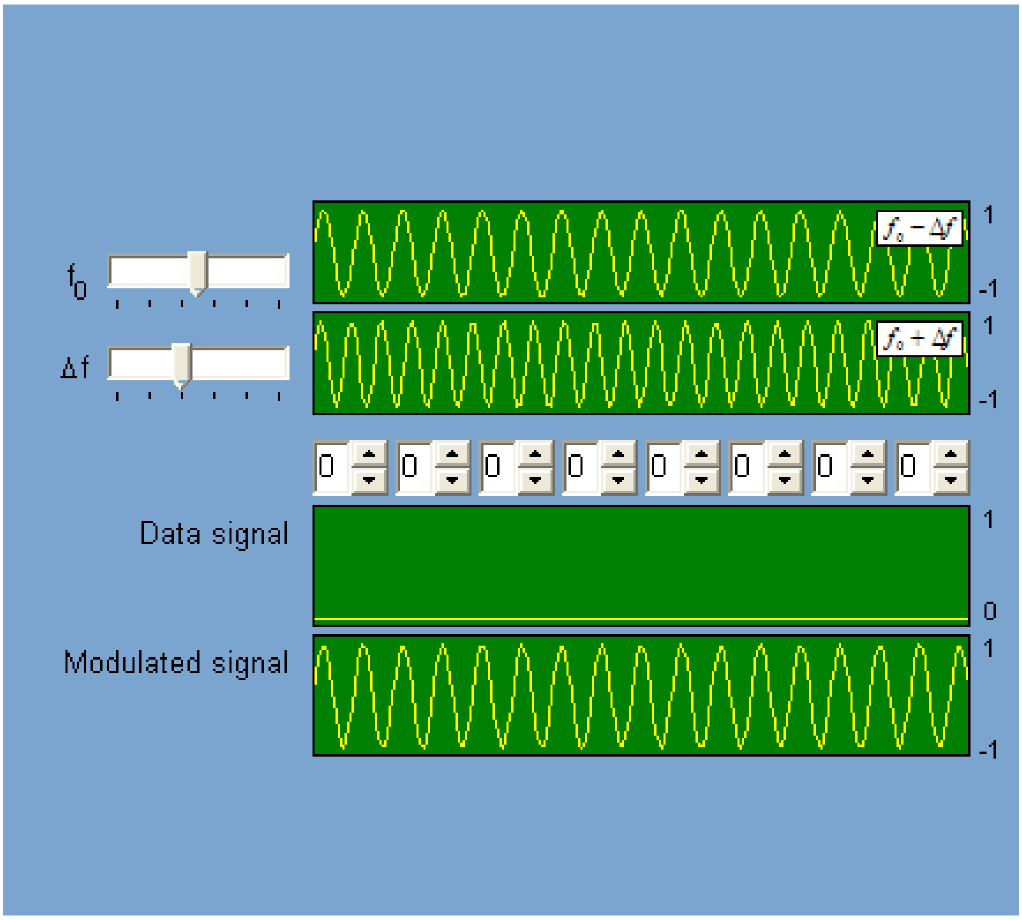
Experiment 2

"FSK Signal Generation"

4.1 Time function



In Frequency Shift Keying (FSK[1]) depending on the data signal the shift is made between two frequencies f_0 - Δf (data bit is logical 0) and f_0 + Δf (data bit is logical 1). The frequency f_0 is termed the center frequency[2], the frequency Δf the frequency deviation[3]. Compared with ASK, FSK is significantly less noise-sensitive.

1 **FSK**

Frequency Shift Keying is a modulation technique whereby the frequency of a sinusoidal carrier signal is changed as a function of the level of the (digital) modulation signal.

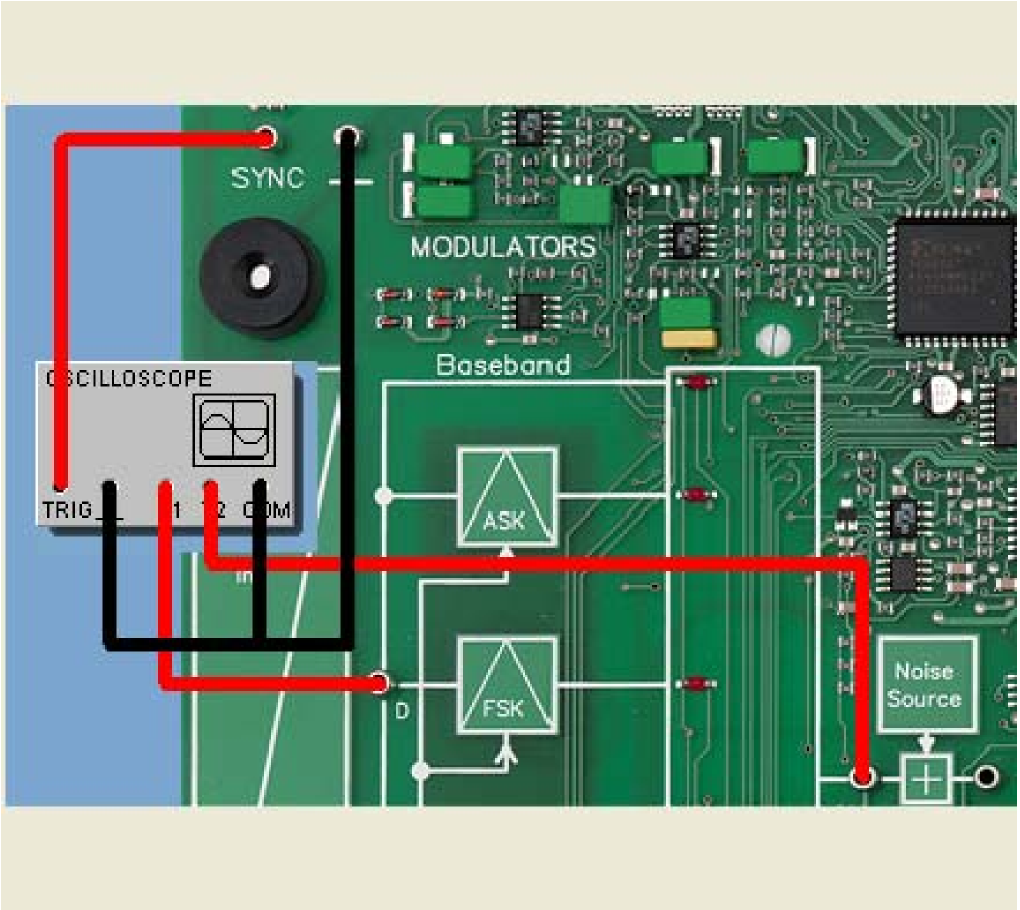
2 **Center frequency**

The center frequency $f_0 = 1/2\,(f_1 + f_2)$ is the average of the two characteristic frequencies f_1 and $f_2$which are alternated in frequency shift keying (FSK).

3 **Frequency deviation**

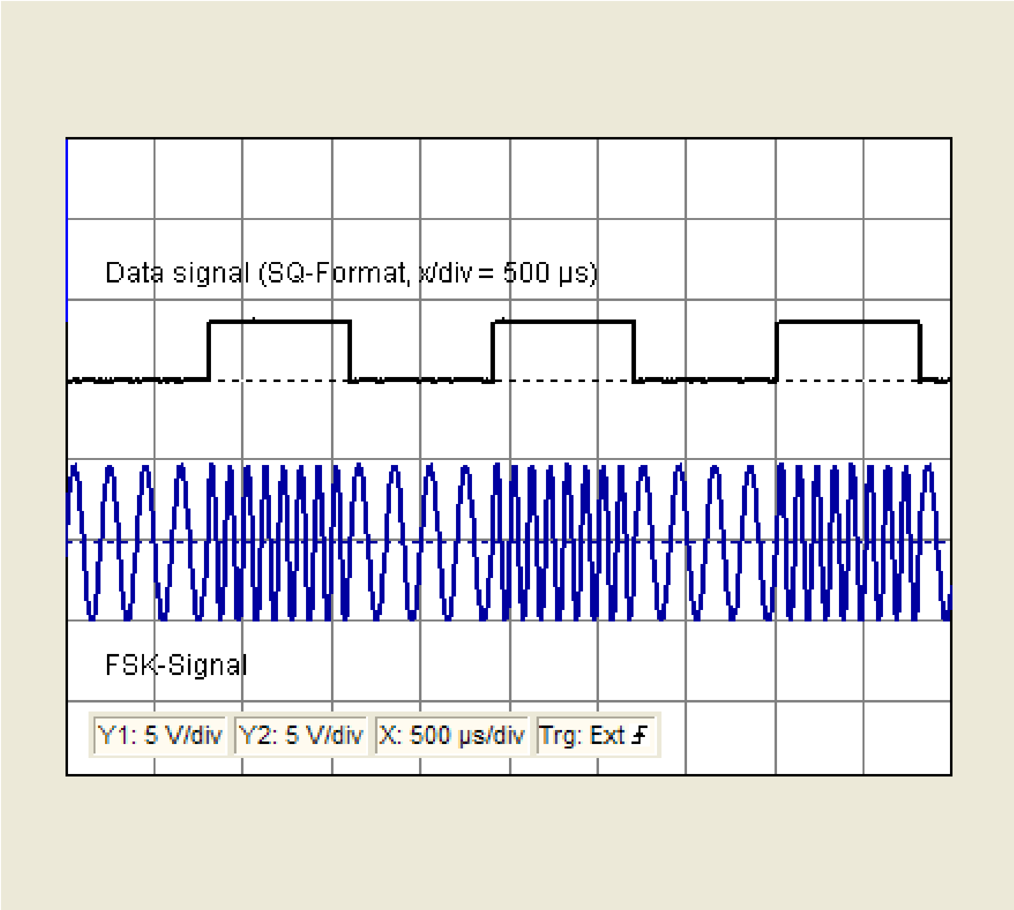
The frequency deviation Δf indicates by what value the two characteristic frequencies used in frequency shift keying (FSK) deviate from the center frequency f_0.

4.2 Experiment: Observing FSK on the oscilloscope



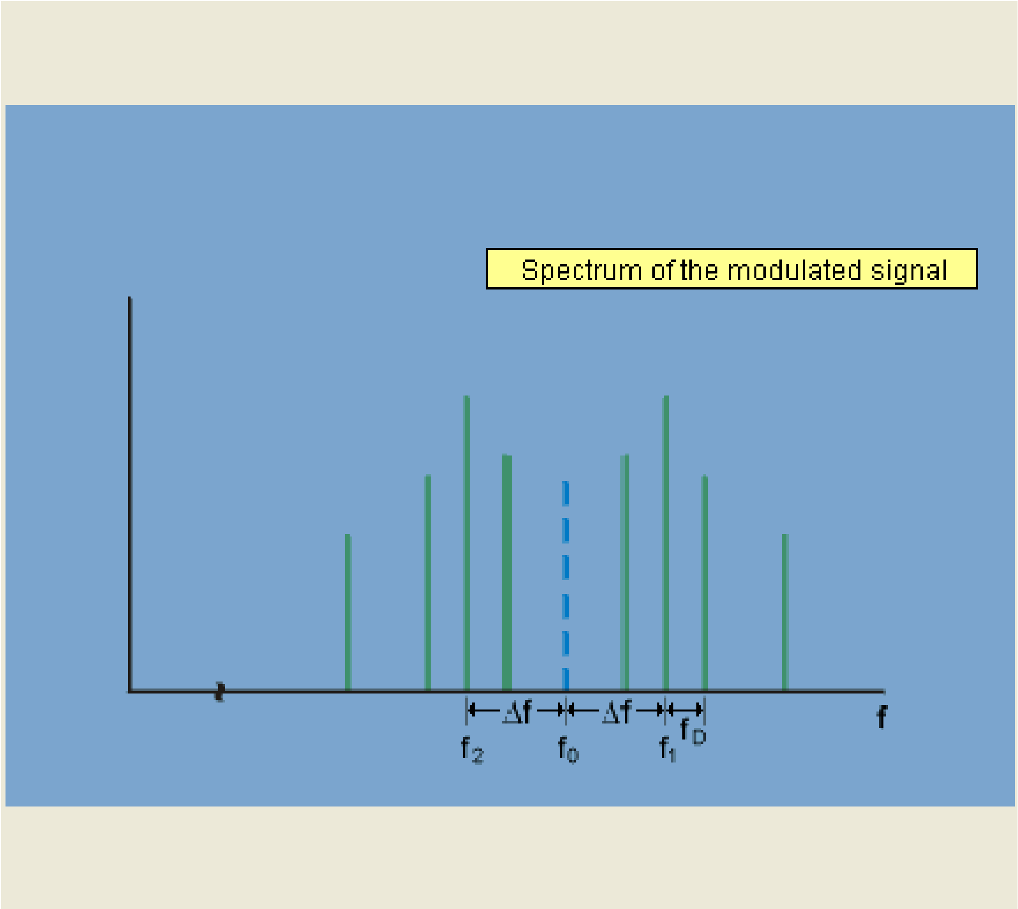
In the following experiment we will first study the modulated signal in frequency shift keying. Periodically a constant data byte will be sent as the data signal and modulated on to the sinusoidal carrier signal. The center frequency and frequency deviation can then be determined from the signals.

4.3 Result



In SQ data format (symmetrical square-wave signal) alternating LOW and HIGH pulses are sent; each has a duration of 800 µs (upper curve). At logical 0 there are four oscillations during this time, or eight at logical 1. This corresponds to frequencies of 5 kHz and 10 kHz. The center frequency is therefore 7.5 kHz and the frequency deviation 2.5 kHz.

4.4 FSK in the frequency range

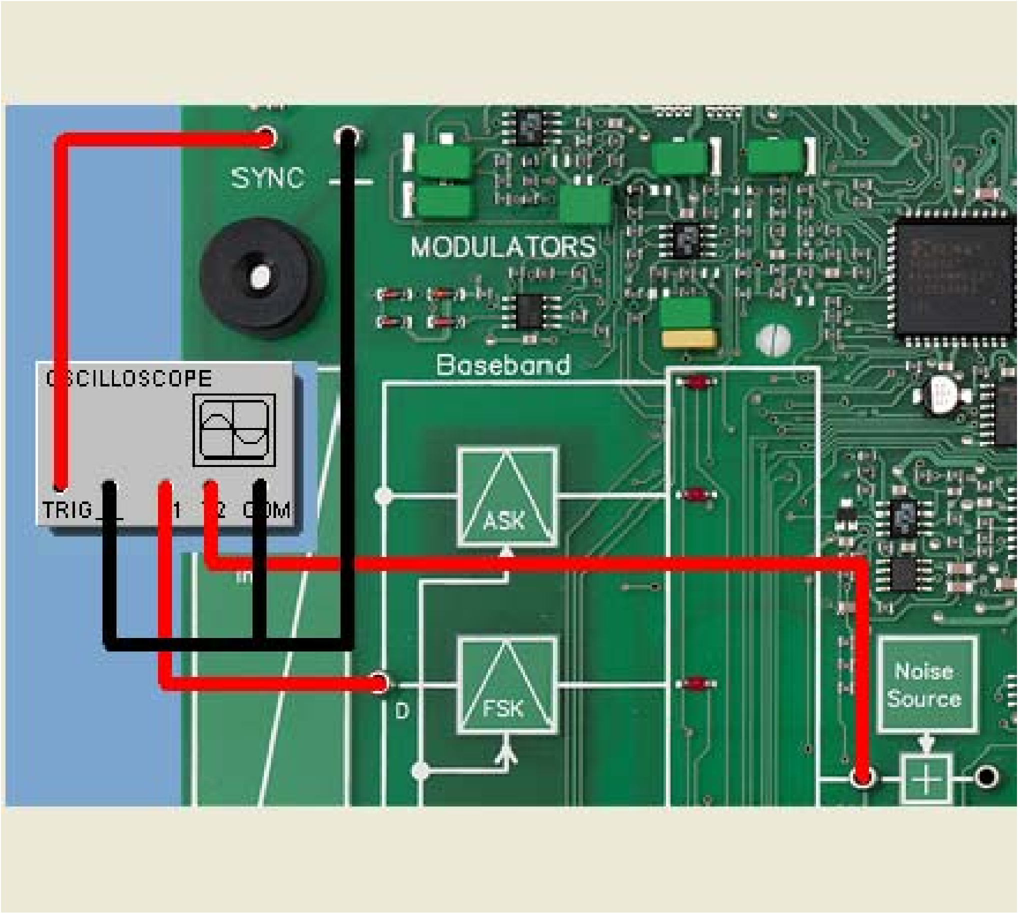


The frequency-shifted signal can be interpreted as the combination of two amplitude-shifted signals having frequencies

$f_1 = f_0 + \Delta f$ and $f_2 = f_0 - \Delta f$.

The required bandwidth is therefore significantly greater than in the case of Amplitude Shift Keying. TO reduce the bandwidth the data signal is therefore usually low-pass filtered first. The graphic at right shows the spectrum of the FSK signal with a square-wave data signal having frequency f_D.

4.5 Experiment: Measuring the FSK spectrum (SQ-Format)



In the following experiment we will investigate the amplitude spectrum of the modulated signal with Frequency Shift Keying. A periodic square-wave signal with a DC component and frequency f_D = 600 Hz will again serve as the data signal.

Procedure:

1- Open the COM3LAB STARTER program
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3- Connect the circuit as required in the experiment and in timely manner as specified during the procedure.
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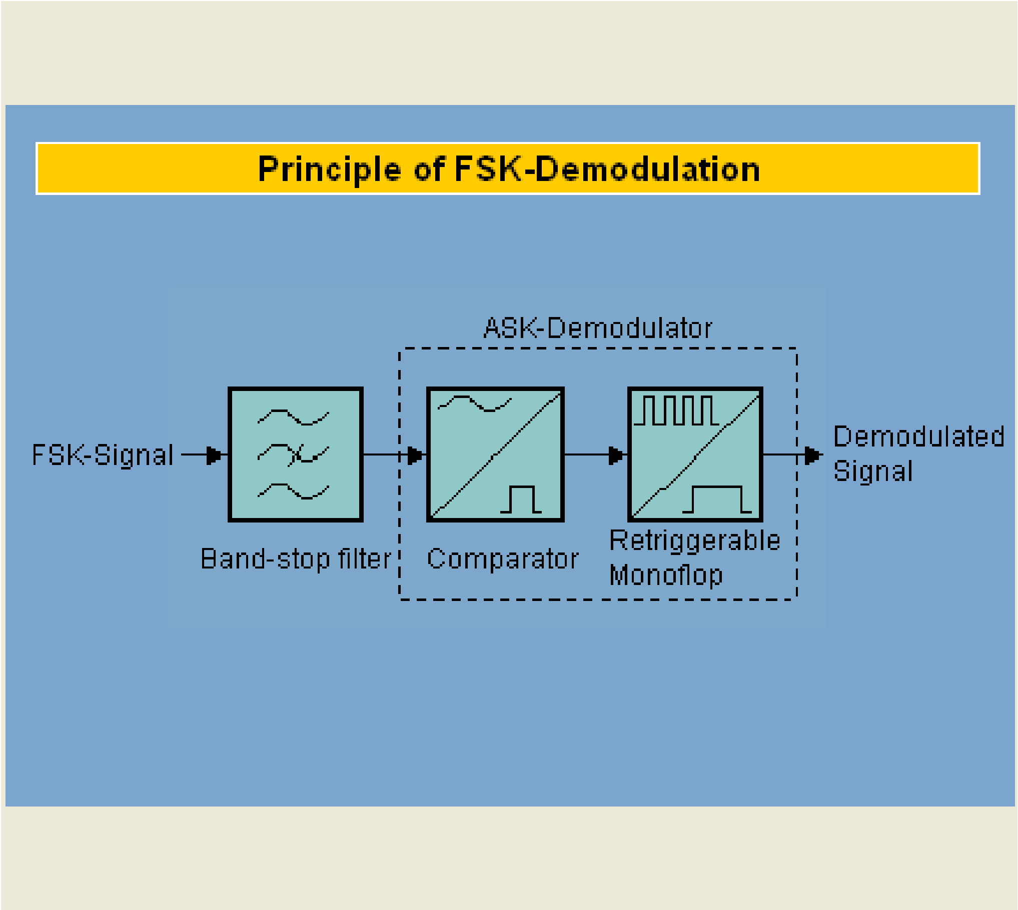
Experiment 3

"FSK Detection"

4.9 Demodulation



To demodulate the FSK signal it is first converted into an ASK signal. This is done using an absorption circuit (edge discriminator[1]), which acts as a band-stop filter and allows the upper frequency (bit logical 1) to pass through virtually unchanged, but which strongly damps the lower frequency (bit logical 0). The ASK signal thus created is then demodulated in the follow-on ASK demodulator (comparator + monoflop). This is referred to as non-synchronous demodulation[2] . Synchronous demodulators are in practice also often used.

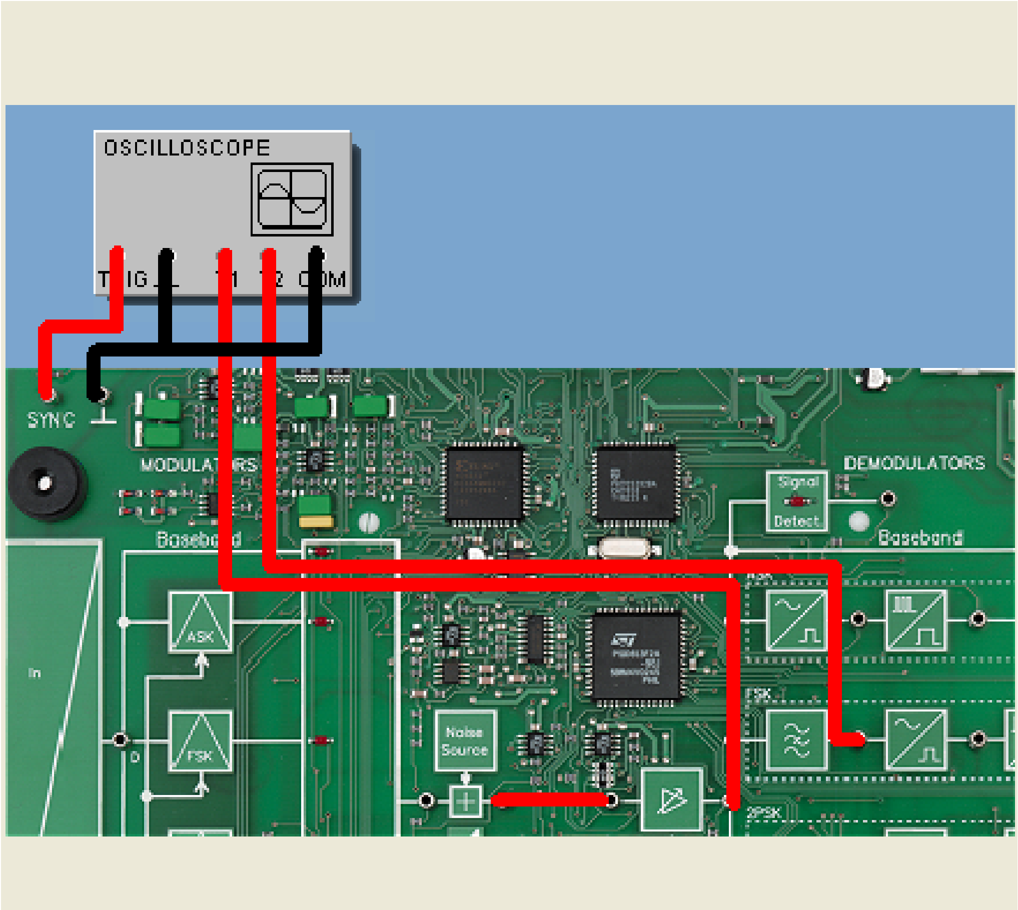
1 **Edge discriminator**

The edge discriminator accomplishes frequency modulation in two steps: FM/AM conversion and amplitude modulation. Here the FM signal is placed on a filter edge. This converts the FM into an AM, because the output voltage fluctuates as a function of the excursion, since a filter in the range of the frequencies has a very differing resistance on the edge. A simple edge discriminator consists of a parallel oscillator, a diode and a smoothing capacitor. Another term for edge discriminator is edge demodulator.

2 **Non-synchronous demodulation**

Non-synchronous demodulation differs from synchronous modulation in that the receiver does not need the phase- and frequency-correct carrier (example: envelope demodulator).

4.10 Experiment: Measurements on the frequency discriminator



In the following experiment we will study the demodulation of an FSK-modulated signal in NRZ formatting more closely. A periodic square-wave signal (SQ format) will be sent and the signal trace recorded in the various stages of the FSK demodulator. The original data signal and demodulated data signal will then be compared.

Procedure:

1- Open the COM3LAB STARTER program
2- Select the Experiment which is to be performed
3- Connect the circuit as required in the experiment and in timely manner as specified during the procedure.
4- Submit the required answers asked during the experiment on computer screen by performing appropriate calculations and using the theory.
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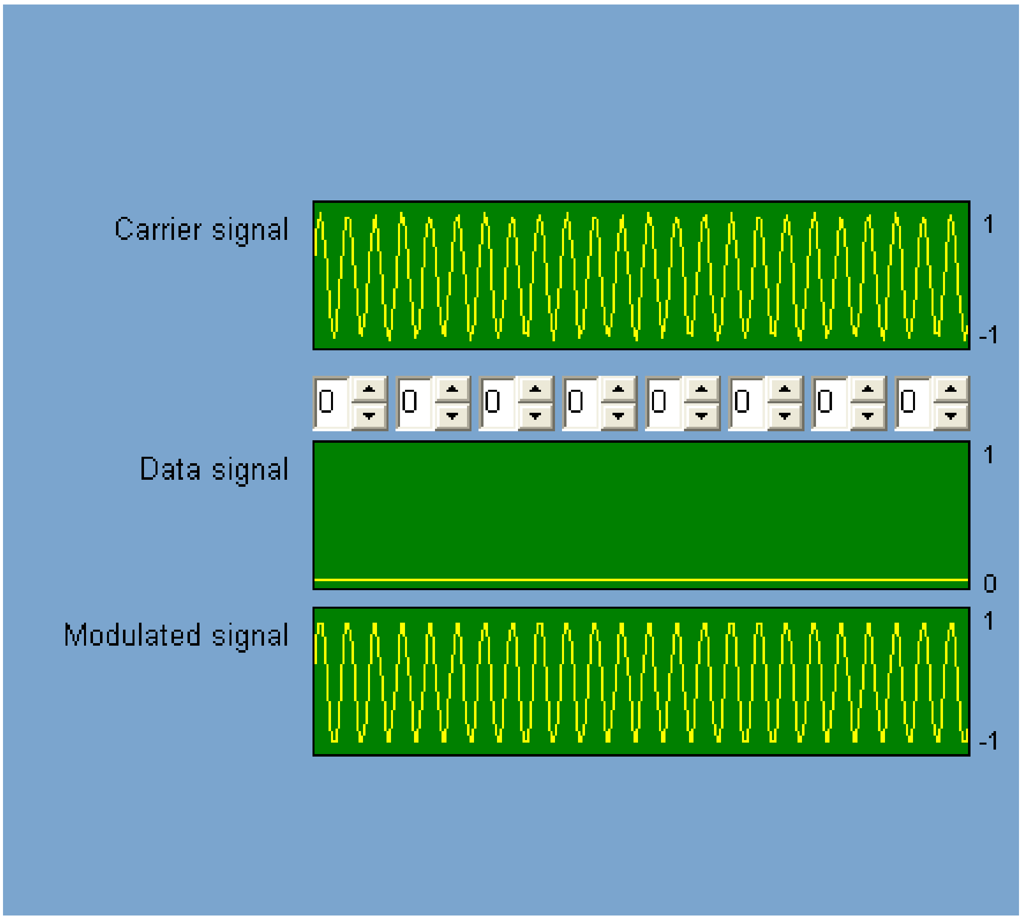
Experiment 4

"PSK Signal Generation"

5.1 Time function

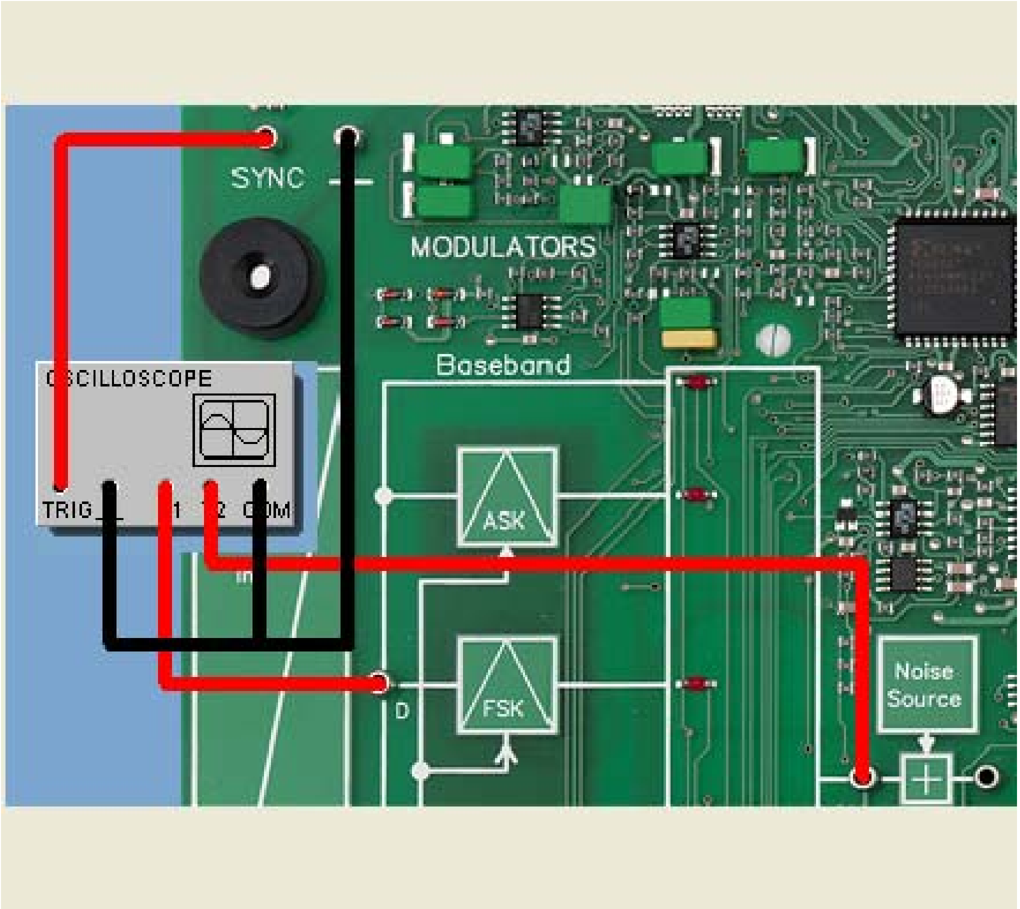


In two-phase shift keying (2PSK[1]) a sinusoidal carrier signal with frequency f_0 is toggled between two different phase positions depending on the data signal. Since disturbances generally affect only the amplitude of the signal and not its phase position, Phase Shift Keying is very noise-immune.

1 **PSK**

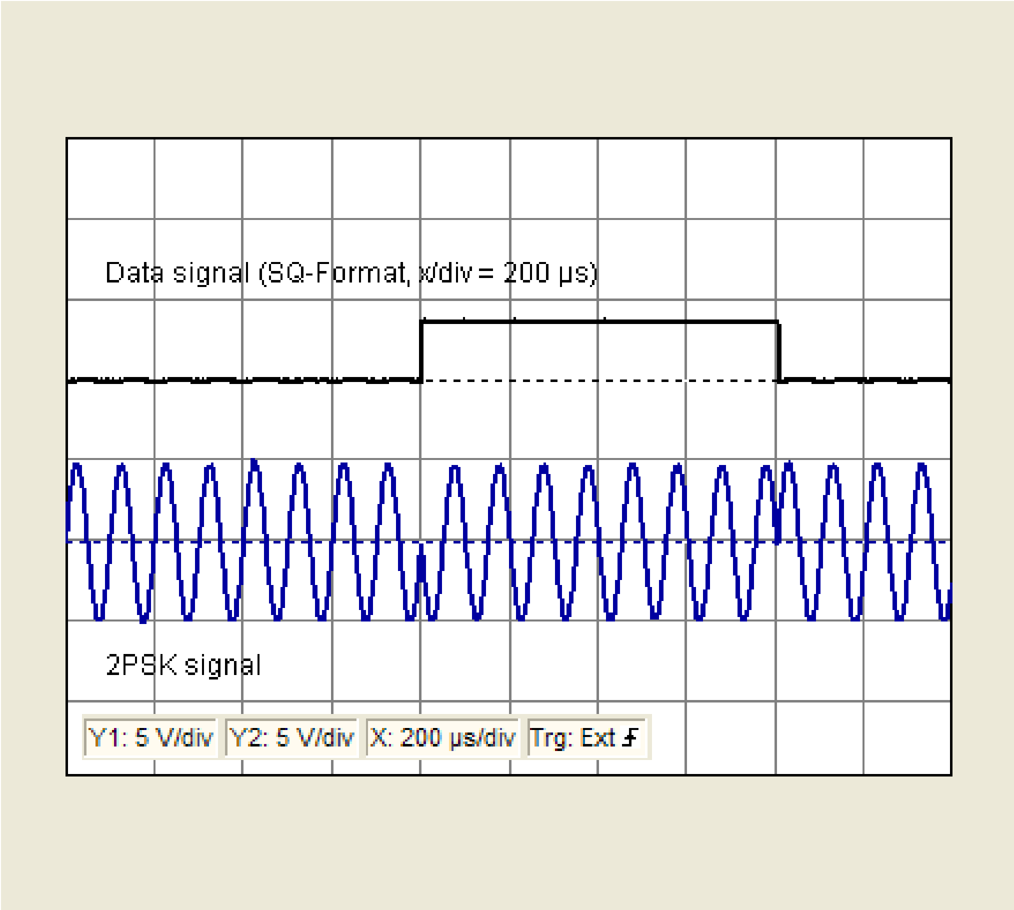
Phase Shift Keying is a modulation procedure whereby the phase position of a sinusoidal carrier signal is changed depending on the level of the (digital) modulation signal. In 2PSK two and in 4PSK four different phase positions are toggled. There are also variations with more phase positions.

5.2 Experiment: Displaying 2PSK on the oscilloscope



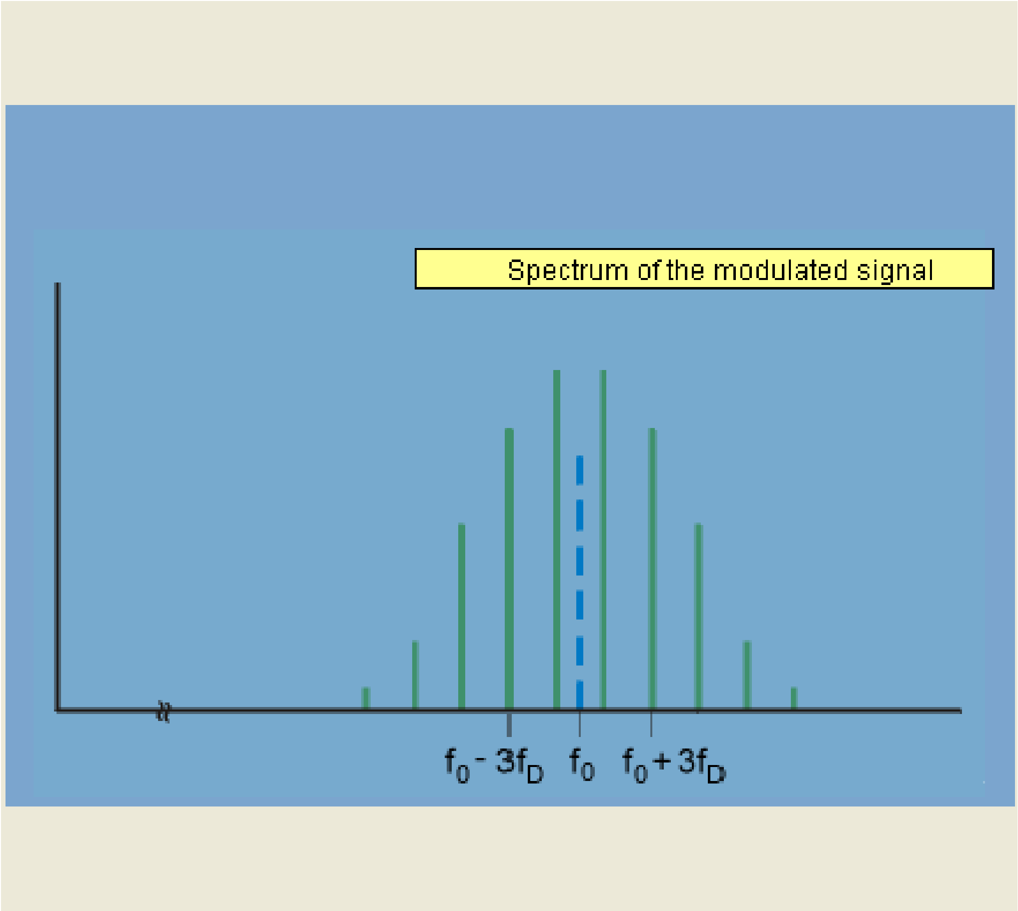
In the following experiment we will first study the modulated signal in two-phase shift keying. A periodic square-wave signal (SQ format) will be sent as the data signal and modulated on to the sinusoidal carrier signal. Both signals will be compared on the oscilloscope. Both the phase positions for logical 0 and logical 1 will be determined from the signals.

5.3 Result



With the selected square-wave data signal alternating LOW and HIGH pulses are sent; each has a duration of 800 µs (upper curve). The frequency of the carrier is constant at a value of 10 kHz. For a data bit of logical 0 the carrier has a phase shift of 0°, and for a data bit of logical 1 a phase position of 180°.

5.4 2PSK in the frequency range

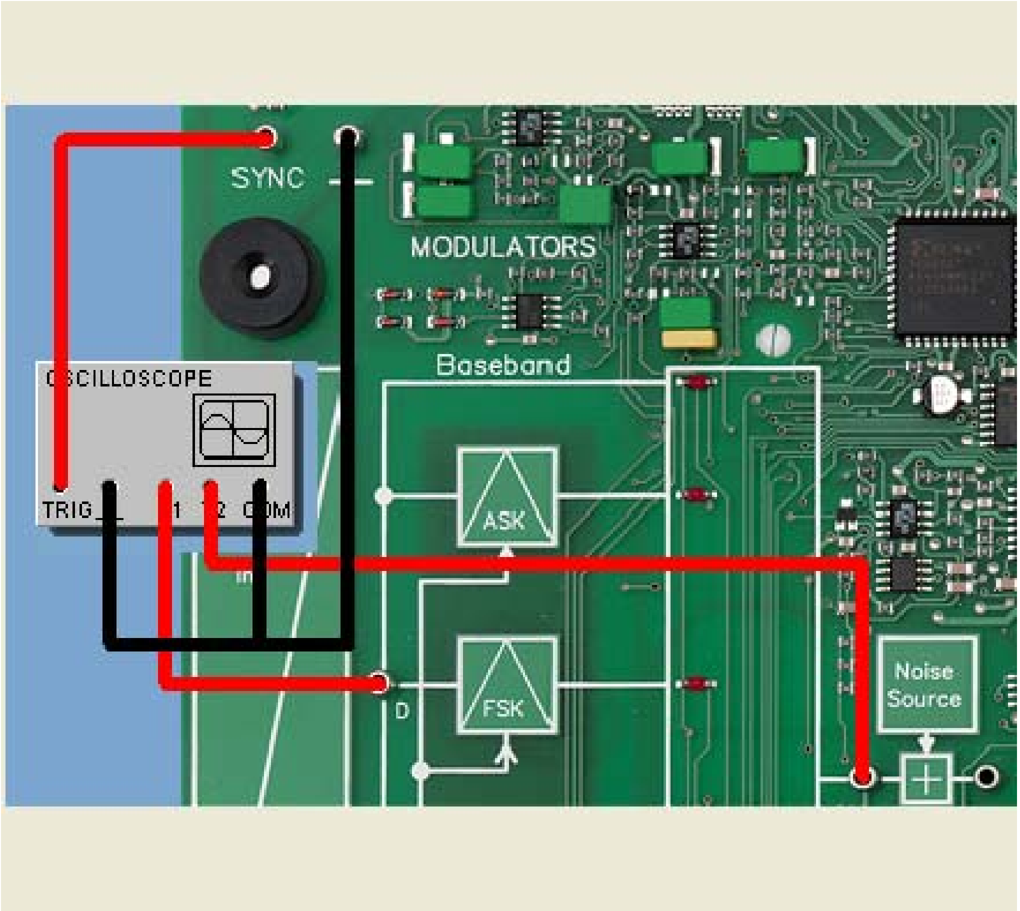


The spectrum of the 2PSK signal corresponds to amplitude modulation with suppressed carrier. The adjacent graphic shows the spectrum for modulation with a square-wave data signal having frequency f_D. As in the case of ASK, the minimum required transmission bandwidth is therefore

$B = 2 \cdot f_D$.

In practice a value of 1.4x is generally used.

5.5 Experiment: Measuring the 2PSK spectrum (SQ-Format)



In the following experiment we will study the amplitude spectrum of the modulated signal in two-phase shift keying. As the data signal we will again use a periodic square-wave signal having a DC component (SQ format) and frequency f_D = 600 Hz.

Procedure:

1- Open the COM3LAB STARTER program
2- Select the Experiment which is to be performed
3- Connect the circuit as required in the experiment and in timely manner as specified during the procedure.
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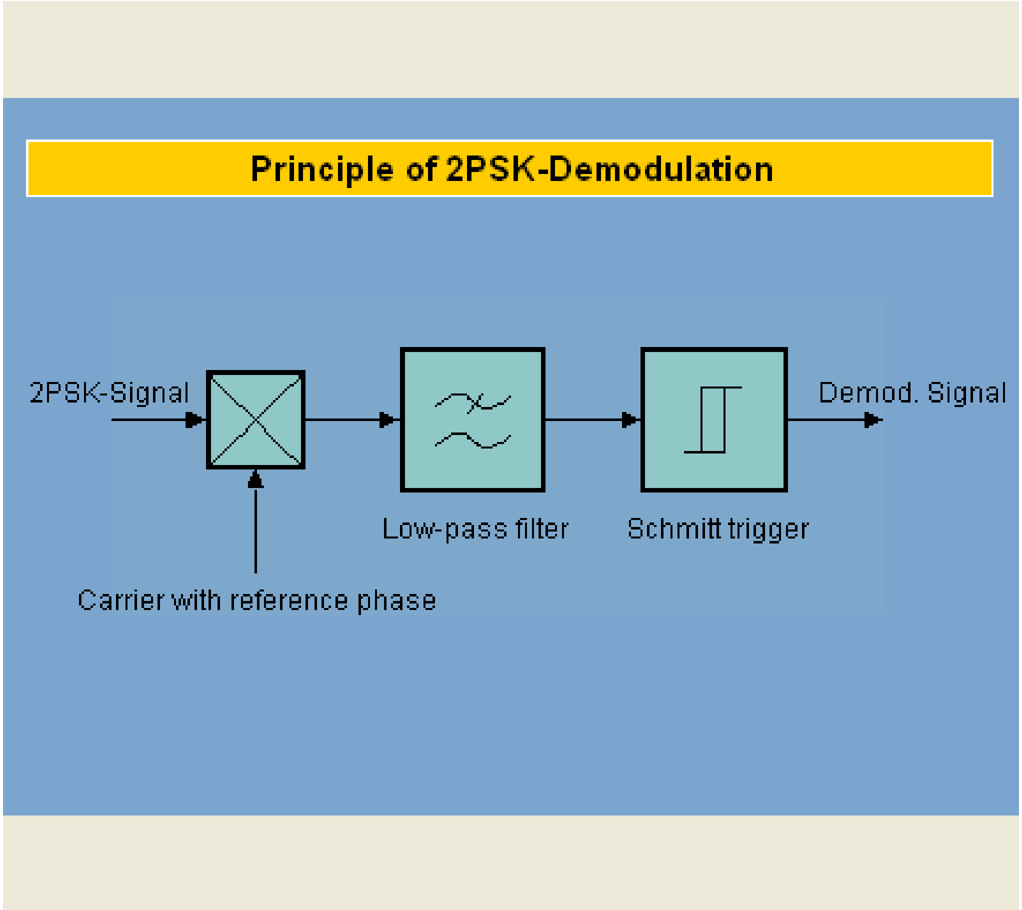
Experiment 5

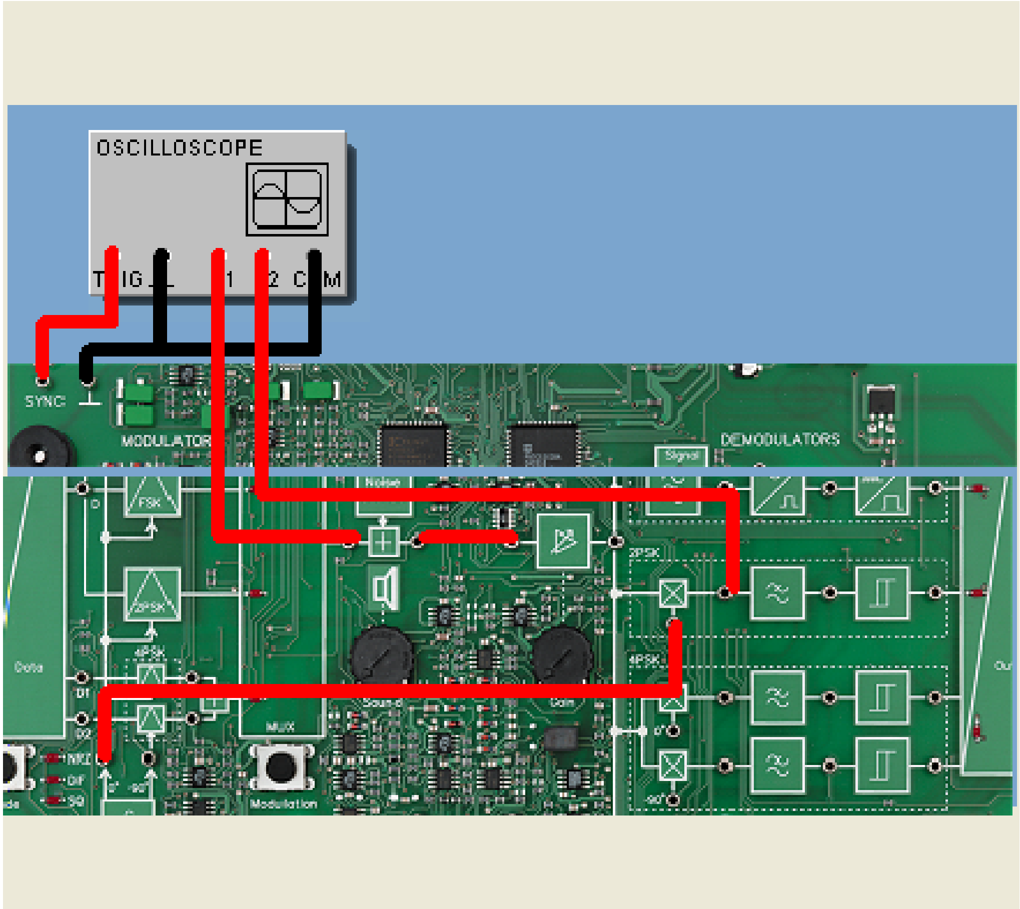
“PSK Synchronous Detection”

5.9 Demodulation



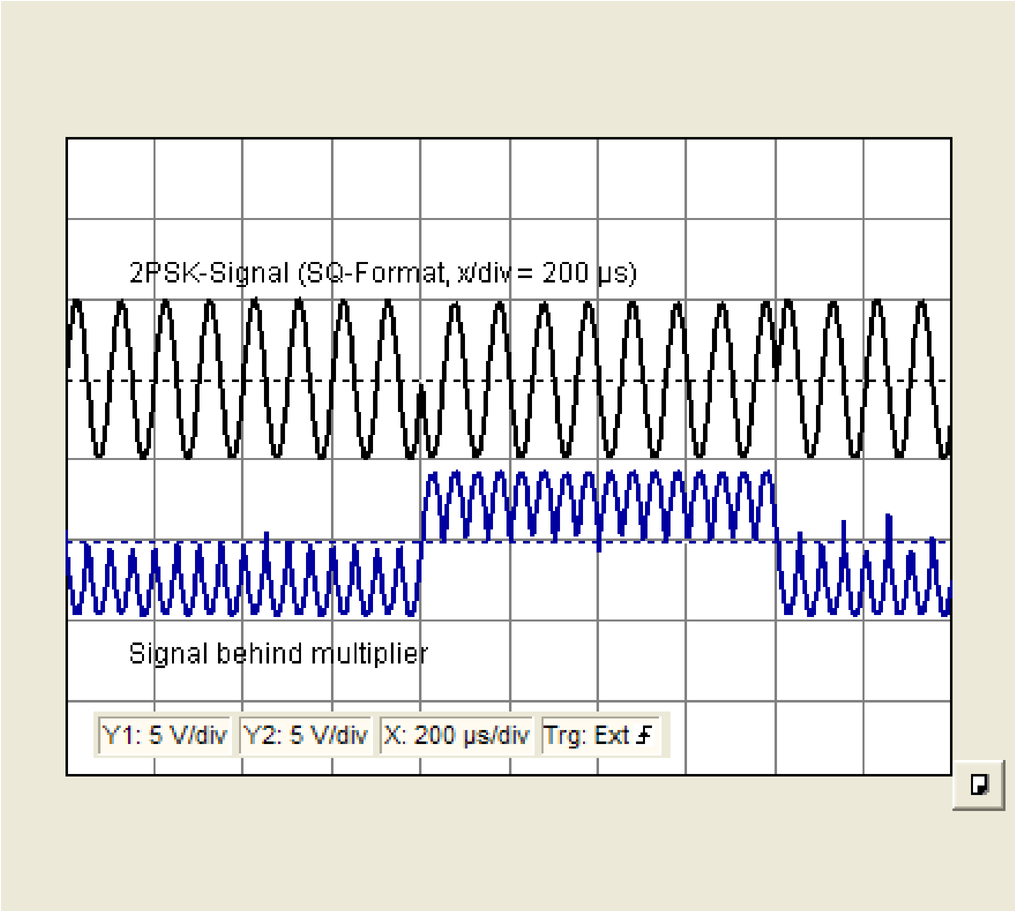
For synchronous demodulation of the 2PSK signal the carrier signal with the reference phase position is required. By multiplying with the 2PSK signal, the result is first a signal with double the carrier frequency whose center value over a bit width varies with the actual data bit. A downstream low-pass filter with pulse former (Schmitt trigger) finally regenerates the original data signal.

5.10 Experiment: Synchronous demodulation with 2PSK



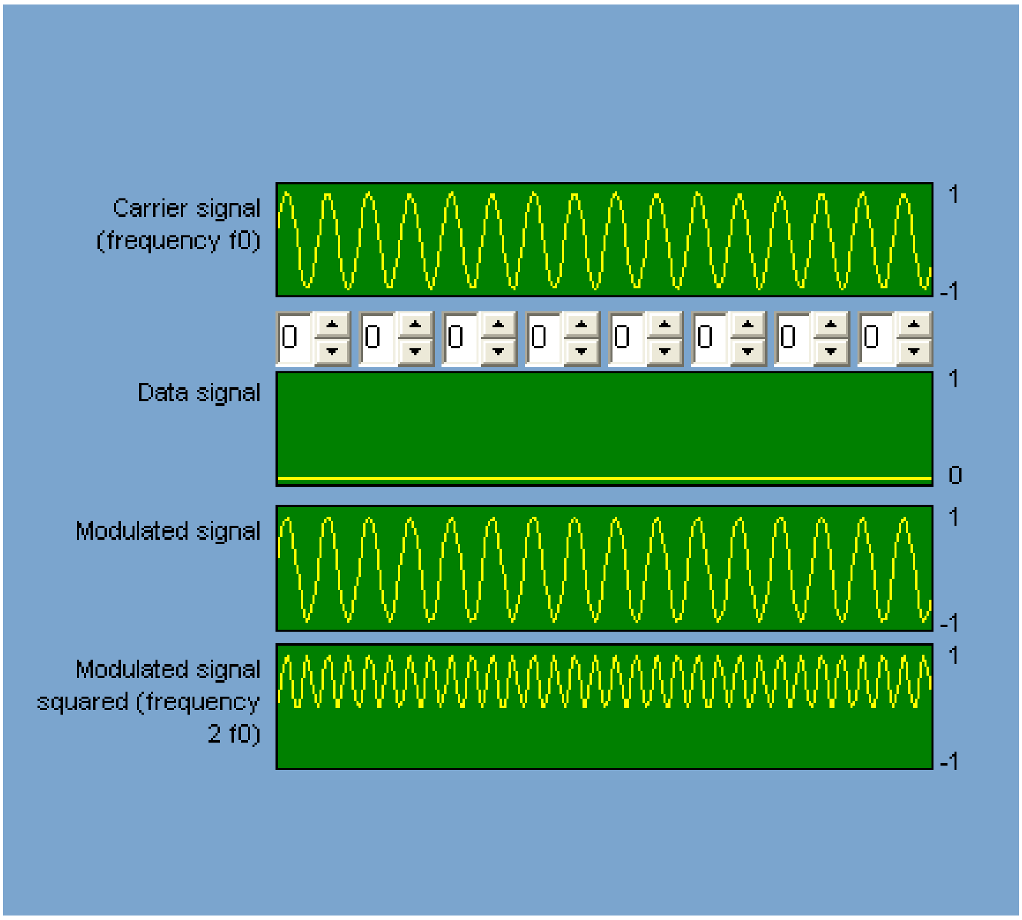
In the following experiment we will investigate in greater detail the demodulation of a 2PSK modulated signal with NRZ formatting. A periodic square-wave signal (SQ format) will be sent and the course of the signal recorded in the various stages of the PSK demodulator. The original data signal and demodulated data signal will then be compared.

5.11 Result



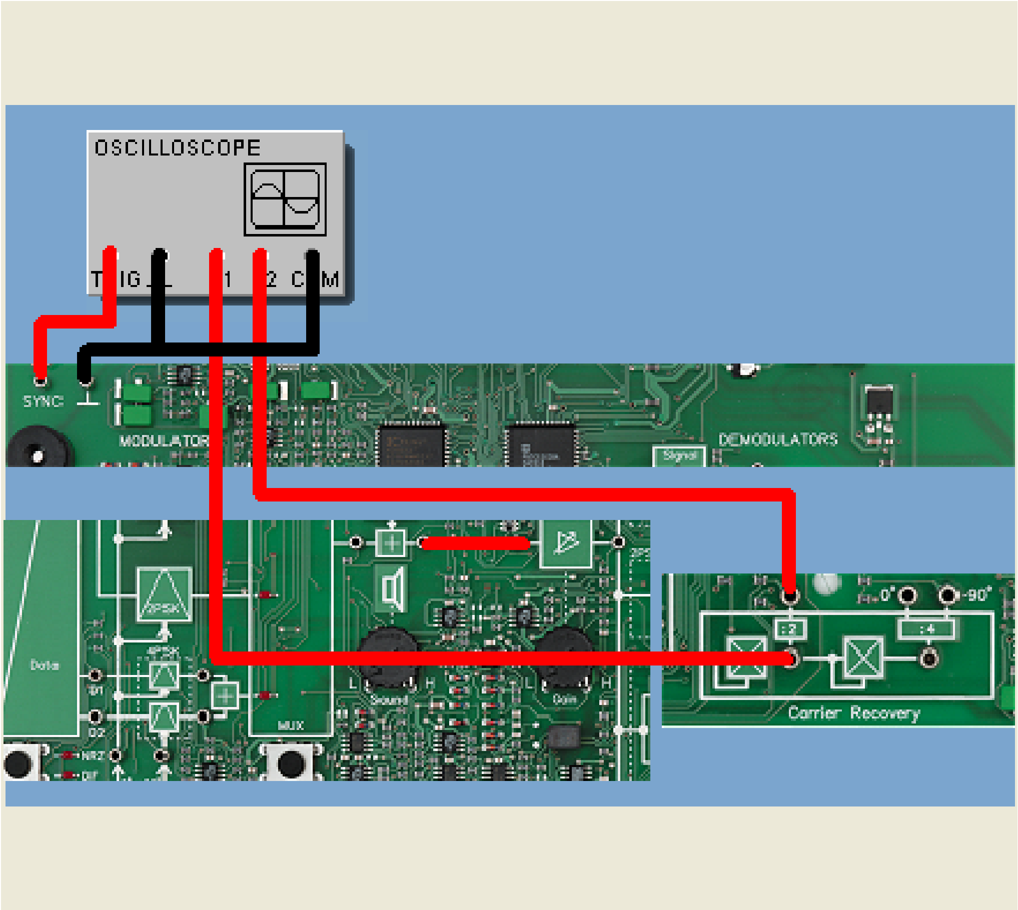
The first thing you notice is the effect of the multiplication by the frequency- and phase-identical carrier signal. The low-pass filter results in a signal with an e-shaped, rising (bit logical 1) or falling (bit logical 0) edge. The Schmitt trigger generates the actual data signal from that, which due to the effect of the low-pass and Schmitt trigger is shifted by around 120 µs from the original signal.

5.12 Carrier recovery



Since the carrier itself is not sent in 2PSK, it must be recovered in correct phase position for coherent demodulation at the receiving site. For this purpose the modulated signal can be squared; the result is a (DC component-containing) oscillation with double the carrier frequency, from which the carrier can be recovered by means of frequency dividing - though with a phase uncertainty of 180°.

5.13 Experiment: Measurements on carrier recovery with 2PSK



In the following experiment we will study carrier recovery with two-phase shift keying by squaring the modulated signal. The analysis will be made both in the time and frequency range. The data signal will again be a periodic square-wave signal with a DC component and a frequency of

f_D = 600 Hz.

Procedure:

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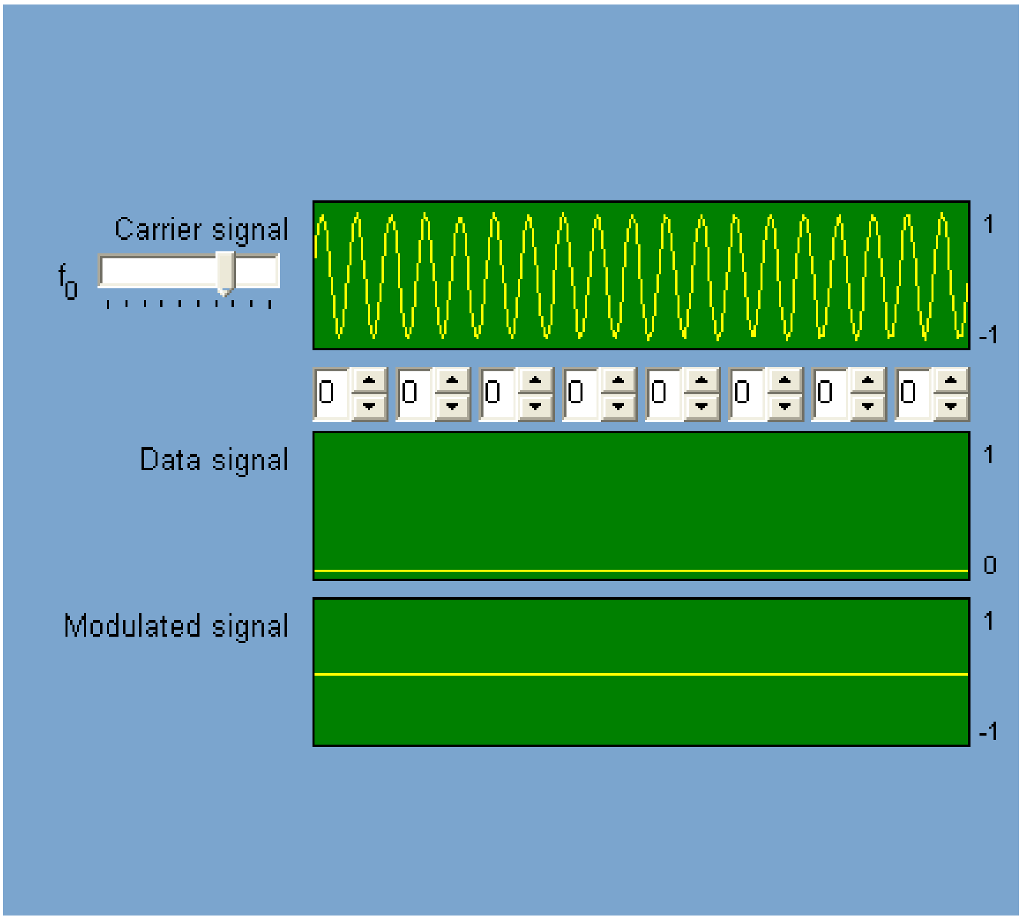
Experiment 6

"ASK Signal Generation"

3.1 Time Function

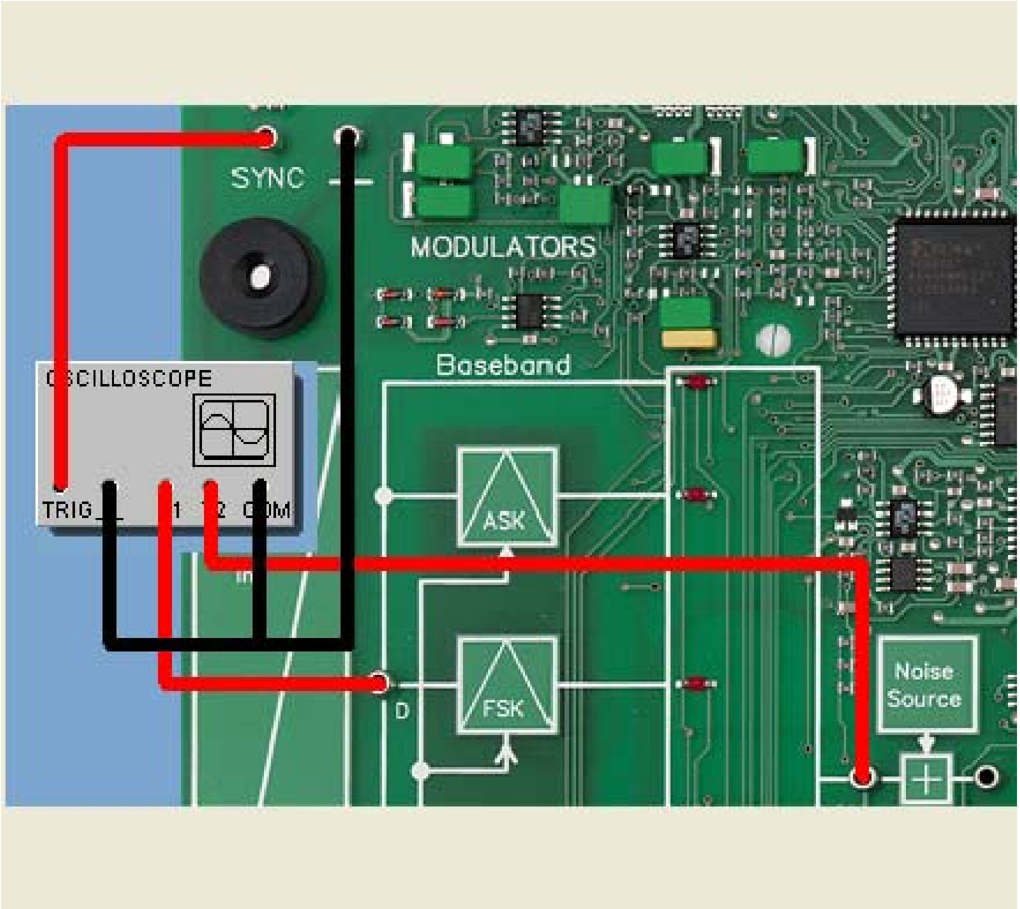


In Amplitude Shift Keying (Amplitude Shift Keying ASK[1]) a sinusoidal carrier signal having frequency f_0 is turned on and off by the data signal (which is why this procedure is also known as ON/OFF keying). If the data signal has the value logical 1 (HIGH), the carrier signal is turned on, and a data signal of logical 0 (LOW) turns it off. ASK can therefore be implemented by means of a switch.

[1] **ASK**

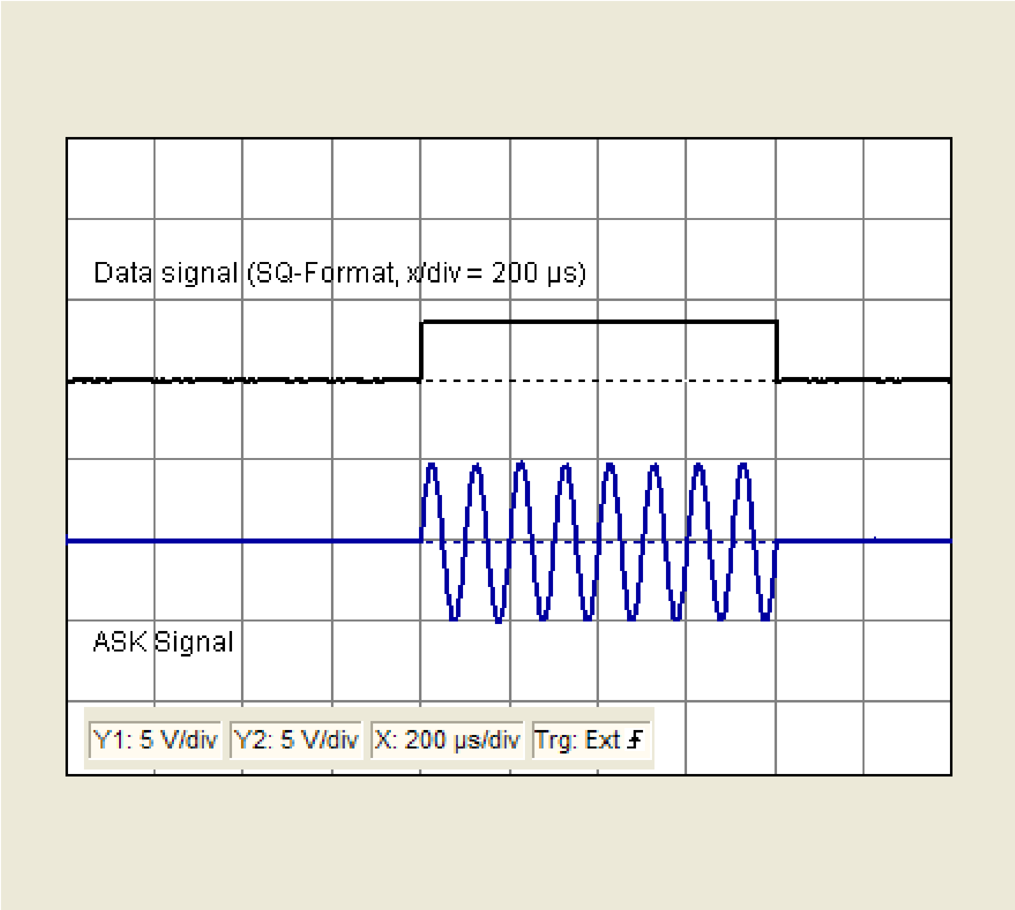
Amplitude Shift Keying is a modulation method whereby the amplitude of a sinusoidal carriers signal is changed as a function of the level of the (digital) modulation signal. The carrier signal is usually turned on and off alternately (ON/OFF Keying).

3.2 Experiment: Time course for ASK



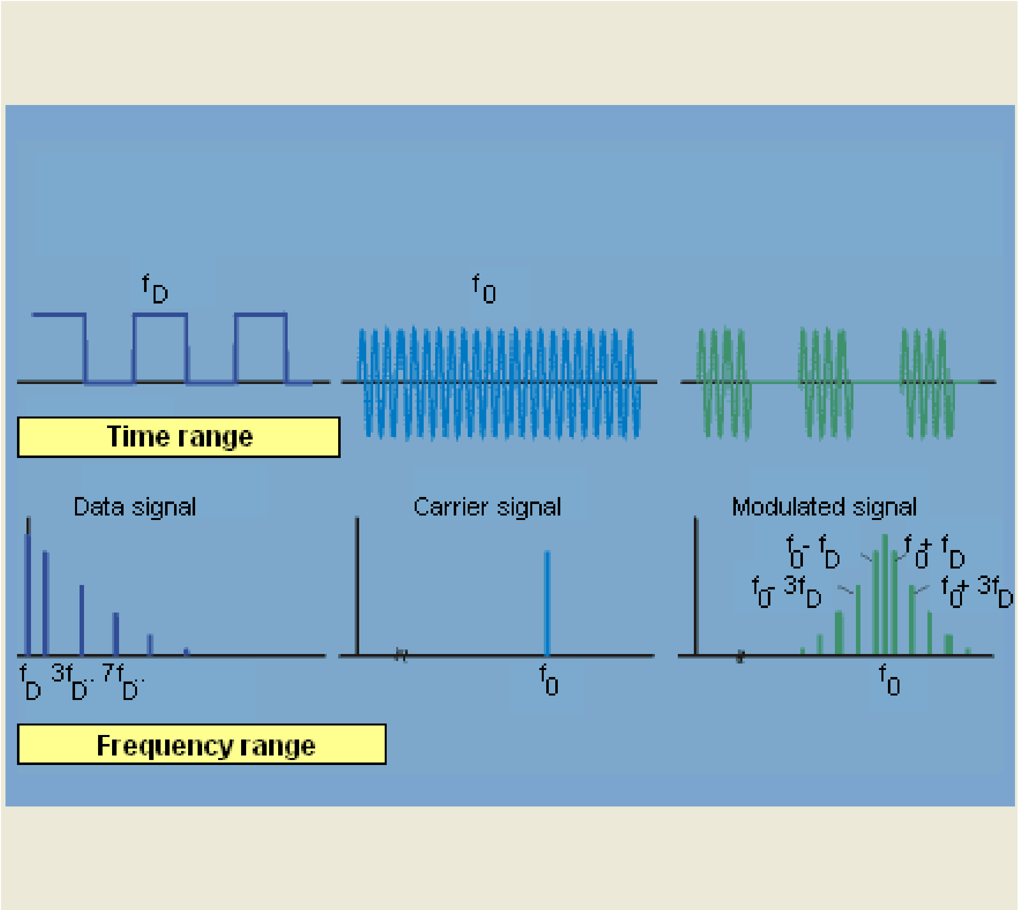
In the following experiment you will first study the modulated signal in amplitude shift keying. Periodically a constant data byte will be sent as a data signal and modulated on to the sinusoidal carrier signal. Both signals will be compared using the oscilloscope.

3.3 Result



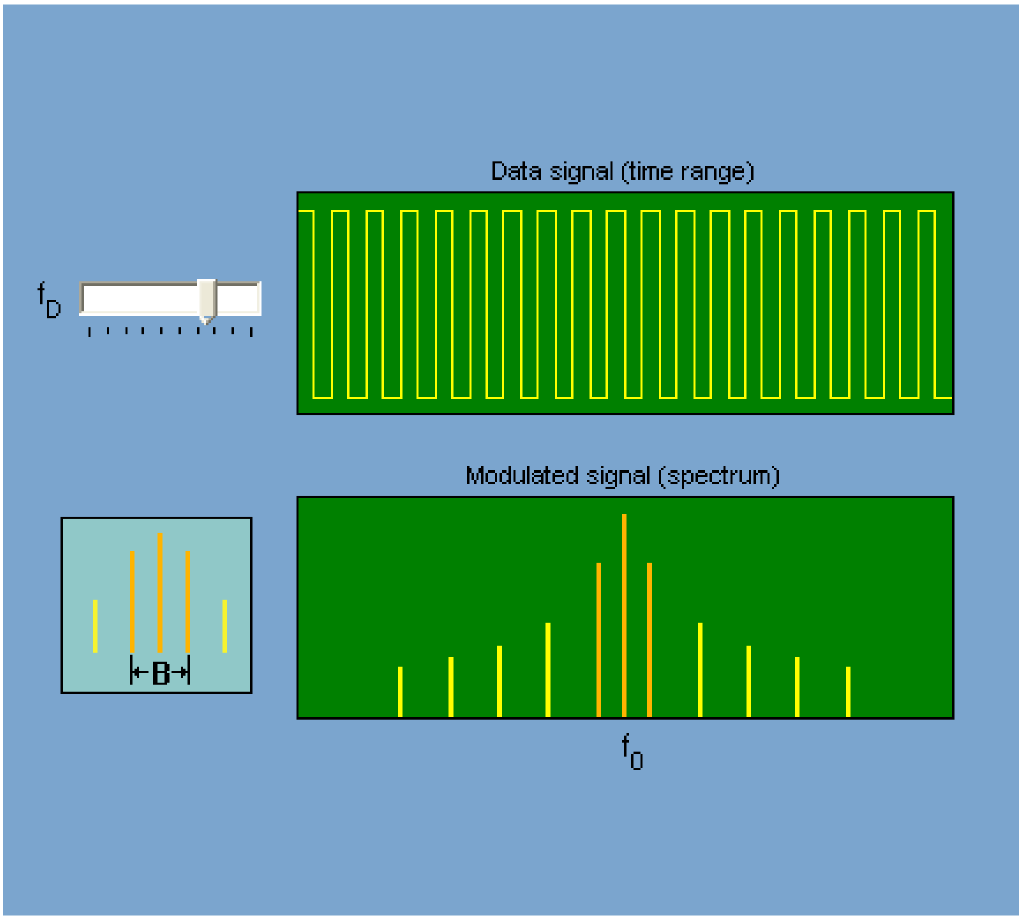
SQ format generates a square-wave signal with a pulse width of 800 µs (upper curve), whereby the pulse width corresponds to the bit width. There are exactly eight oscillations of the carrier signal for each pulse (lower curve). The carrier signal thus has a frequency of f_0 = 10 kHz.

3.4 ASK in the frequency range



In the frequency range amplitude shift keying causes a shift of the data signal spectrum by the frequency f_0 of the carrier signal. The graphic at the right shows this using the example of a periodic square-wave signal having frequency f_D. This signal has a line spectrum consisting of spectral lines with odd multiples of the base frequency f_D, in other words for the frequencies f_D, 3 f_D, 5 f_D ... The form of the spectrum itself is not changed by ASK.

3.5 Bandwidth requirements for ASK



For unambiguous detecting of the signal state on the receiver side, it is sufficient if the spectrum is transmitted up to the first pair of side-bands, in other words in the range $f_0 - f_D$ ... $f_0 + f_D$. The theoretical minimum required bandwidth[1] is therefore

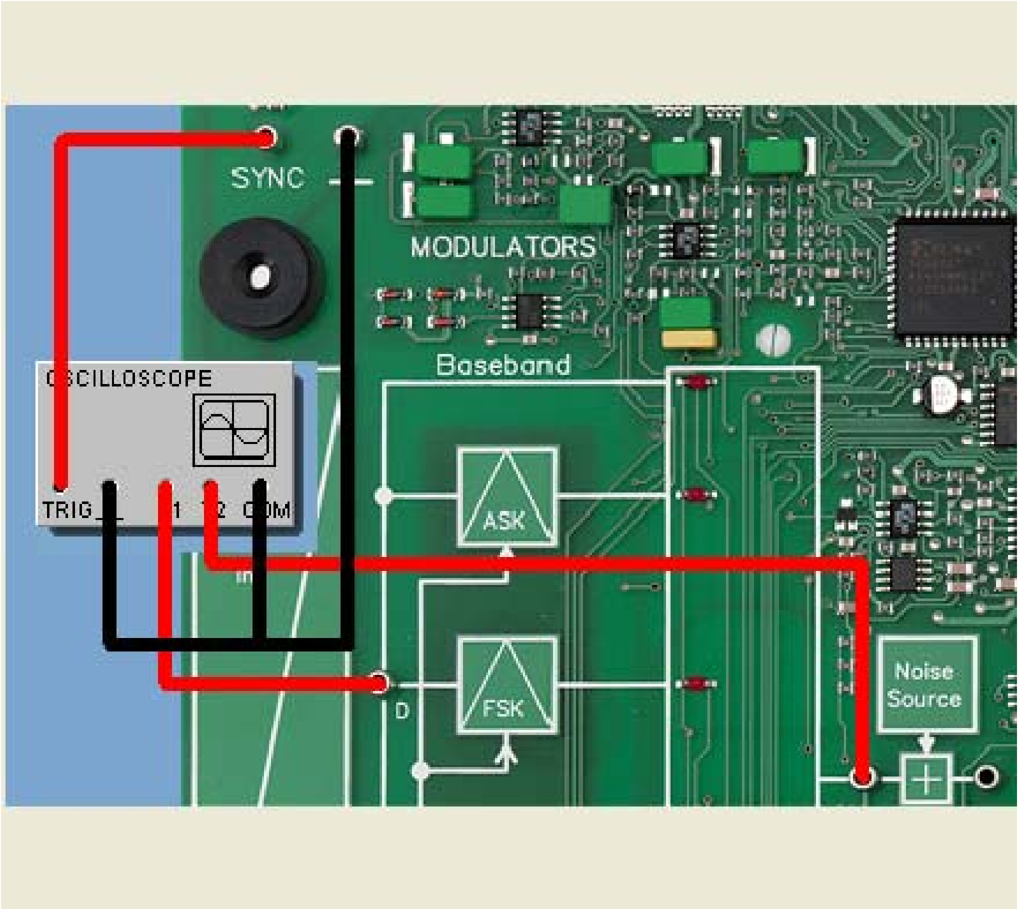
$$B = 2 \cdot f_D.$$

In practice a value of 1.4x is generally used.

1 **Bandwidth**

The bandwidth B indicates the width of the frequency range occupied by the modulated signal. The less the bandwidth of a signal, the more signals can be sent side-by-side within a certain frequency range with no overlap.

3.6 Experiment: Measuring the ASK spectrum (SQ Format)



In the following experiment you will study the amplitude spectrum of the modulated signal in amplitude shift keying. A periodic square-wave signal having a DC component and generated by the SQ format will be used as the data signal. The COM3LAB Spectrum Analyzer will be used to obtain the spectrum; open the analyzer by clicking on the button .

Procedure:

1- Open the COM3LAB STARTER program
2- Select the Experiment which is to be performed
3- Connect the circuit as required in the experiment and in timely manner as specified during the procedure.
4- Submit the required answers asked during the experiment on computer screen by performing appropriate calculations and using the theory.
5- Open the appropriate windows for oscilloscope, Spectrum analyzer and other software devices specified on the computer screen.
6- Use appropriate procedures and techniques to get required plots and graphs on the computer screen.
7- Note down, screenshot and print appropriate graphs and answers to add in report.

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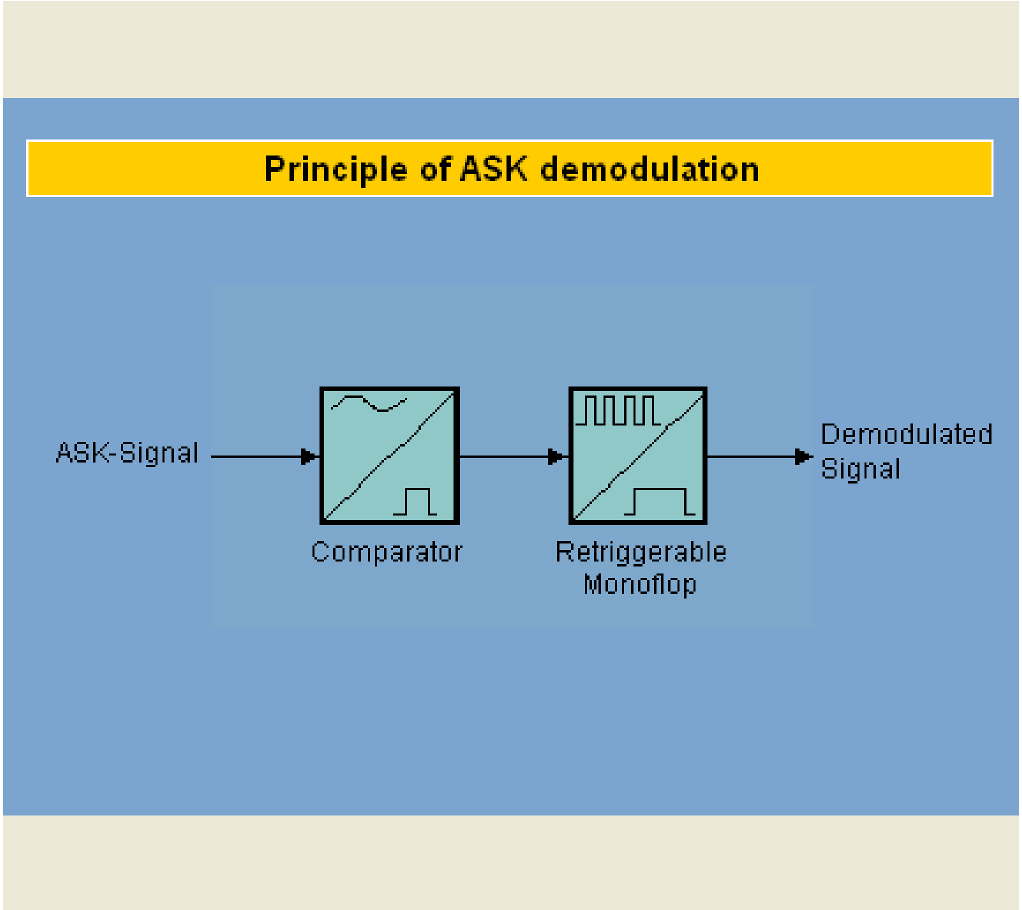
Communication 2 Lab

Experiment 7

"ASK Signal Detection"

3.10 Demodulation



For demodulating[1] the ASK signal, envelope curve demodulation[2] is used. In the first step a comparator is used to hide the negative half-waves of the sinus oscillations and their amplitude is restricted to TTL level. In a second step a re-triggerable monoflop generates a single total pulse from the individual pulses belonging to a bit at logical 1; this total pulse then has the original length of the bit duration.

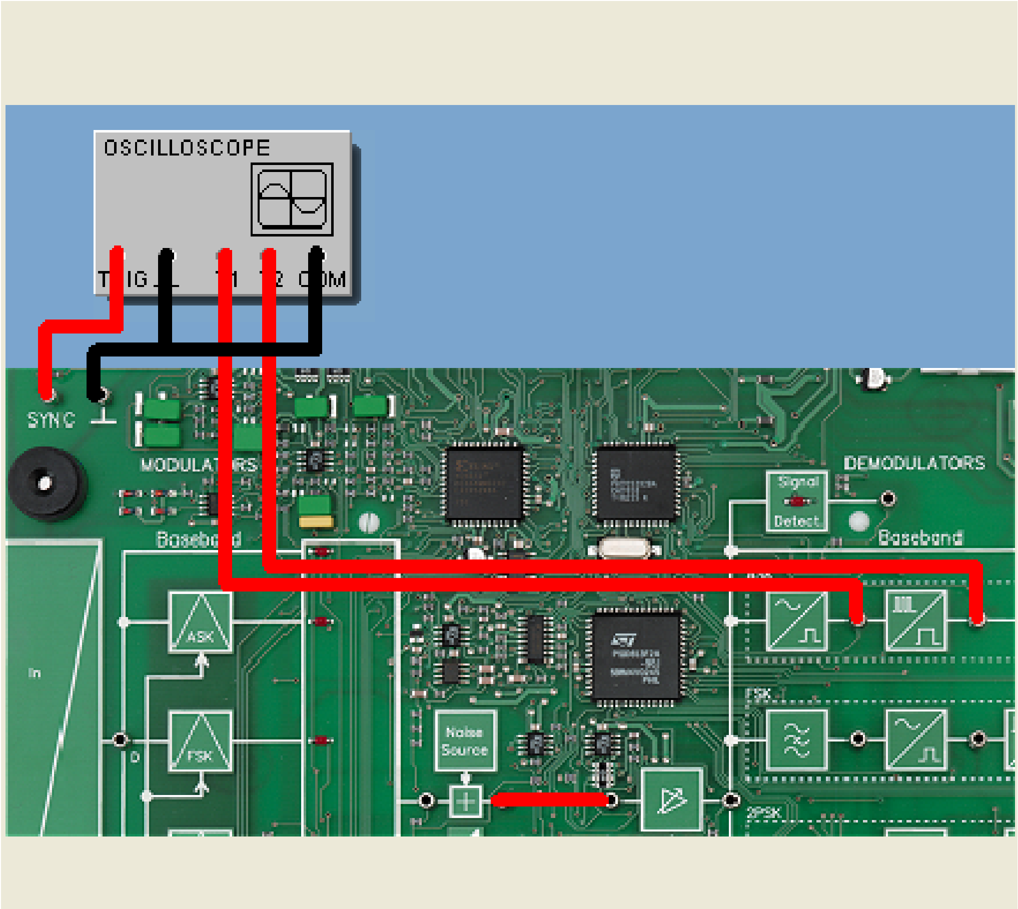
1 **Demodulator**

The demodulator extracts the original modulation signal (data signal) from the signal generated by the modulator. A distinction is made between synchronous (coherent) demodulation, in which the phase- and frequency-correct carrier is required, and non-synchronous (incoherent) demodulation (Example: envelope demodulator), in which this carrier is not required. Synchronous demodulation is generally more noise-immune.

2 **Envelope curve demodularion**

Envelope curve demodulation is a non-synchronous demodulation which does not need explicit provision of the phase-correct carrier signal. In a synchronous demodulator (coherent detector) the phase-synchronous carrier is required. Synchronous demodulators are characterized by low distortion as compared with non-synchronous demodulators.

3.11 Experiment: Investigate the envelope curve demodulator with ASK



In the following experiment the demodulation of an ASK-modulated signal with NRZ formatting will be studied more closely. Periodically a data byte of 55 will be sent and the course of the signal behind the comparator and monoflop of the ASK demodulator recorded. **Note:** Be sure that the ‚Gain' adjustment is at full left for this and all following experiments.

Procedure:

1- Open the COM3LAB STARTER program
2- Select the Experiment which is to be performed
3- Connect the circuit as required in the experiment and in timely manner as specified during the procedure.
4- Submit the required answers asked during the experiment on computer screen by performing appropriate calculations and using the theory.
5- Open the appropriate windows for oscilloscope, Spectrum analyzer and other software devices specified on the computer screen.
6- Use appropriate procedures and techniques to get required plots and graphs on the computer screen.
7- Note down, screenshot and print appropriate graphs and answers to add in report.

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Communication 2 Lab

Introduction to Optical Fiber Lab

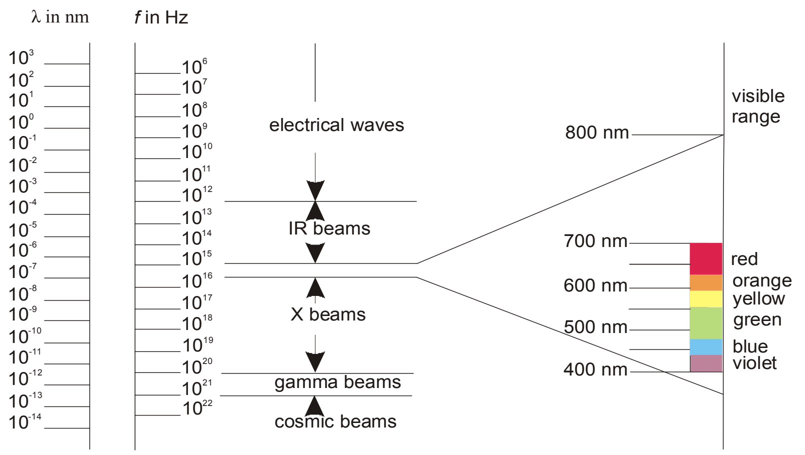
Theory

Physical principles

The electromagnetic spectrum

For the transmission of messages, the propagation of electromagnetic waves in a transmission medium is of fundamental importance. The medium does not have to be a metalic conductor, waves can also propagate in a vacuum or in a dielectric material. The spectrum of electromagnetic waves reaches from the long radio waves up to short-wave cosmic beams. For optical communications technology only a very small range is suitable, namely infrared (IR) and visible (VIS), as well as the ultraviolet (UV) part of the electro-magnetic spectrum. Visible light takes up only the narrow range of 380 nm (violet) up to 780 nm (red). Bordering this range toward the smaller wavelengths are the ultraviolet beams while the IR beams are located at larger wavelengths. Light in the narrow sense of the word refers to the electromagnetic waves in the visible range, although this definition often includes the IR and UV range. The following relationship (1) exists between the wavelength λ and the frequency *f*:

$$\lambda = \frac{c_0}{f}$$



Where c_0 stands for: $c_0 = 3 \cdot 10^8$ m/s, the velocity of light in free space. The range from 500 nm up to 1500 nm is particularly well-suited for optical transmission.

Beam optics

Light propagation in a multimode optical waveguide can be explained using the laws of geometrical optics. Light serve as a simple theoretical concept (model). They represent the ideal form of cones of light with small aperture angles, propagating in straight lines. They can be guided or deflected into other directions using mirrors, prisms or lenses. The process of guiding light in an optical waveguide is based on the laws of refraction and reflection. As a rule both processes occur when a beam incidents a dielectric surface. If a beam strikes the surface of two different substances with different refractive indexes *n*, then the following holds true according to the law of reflection:

$$\alpha = \alpha'$$

The angle of incidence α and angle of reflection α*'* are in the same plane.

$$\frac{\sin\alpha}{\sin\beta} = \frac{c_1}{c_2}$$

The ratio of light velocity c_0 in vacuum to the velocity of light *c* of the medium is called the refractive index *n.* It is a material constant and indicates by how much the light velocity in a medium is smaller than in a vacuum.

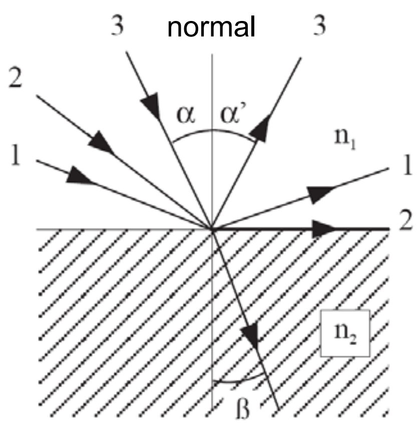
$$c = \frac{c_0}{n}$$

Using the equation we obtain:

$$\frac{\sin\alpha}{\sin\beta} = \frac{n_2}{n_1}$$

When the angle of incidence α is increased, the angle of refraction *ß* reaches the value *ß* = 90° during the transition from an optically denser medium with refractive index n_1 to an optically less dense medium with refractive index n_2. In the case of two opaque media the one designated optically denser is the one in which the light velocity is lower. The corresponding angle of incidence α_c is:

$$\sin\alpha_c = \frac{n_2}{n_1}$$



Reflection and refraction

Thus, if the angle of incidence surpasses the critical angle α_c, no refraction can occur and the beams are totally reflected at the surface. This phenomenon is called total reflection. It only takes place during the transition from an optically denser medium to an optically less dense one.

Fiber optic telecommunications systems

Design of optical waveguides

Total reflection is exploited as the guiding mechanism in optical waveguides (multimode fibers). For this reason the optical wave guide consists of a cylindrical core and a concentric cladding surrounding. Here the refractive index n_1 in core glass is somewhat larger than that of refractive index n_2 in the glass cladding. All light beams which do not deviate more than ($90° - \alpha_c$) from axial direction of the optical waveguide are guided inside the glass core. In order to launch a light beam into the glass core from an external source (air with refractive index $n_0 = 1$) the following holds true for the coupling angle Θ (Θ = angle between beam and fiber axis):

$$\frac{\sin\theta}{\sin(90^{\circ}-\alpha)} = \frac{n_1}{n_0}$$

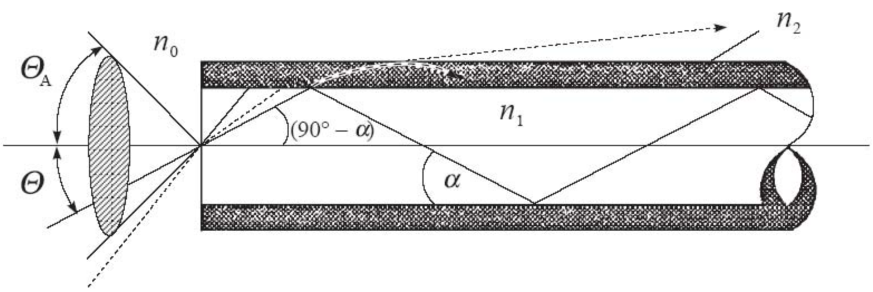
From this it follows with $n_0 = 1$:

$$\sin\theta = n_1 \cos\alpha = n_1\sqrt{(1-\sin^2\alpha)}$$

The largest coupling angle Θ_A is called the acceptance angle of the fiber optic waveguide and is only dependent on the two refraction indexes n_1 and n_2. The sine of the acceptance angle is called the numerical aperture *NA* of the optical waveguide:

$$NA = \sin\theta_A = \sqrt{(n_1^2 - n_2^2)}$$

This numerical aperture *NA* B is an important quantity for coupling light into a fiber optic waveguide. The greater the numerical aperture of an optical fiber, the more light can be coupled, but this also introduce more propagation time differences between higher order modes.



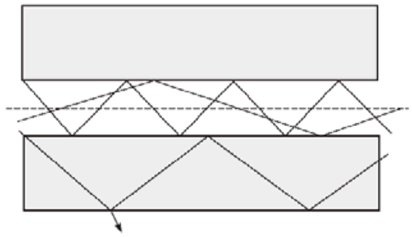
Light guided through a fiber optic waveguide

Fiber optic profiles

If we consider the refractive index *n* of a fiber optic waveguide as a function of the radius *r* of the core material, this relationship is referred to as an index profile. In practice two refractive index profiles have prevailed:

- Step index profile (SI)
- Graded index profile (GI)

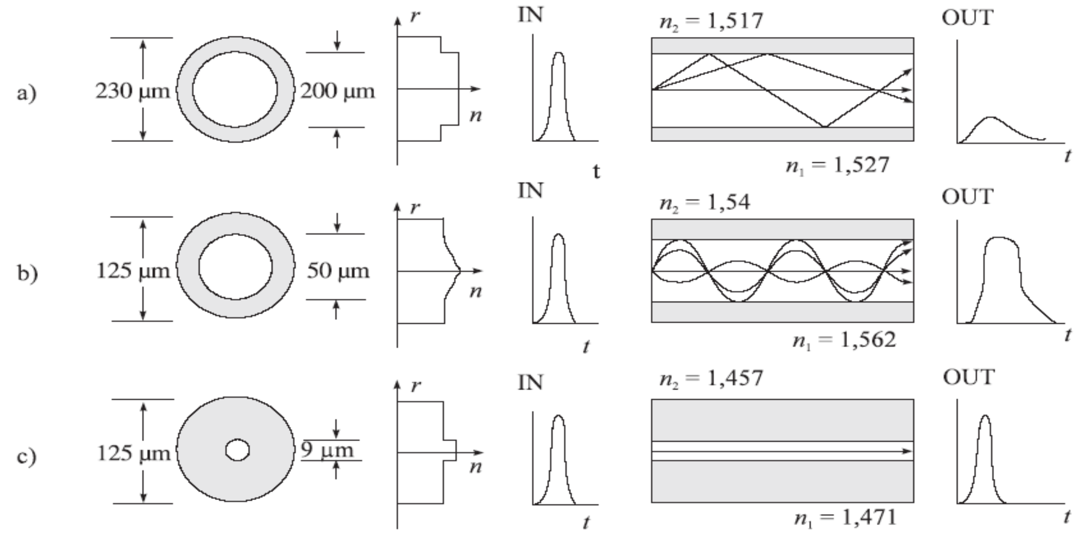
The step-index profile is characterized by a constant refractive index n_1 within the core and a sharp drop to n_2 $(n_1 > n_2)$ at the boundary between the core and cladding.



Mode distribution in a step index fiber

The figure shows that beams guided in a flatter fashion travel a shorter distance than the ones traveling at a steep angle because the latter types are reflected more frequently. This is referred to as modes of higher order (multiple zigzag course) and accordingly modes of a lower order (few reflections). Modes are possible propagation paths in a fiber optic waveguide. The existence of mode of various orders leads to complications in signal transmission. A light pulse of short duration may be guided over many different paths, (higher modes with various propagation times). Out of brief, sharply time limited input pulses, a severely dispersed pulse (mode dispersion) appears at the output, which is the sum of all signals reaching the fiber's end one after the other. Thus the step index fiber is not suited for the transmission of broad band signals. The graded-index profile provides assistance here. In contrast to the step-index profile the light beams in a fiber optic waveguide do not propagate in zigzag fashion. The refraction index profile of a graded index fiber changes continuously over the radius of the fiber. The guiding mechanism of the graded index fiber is no longer based on total reflection, but on refraction. Frequently a parabolic profile is used. Due to the continuously changing refractive index $n_{(r)}$ in the glass core, the beams are constantly subjected to refraction. The propagation direction is constantly changing running in wavelike paths along the axis of the fiber. Steep beams oscillating around the axis always have farther to travel than the light beams traveling along the axis. However, due to the lower refractive index outside the axis of the fiber these beams travel at faster speed, through which the longer distance is made up for in time. As a result, the differences in propagation time for the individual beams disappear almost completely. Modal dispersion is only slight. However in order to achieve maximum transmission performance, a special kind of step index fiber is used; the single mode fiber (monomode fiber). The fiber radius must be in the range of 2 µm – 10 µm. Only one single mode can propagate along the core thus eliminating the possibility of any propagation time difference (no modal dispersion). The following figure provides an overview concerning the dimensions, refractive index profiles and some additional characteristic variables.

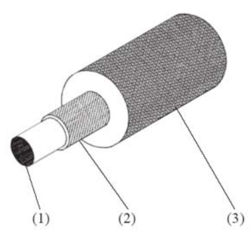
Common types of fiber optic waveguides



a:	step index (SI)	multimode	diameter core/cladding	230/200
b:	graded index (GI)	multimode	diameter core/cladding	50/125
c:	step index (SI)	monomode	diameter core/cladding	9/125

Fiber production, material selection

Plastic and silica glass have gradually become predominant for the production of fiber optic waveguides. So-called all plastic waveguides are used for simple communication systems. The most common fiber type consists of an approx. 970 µm thick core of poly-methyl-methaacrylat (PMMA) and an approx. 15 µm thick cladding made of silicone or Teflon. PMMA is primarily used to manufacture step index fibers. They are easy to handle, robust and are well suited for employment in industrial application for short and medium length left (up to approx. 100 m). The figure shows the schematic design of a PMMA fiber. The *NA* amounts to 0.47 which corresponds to an acceptance angle of 28°. For high traffic transmission left (e.g. cable networks and telecommunication networks operated by telephone and communications companies) monomode fibers are needed. These are manufactured out of silica glass like step index fibers. The advantage of silica fibers is a considerably lower attenuation.



Design of a PMMA fiber

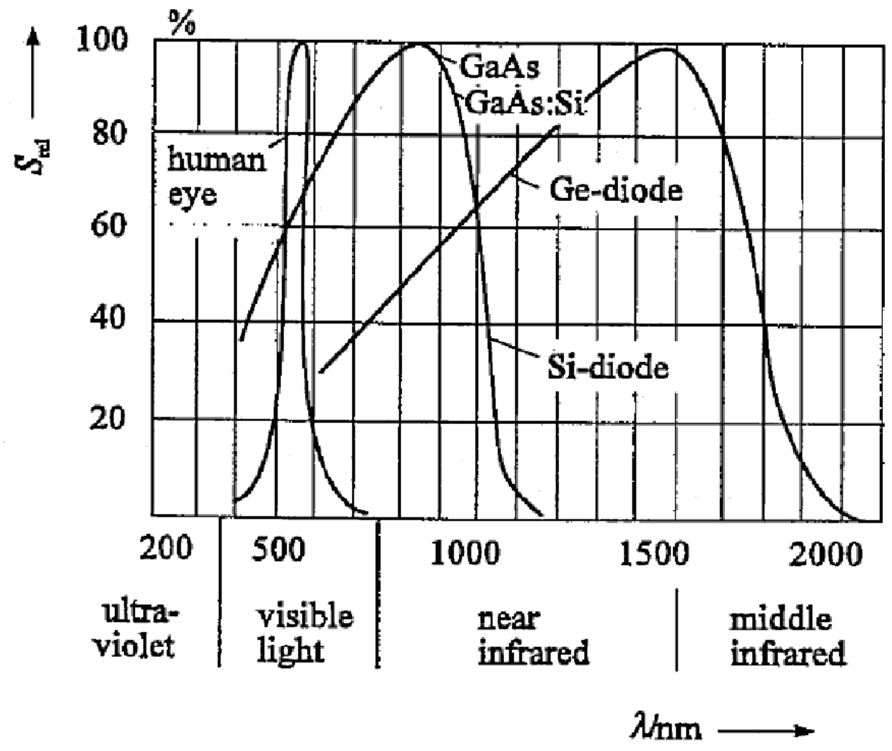
1: core, diameter:	970 µm, n_1 = 1.492
2: optical cladding:	15 µm, n_2 = 1.417
3: protective jacket, diameter:	2.2 mm

Light sources

In optical communications technology LED and solid-state lasers (LD) are primarily used as light sources. Taken from the electrical point-of-view these semiconductor light sources are considered PN diodes, which are operated in the forward direction. The effect of spontaneous recombination is exploited in LED sources.

Detectors

The opto-electrical conversion brought about by the absorption of the light beam takes place in the photodiode. In actual practice the spectral sensitivity S_{rel} is important. This indicates which current *I*p is obtained at the photodiode for prespecified, incident light power P_2. Typical values for silicon diodes for a wavelength of 850 nm are at about S_{rel} = 0,5 A/W. The figure demonstrates the relative sensitivity of photodiodes as a function of the wavelengths for various semiconductor elements when compared to the sensitivity of the human eye.



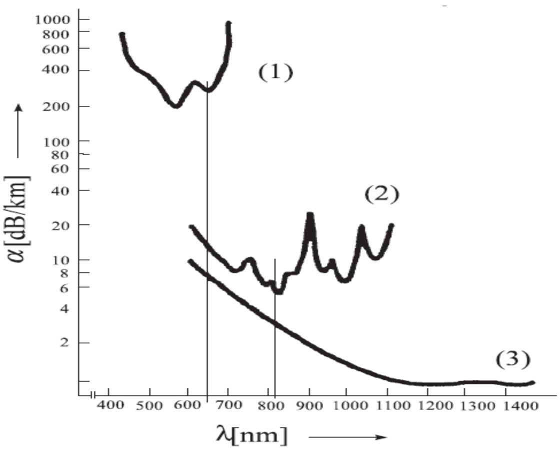
Attenuation

Any form of energy transmission involves power losses. In communications this is referred to as attenuation. Important examples of this in optical communications technology are:

- Coupling attenuation of the connectors
- Material attenuation of the fiber optic waveguide

The attenuation of the fiber optic waveguide depends on the wavelength, while, the attenuation of the connectors is independent of the wavelength. The coupling attenuation mainly depends on the beam angle of the light source and the aperture angle or numerical aperture of the optical fiber. During the transition from connector to connector the light is refracted while passing through the air. As a result, a portion of the light no longer arrives at the aperture angle opposite fiber and is thus lost for signal transmission. Material attenuation of the fiber optic waveguide is caused by:

- Light scattering
- Light absorption
- Beam losses related to the guidance of the waveguide.



Fiber optic attenuation

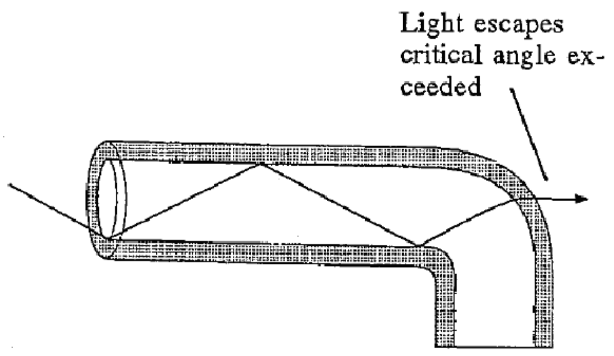
(1) APF Cable (all plastic fiber e.g. PMMA

(2) PCF plastic cladding fiber

(3) Glass fiber

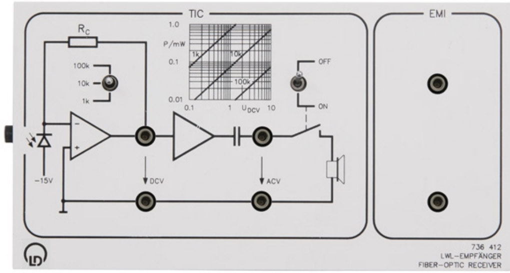
Linear scattering (Rayleigh scattering) is due to statistical fluctuations in the refractive index. These result from random molecular structures in the waveguide material. The refractive index varies in sections which are small in comparison with the wavelength of light. Absorption means the conversion of beam energy into heat when impinging on impurities (atoms or molecules). The severity of the effect depends on the wavelength and spans the entire range, from ultraviolet to infrared.

In addition to the scattering and absorption there also exists beam losses through conversion from guided to unguided modes. Fluctuations in diameter or concentrations etc. are responsible for this. Furthermore, there are modes in which energy flows from the core into the cladding: Leaky modes are produced. The tendency to leaky mode formation increases, when the fiber becomes bent.



However, due to the relatively high attenuation in the cladding material mantle modes are incapable of propagation even without a bent optical waveguide. Ranges in which the attenuation assumes minimum values are referred to as optical windows. In conjunction with the corresponding emitter elements the range around 660 nm is used in plastic optical fibers and the range around 850 nm (1st window) and 1300 nm (2nd window) for glass optical fibers.

Training system



736 411 Fiber optic transmitter

Three integrated, LED for experiments at various wavelengths. Potentiometer for the continuous setting of the bias voltage for recording characteristics. 4-mm sockets for the connection of the Sensor-CASSY interface. Internal signal generator (triangular/ square-wave) with BNC/4-mm output sockets for experiments involving modulation. **Note:** LEDs are subject to change in production. Thus the wavelengths of the LEDs within the Fiber optic transmitter can deviate from solutions given in the text.

736 412 Fiber optic receiver

Discretely assembled transimpedance amplifier with switchable conversion resistors. Separate DC and AC output. The DC output permits investigation of the dark current. With the AC output the advantages of modulation can be demonstrated. Built-in piezo loudspeaker.

736 421 Set of optical fibers and accessories

Set of PMMA fiber-optic cables with step index profile and 980/1000 µm core/cladding diameter. Plastic cladding with 2.2 mm external diameter.

1 Optical fiber, length 50 m
1 Optical fiber, length 20 m
1 Optical fiber, length 10 m
1 Optical fiber, length 5 m
1 Plastic optical fiber, transparent, length 10 m
  diameter 1 mm with connection piece 2.2 mm
1 Plexiglas directional coupler
1 Polishing tool
1 Abrasive cloth

736 429 Fiber optic microscope

The light is switched on, when the microscope is opened. In order to spare the batteries close the microscope after use.

Loose fiber adapter for checking the fiber end surfaces of bare PMMA sections. Only tighten when necessary.

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Experiment 8

“Optical Power of Emitting Diodes”

Optical power of the emitting diodes

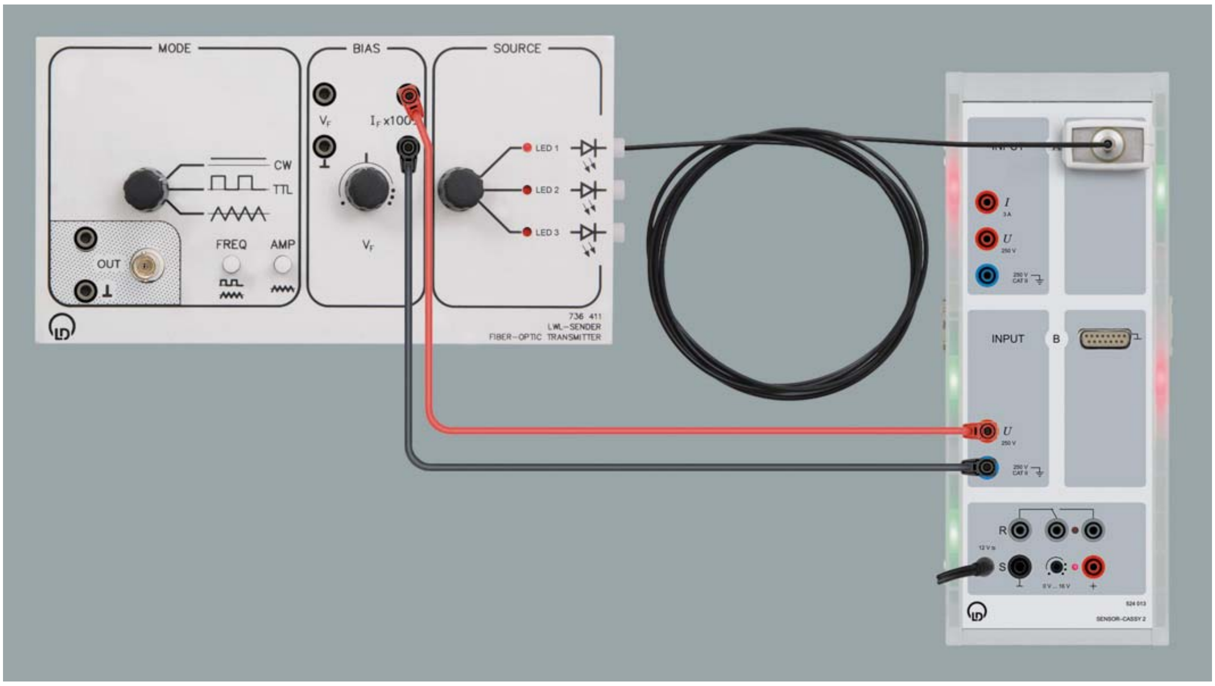
Theory

In this experiment the optical power P_2 emitted by the LED is determined. Since we already know from the last experiment the electrical power consumption P_1 of the LED as a function of the forward current the electro-optical efficiency η can be calculated as the quotient P_2/P_1 and represented as a function of the forward bias current I_F. An optical power meter is needed to measure the absolute optical power P_2. This is normally calibrated in dBm and gives a direct optical power reading.

Material

1	736 411	Fiber optic transmitter
1	736 421	Set of fiber-optic waveguides and accessories
1	562 791	Plug-in power supply 12 VAC
1	524 013S	Sensor-CASSY 2 Starter
1	524 0512	Optical power sensor S
1	500 644	Safety connection lead 100 cm, black
1	500 641	Safety connection lead 100 cm, red
1	564 482	Book: Experiments with PMMA fibers
1		PC

Carrying out the experiment



Presetting

Fiber optic transmitter		Fiber	Optical power sensor S	
MODE	CW			
BIAS	$V_F \rightarrow$ left	5 m	CASSY	channel A
SOURCE	LED 1			

Recording the power characteristic

- Set up the shown experiment.
- Put the fiber at both ends firmly into the connectors.
- Load the CASSY Lab example OpticPower.labx.
- Start the measurement by pressing *F9.*
- Turn the potentiometer V_F slowly to the right.
- Reaching the top right position, press *F9* again.
- Repeat the measurements for LED 2 and LED 3.

Determining the electro-optical efficiency

- Determine for each LED the forward voltage U_F, which comes with the forward bias currents I_F = 10/20/30 mA.
- Determine the electrical input power $P_1 = I_F \cdot U_F$.
- Calculate the electro-optical efficiency of the total transmission line $\eta = P_2/P_1$.
- Take the values for P_1 and P_2 from the CASSY tables.
- Note all values into the table.

Electro-optical efficiency

	I_F = 10 mA			I_F = 20 mA			I_F = 30 mA		
SOURCE	**P_1/mW**	**P_2/µW**	**η/%**	**P_1/mW**	**P_2/µW**	**η/%**	**P_1/mW**	**P_2/µW**	**η/%**
LED 1									
LED 2									
LED 3									

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Communication 2 Lab

Experiment 9

"Attenuation In Optical Fiber"

Attenuation

Theory

Attenuations can be measured either according to the throughput method or according to the principle of pulse reflectometry. Throughput measurements require access to both ends of the cable (normally not possible for installed cables). The pulse reflectometry only needs measurements on one end of the cable but also requires considerably more measurement equipment. One standard throughput the measurement is performed according to the cutback method. Here the optical power P_2 is measured at one end of a known cable length *l*. Then the cable is cut back to a few meters in length and the transmitted optical power is determined again. This method is used to keep the launch conditions the same. This advantage is offset by the disadvantage that measurement method is not without damage. Every measurement irreversibly means the loss of a section of fiber. After a finite number of measurements the fiber becomes too short. This procedure is too expensive for student experiments. Thus for the purpose of experimentation the attenuation measurements are described as throughput measurements on premade optical fibers of different length. A typical parameter for an optical waveguide is the attenuation coefficient *a,* which is defined as attenuation per km of waveguide material. The attenuation of an optic waveguide for a fixed wavelength is given by:

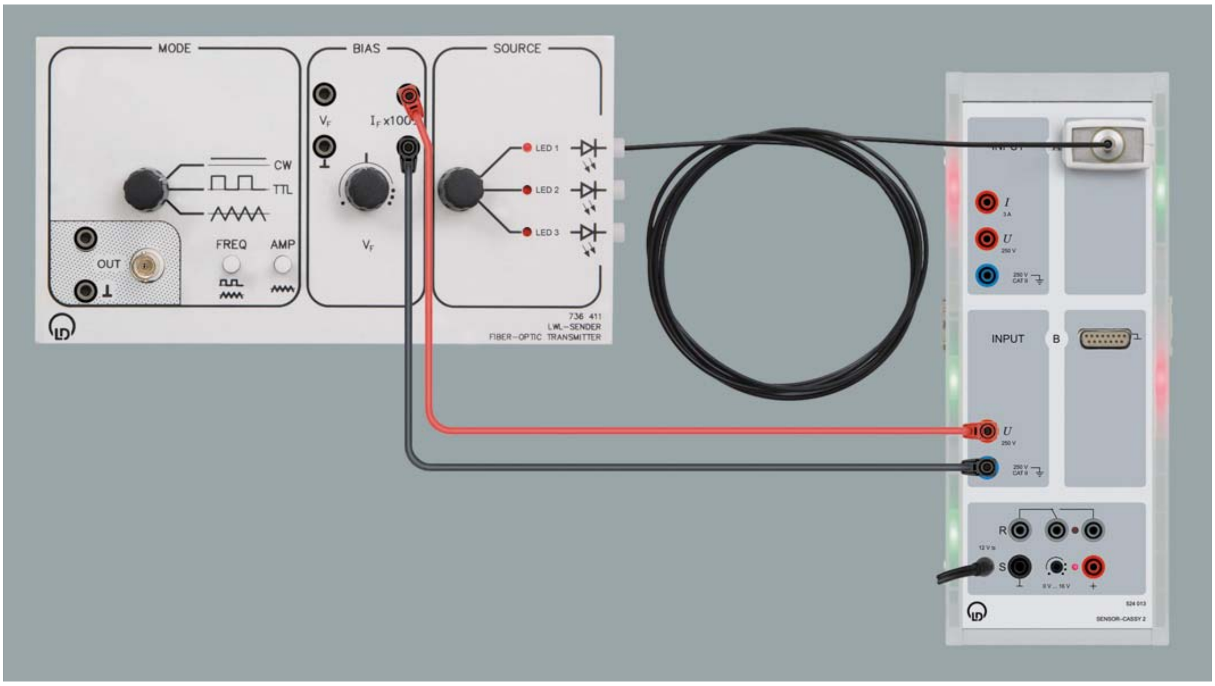
$$\frac{a}{dBkm^{-1}} = \frac{10.000}{\Delta l} \log \frac{P_1}{P_2}$$

Enter Δl in m.

Material

1	736 411	Fiber optic transmitter
1	736 421	Set of fiber-optic waveguides and accessories
1	562 791	Plug-in power supply 12VAC
1	524 013S	Sensor-CASSY 2 Starter
1	524 0512	Optical power sensor S
1	500 644	Safety connection lead 100 cm, black
1	500 641	Safety connection lead 100 cm, red
1	564 482	Book: Experiments with PMMA fibers
1		PC

Carrying out the experiment



Presetting

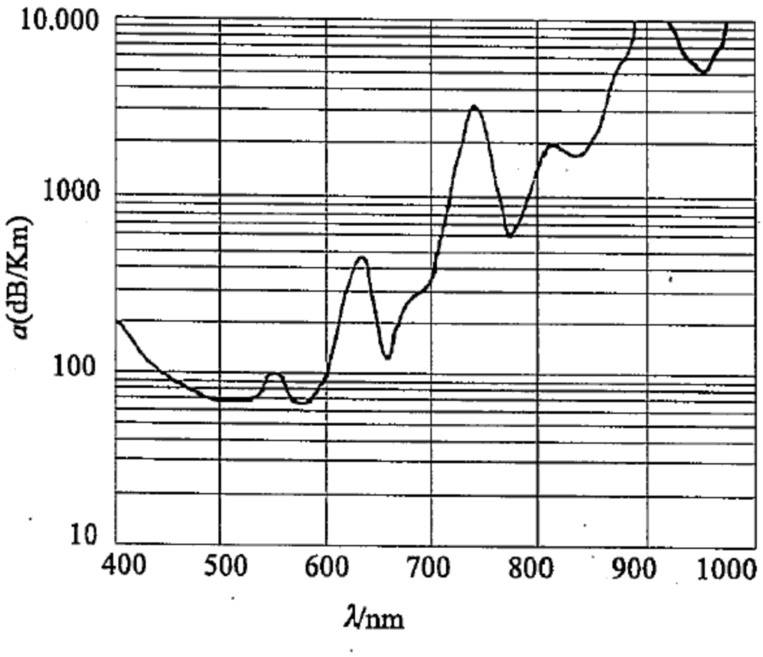
Fiber optic transmitter		Fiber	Optical power sensor S	
MODE	CW	all		
BIAS	V_F → right	lengths	CASSY	Input A
SOURCE	LED 1/2/3			

- Set up the shown experiment
- Select LED 1 with SOURCE.
- Put the fiber with *l* = 5 m firmly into the connector of the LED.
- Load the CASSY Lab example Attenuation.labx.
- Right mouse click into the instrument PA1 activate *settings sensor input* → 0 ←. The display changes to 0 dB.
- Measure successively the fibers with *l* = 10/20/50 m.
- Calculate the attenuation a/dBkm^{-1}. For that, insert the attenuation values into the appropriate formulas.
- Repeat the measurement for LED 2 and LED 3 respectively. If necessary, change the settings in CASSY Lab.

I_F/mA	SOURCE	PA1/dB l = 5 m	l = 10 m	l = 20 m	l = 50 m	a/dBkm^{-1}
42.45	LED 1					$a = \frac{1000}{45} a_{50} =$
	LED 2					$a = \frac{1000}{15} a_{20} =$
	LED 3					$a = \frac{1000}{5} a_{10} =$

Variant

- Demonstrate the bend attenuation.



Principal characteristic of attenuation for PMMA

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Experiment 10

"Coupling Losses in Optical Fiber"

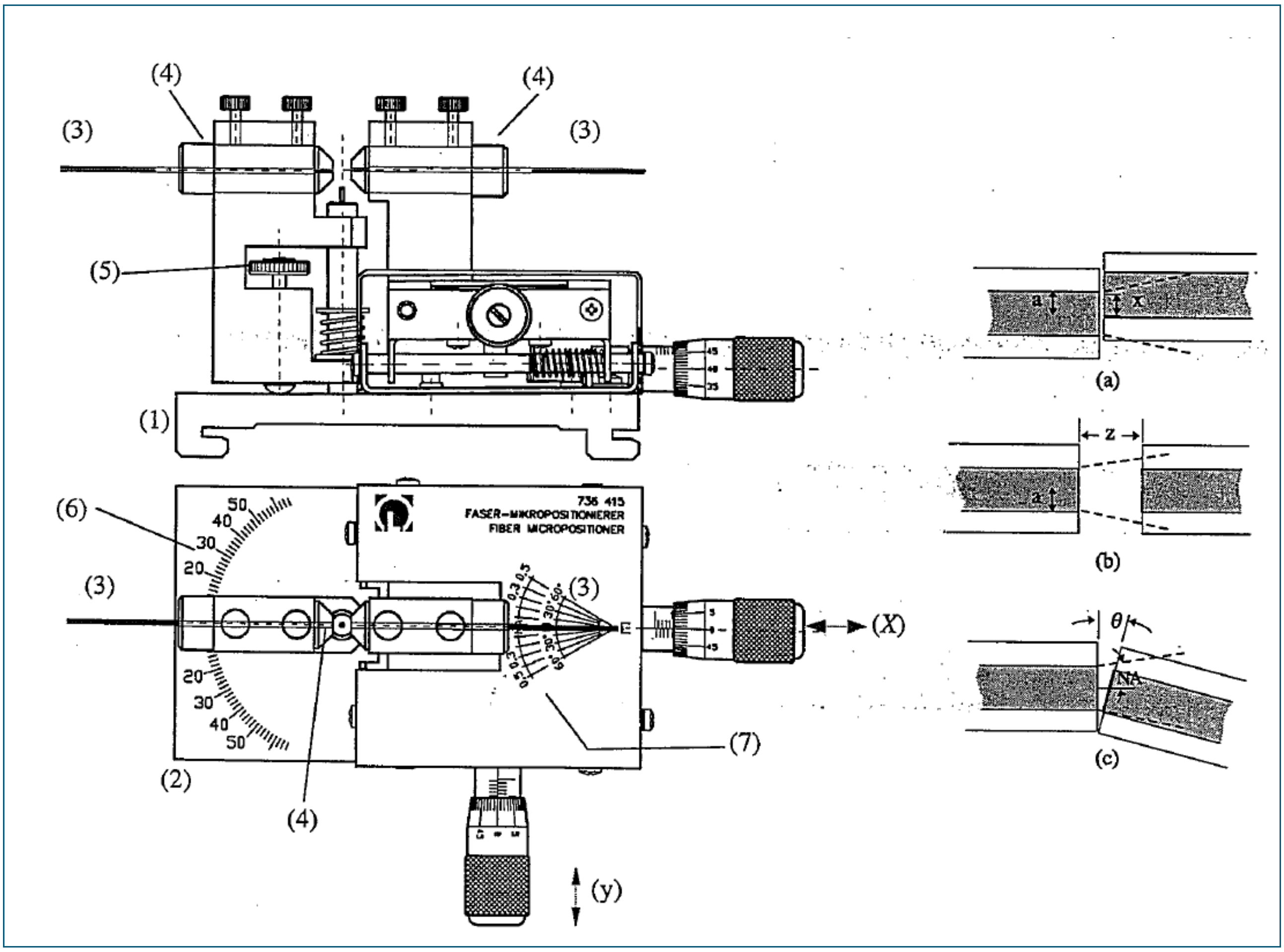
Coupling losses

Theory

Plug connections can contribute additional coupling losses in an optical transmission network due to the following fault sources:

- transversal offset
- longitudinal offset
- angular offset (axes of the optical fibers are at an angle to each other)

Optimally both fiber end faces should be lined up evenly and without any air gaps when two optical fibers are connected to each other.



a: transversal offset

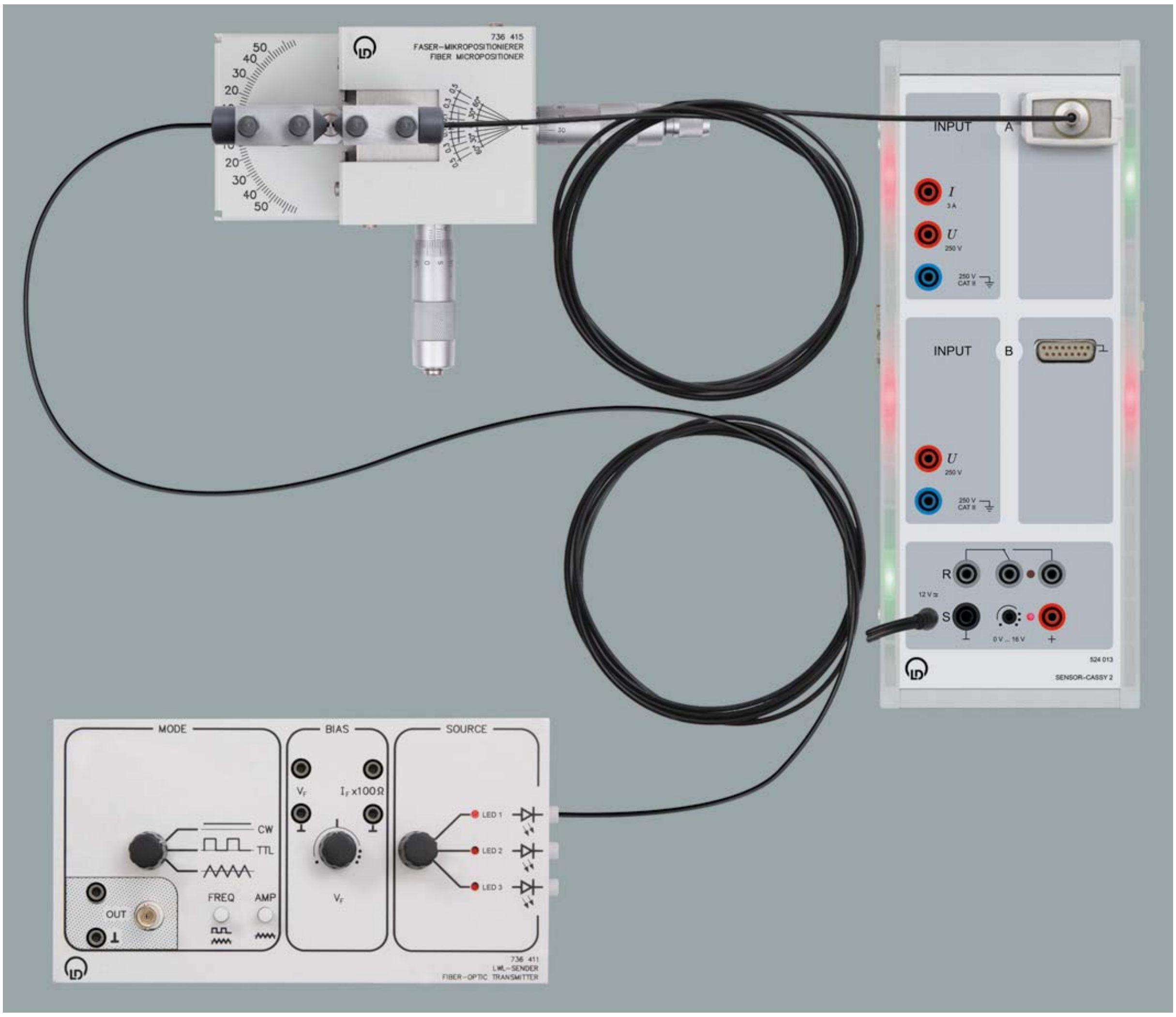
b: longitudinal offset

c: angular offset

Material

1	736 411	Fiber optic transmitter
1	736 415	Fiber micropositioner
1	736 421	Set of fiber-optic waveguides and accessories
1	736 429	Fiber-optic microscope
1	562 791	Plug-in power supply 12VAC
1	524 013S	Sensor-CASSY 2 Starter
1	524 0512	Optical power sensor S
1	500 644	Safety connection lead 100 cm, black
1	500 641	Safety connection lead 100 cm, red
1	564 482	Book: Experiments with PMMA fibers
1		PC

Carrying out the experiment



Presetting

Fiber optic transmitter		Fiber	Optical power sensor S	
MODE	CW	fibers		
BIAS	$V_F \rightarrow$ right	from	CASSY	channel A
SOURCE	LED 1	micropositioner		