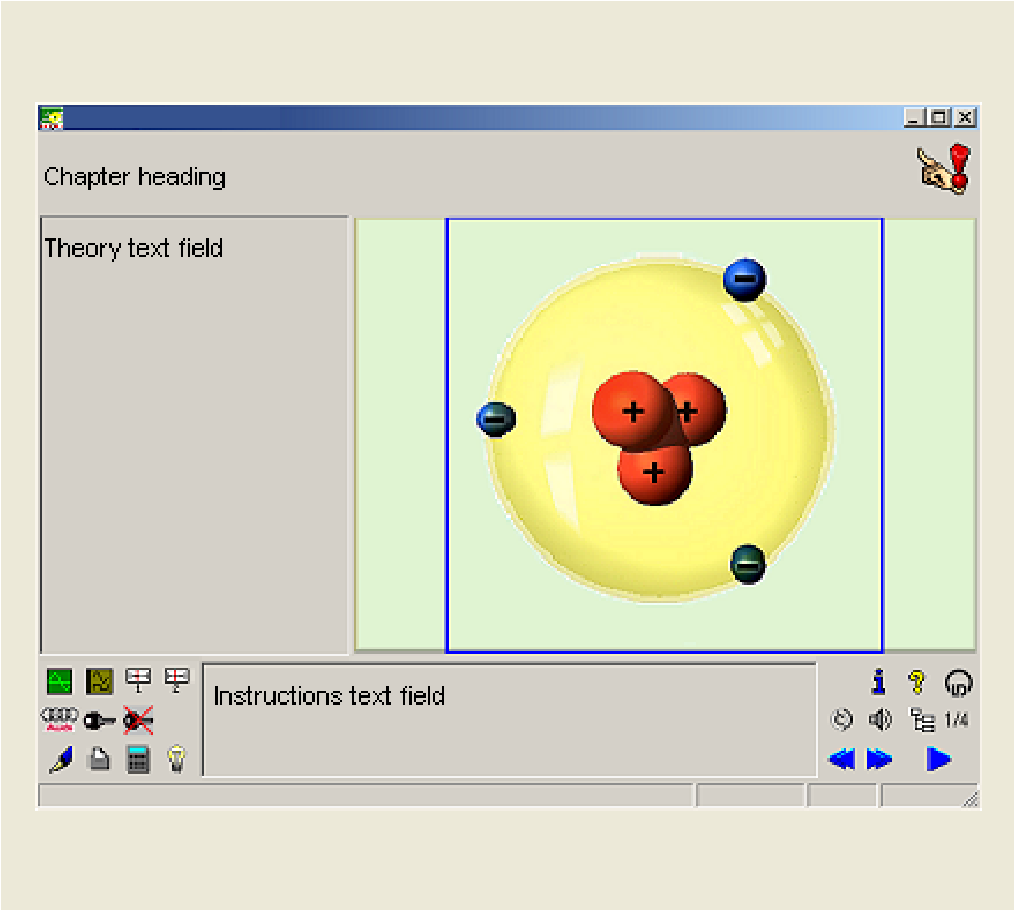
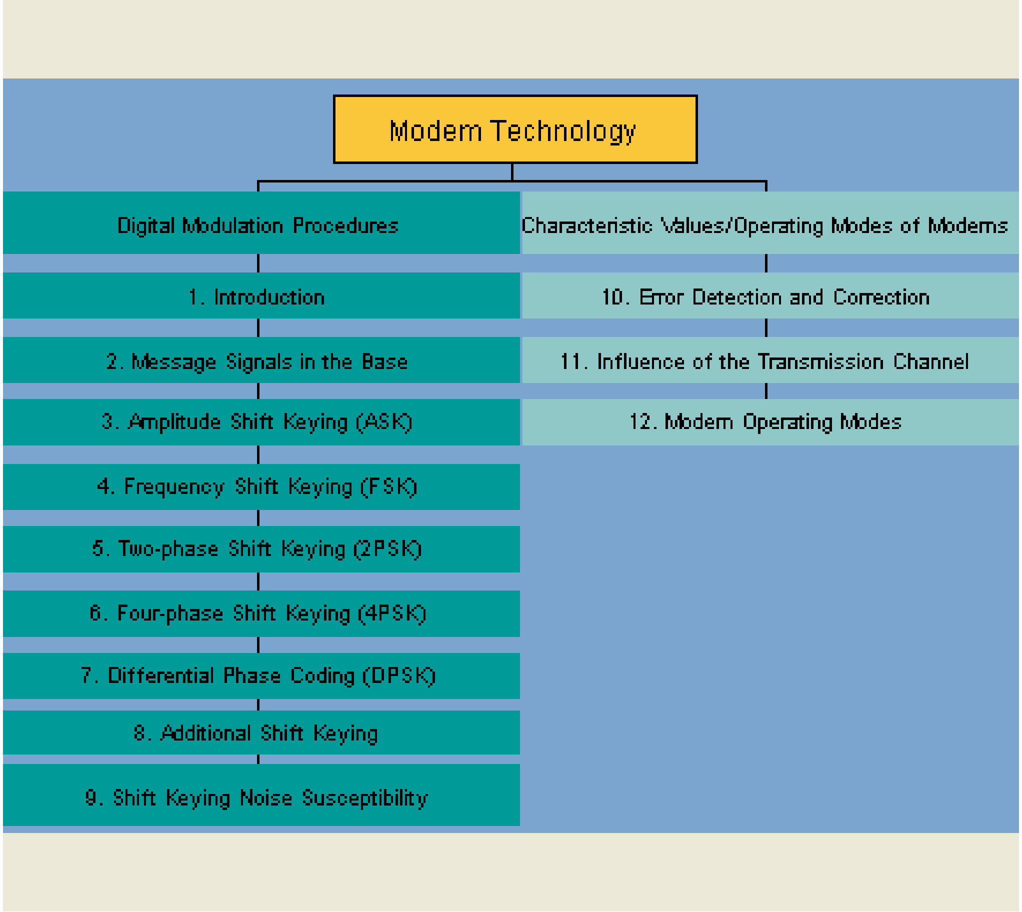
### 1.1 Using the course




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.

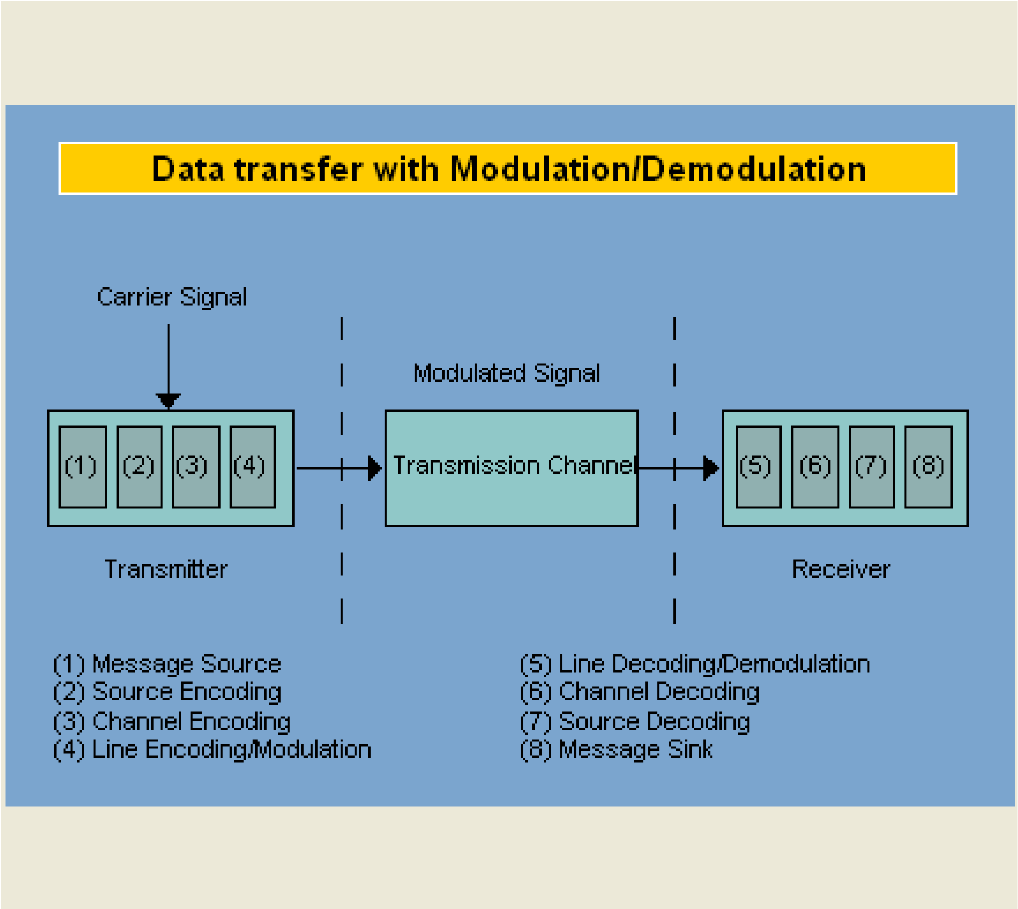
### 1.3 History


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.

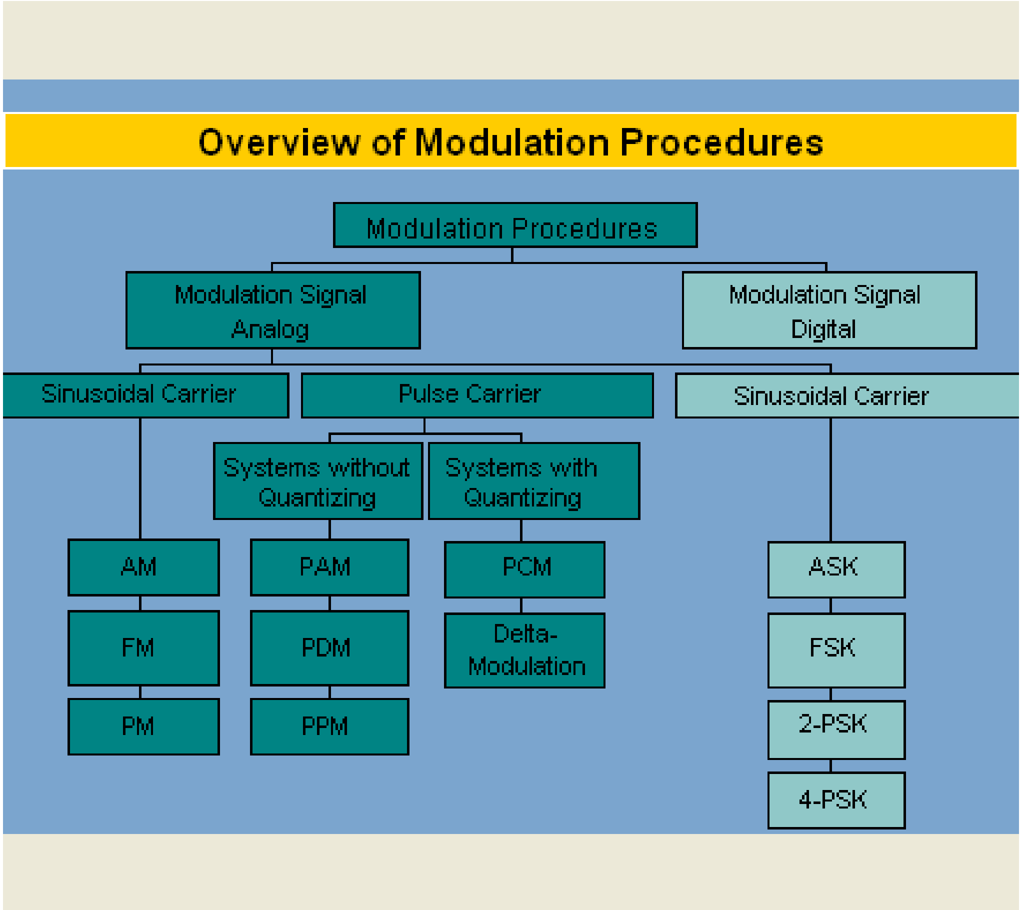
3 **Carrier signal**

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.

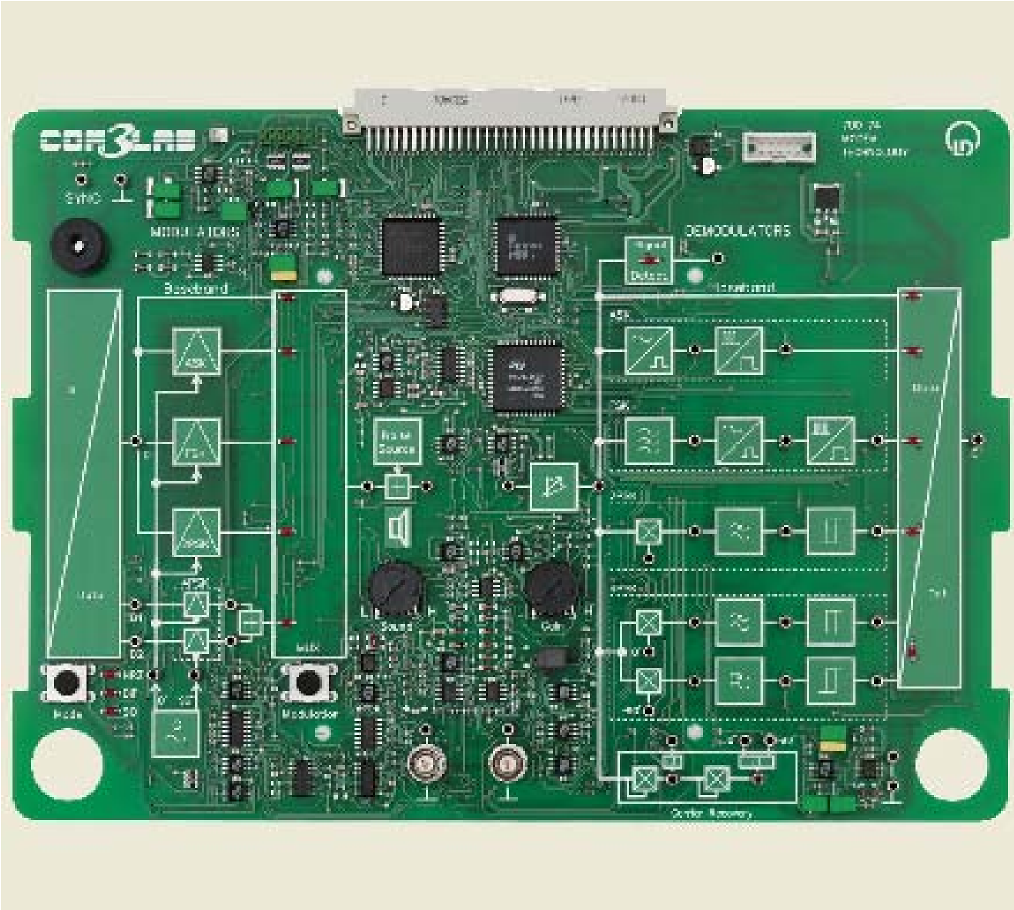
### 1.5 Modulation Procedures




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] .

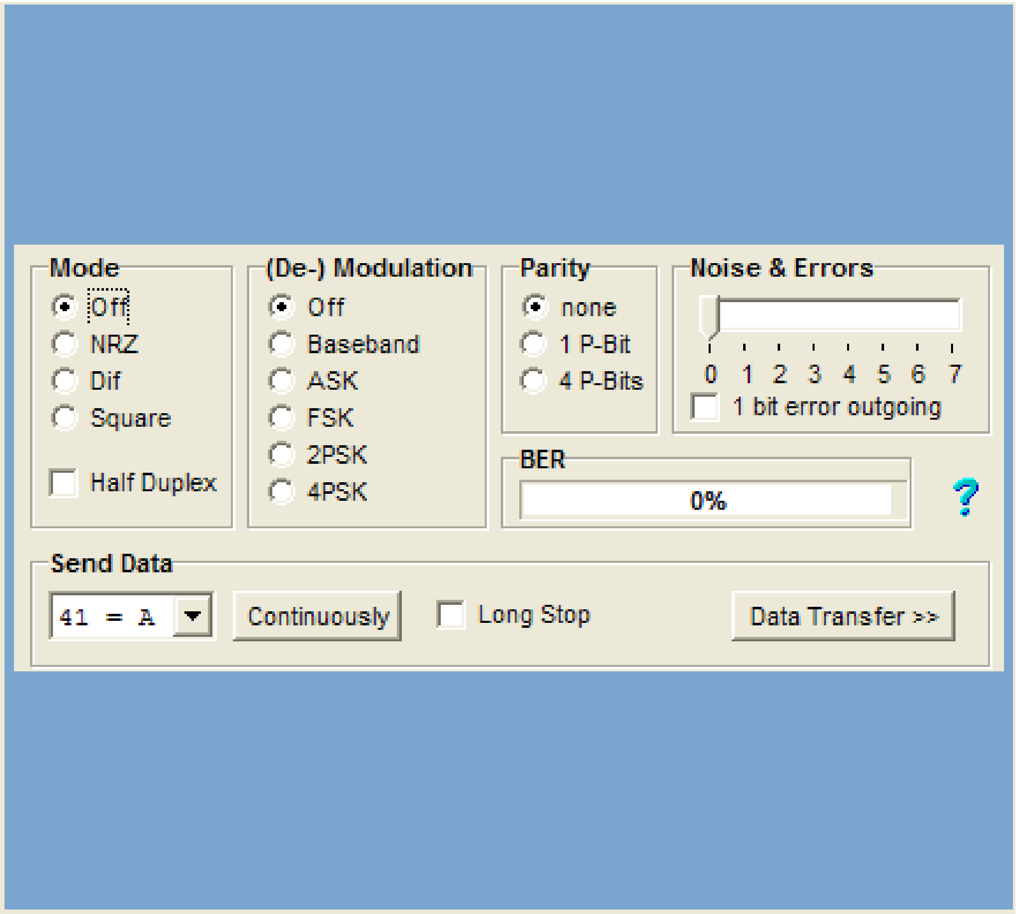
[1]
- T 7.2.1.3 Amplitude Modulation
- T 7.2.1.5 Frequency and Phase modulation
- T 7.2.2.1 Pulse Code Modulation
- 700 71 TX 433 Transmission Technique
- 700 72 RX 433 Receiving Technique

### 1.6 The COM3LAB-Board 700 74



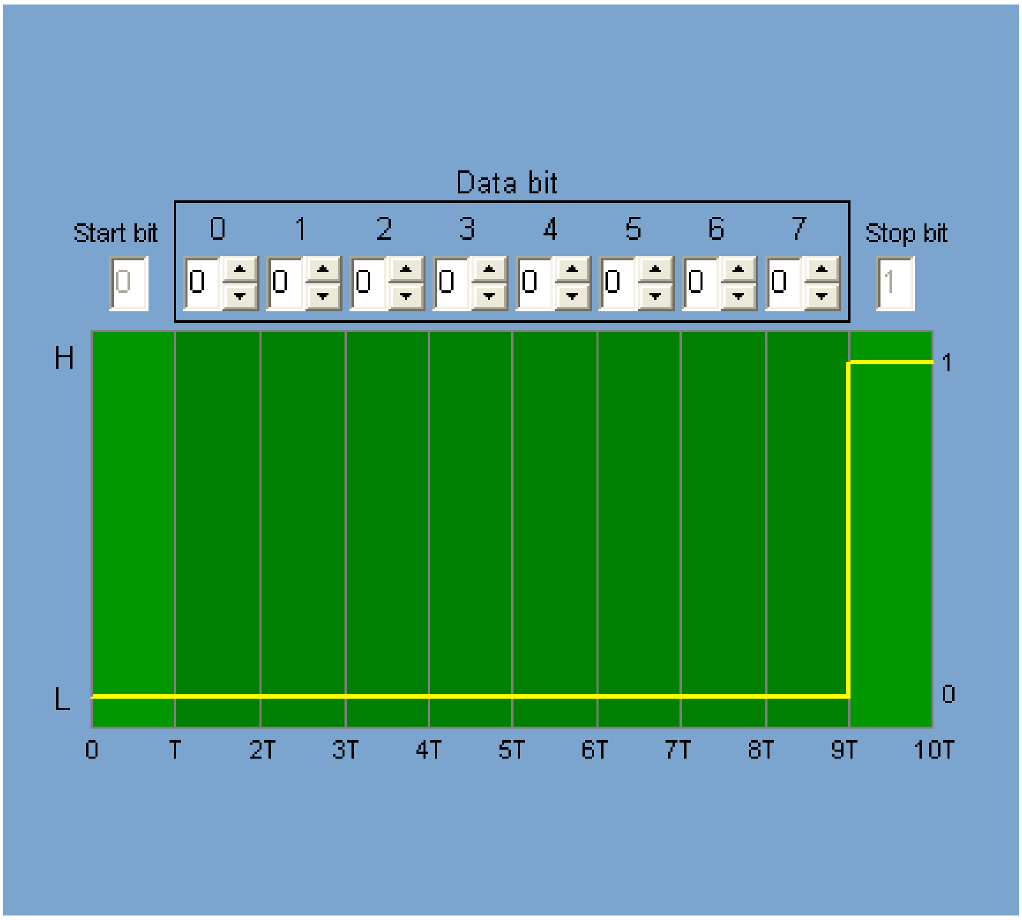
The COM3LAB-Board 700 74 Modem Technology contains all the components needed for an introduction to digital modulation. This includes especially modulators for amplitude, frequency and two- and four-phase shift keying as well as the corresponding demodulators. Data transfer can be performed over various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

### 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 .

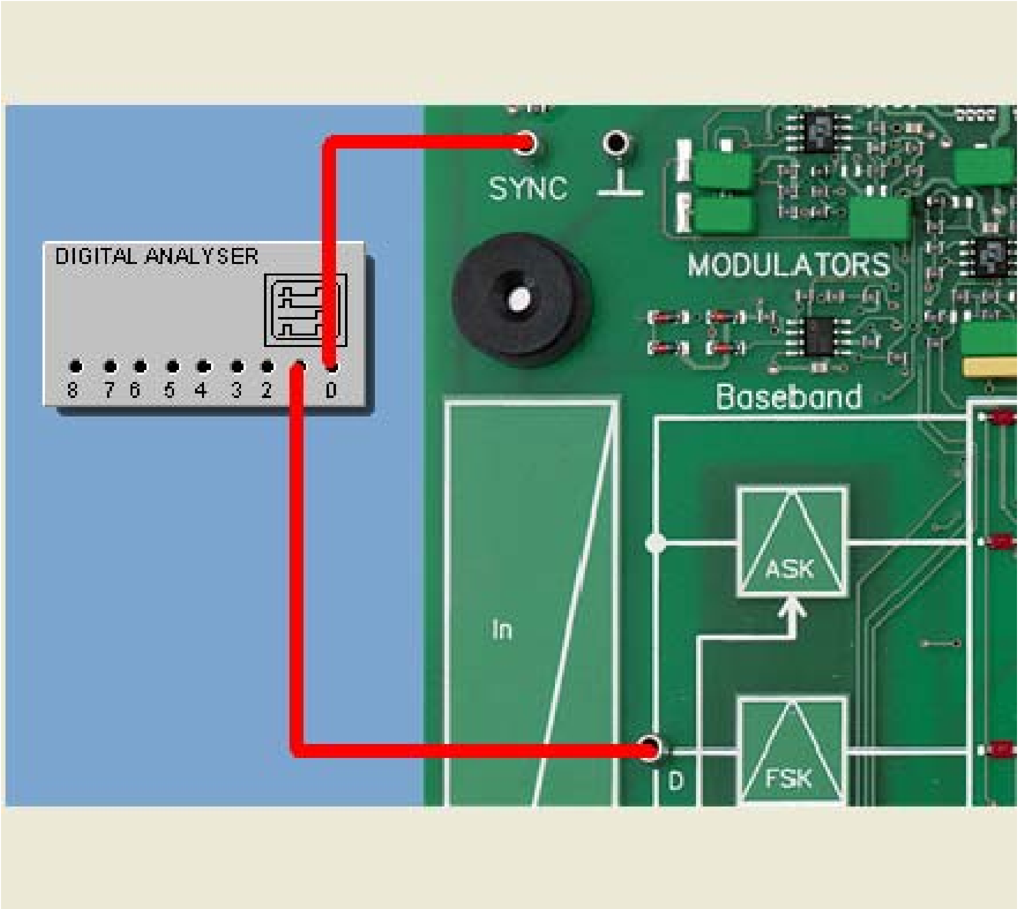
[3] **Start bit**

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.

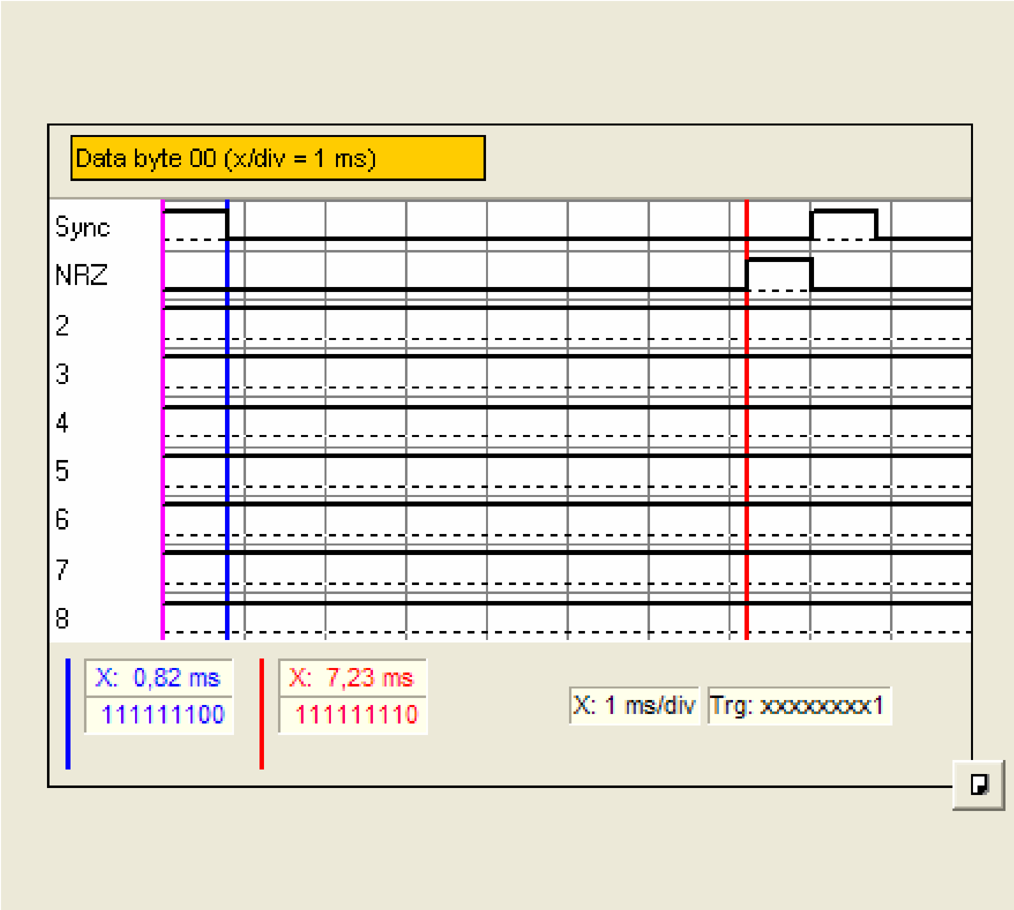
[1] **Bit rate**

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.

### 2.3 Result




The curves show the expected structure of the signal consisting of the start bit[1], data bits[2] (between the blue and red cursor) and the stop bit[3] (logical 1, to the right of the red cursor). After the start bit follows first the least significant bit (LSB), then the higher value data bits. For the total of ten bits (start bit, stop bit, eight data bits) a transmission time of 8 ms is required. This results in a bit rate of 10 • 1000 / 8 = 1250 bps.

[1] Logical 0, appears time-synchronous with the sync signal

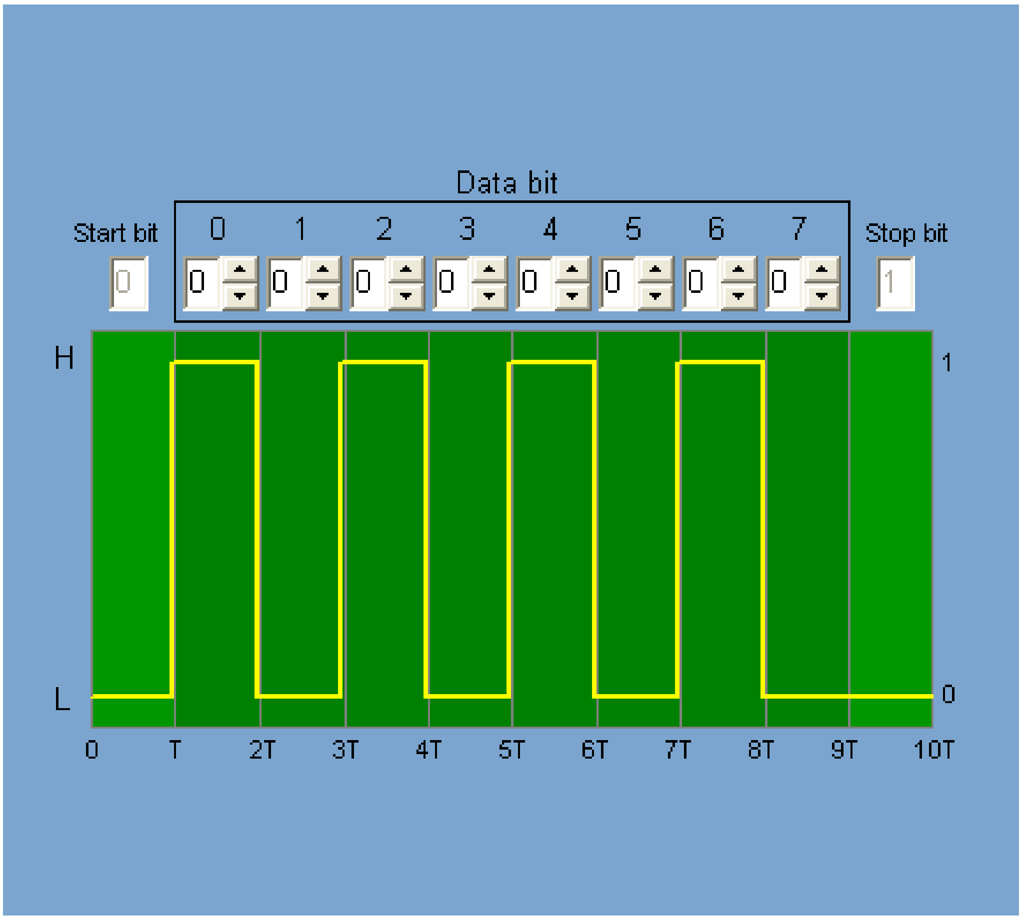
[2] **Interpretation:**

- The eight payload bits can be divided into two groups of four for simpler interpretation and be interpreted with hexadecimal code.
- The groups of four (half-bytes or nibbles) lie between the blue and red cursor. In the example "Datum 09" the four first bits right of the blue cursor represent the "9" and the following four bits the 0.
- Each group represents one of the 16 states 0..F.

[3] **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.

### 2.4 Differential Format



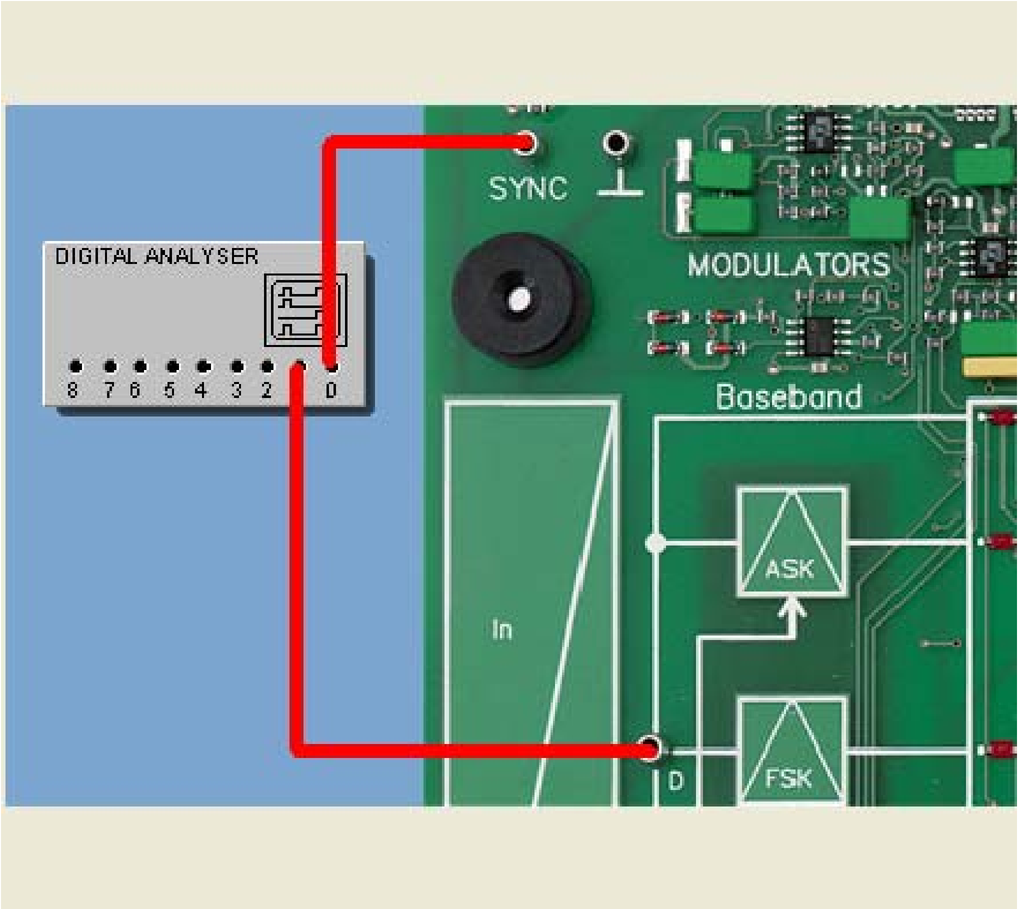

In differential format the signal amplitude is likewise constant during the entire duration T of a data bit. Each data byte is introduced by a start bit and ended by a stop bit. The signal level is however dependent on the **preceding** signal level: If a bit (start, stop or data bit) is at logical 1, the signal level does not change; if it is at logical 0, it is inverted. As will be shown at a later time[1], differential format is especially suited for use with 2PSK/4PSK (DPSK[2]).

[1] see experiments on pages 7/3, 7/5 and 7/7

[2] **DPSK**

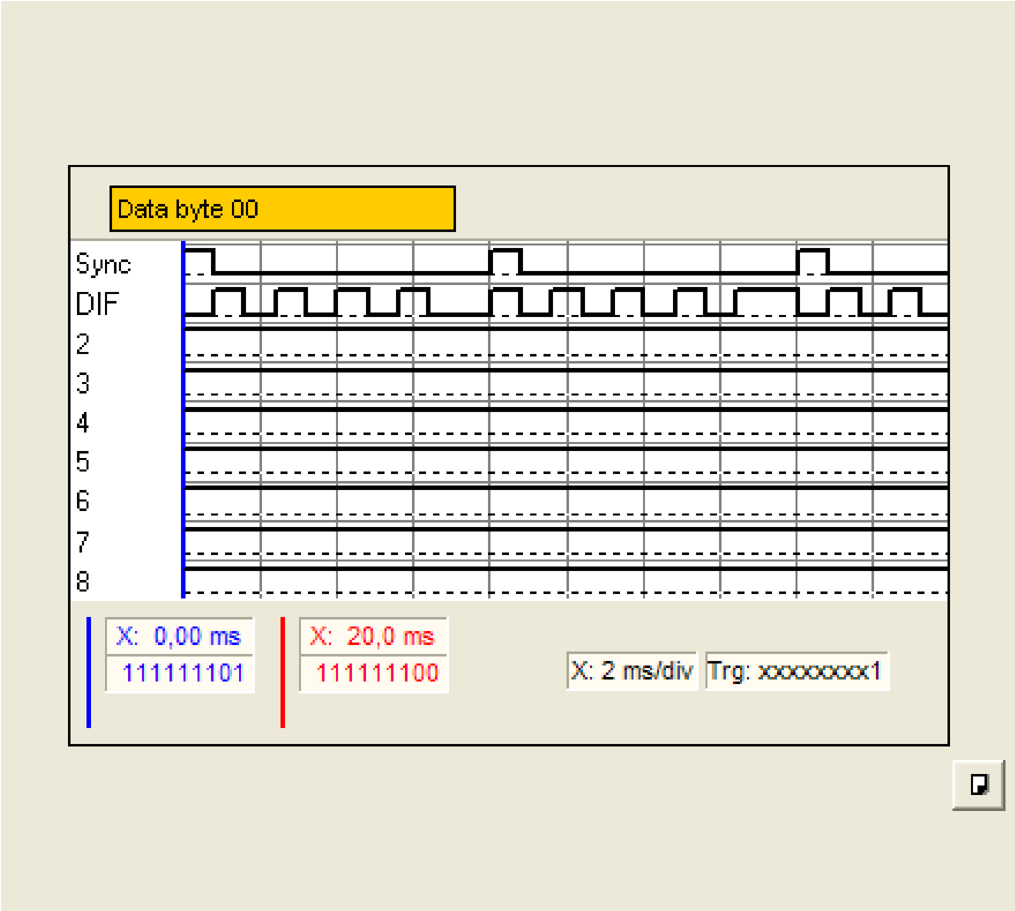
In *Differential Phase Shift Keying* a data bit is encoded not by the absolute phase position of the carrier, but rather by the phase difference from the preceding value. A phase shift between sender and receiver can therefore be ignored.

**2.5 Experiment: Time course of the differential data signal**



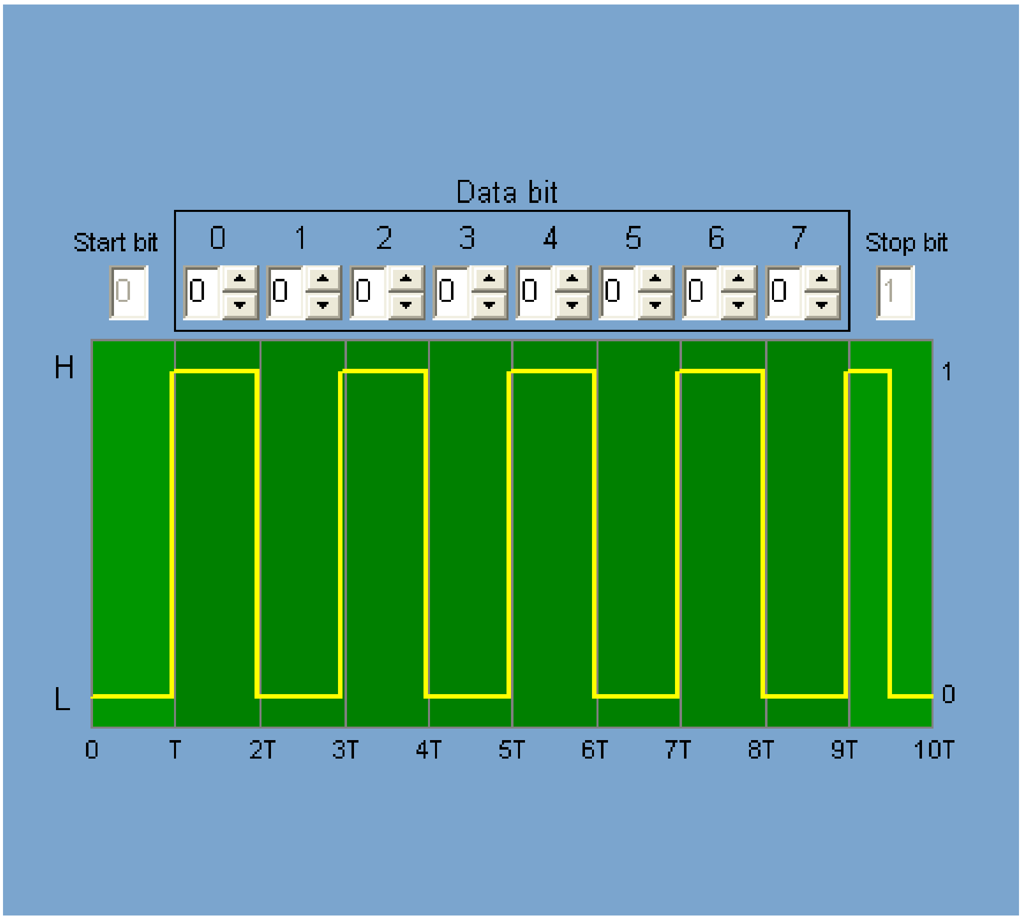

In the following experiment you will study the differential data format more closely. Periodically differing data bytes will be transmitted and the course of the encoded data signal will be recorded with the digital analyzer. The obtained signals will be compared with those of the NRZ encoding.

**2.6 Result**




With a data byte of 00 the signal level changes with each data bit; with a data byte of FF it remains constant. With a data byte of 55 the level changes with each second data bit. Since the start bit has the value logical 0, the signal level changes at the beginning of each bit sequence. This results in every second bit sequence being sent inverted (you can see this especially clearly with FF).

### 2.7 Manchester Format




In Manchester format the transmission clock can be derived from the signal. At the start of each bit a signal edge (0-1 or 1-0 transition) is generated. For each bit having logical 1 an additional signal edge is also generated in the middle of the bit. The constant signal change gives the signal an AC voltage-like character in this format, giving it advantages with respect to what kinds of amplifiers can be used.

### 2.8 Knowledge Check

On the right side you will see a summary of the material covered in this chapter.

#### Check your knowledge

Which of the following statements apply?

- In NRZ coding the signal level depends only on the bit value.
- In NRZ coding the signal level depends on the preceding bit value.
- In DIFF coding the signal level depends only on the bit value.
- In DIFF coding the signal level depends on the preceding bit.
- In Manchester coding the signal level is constant during a bit duration.

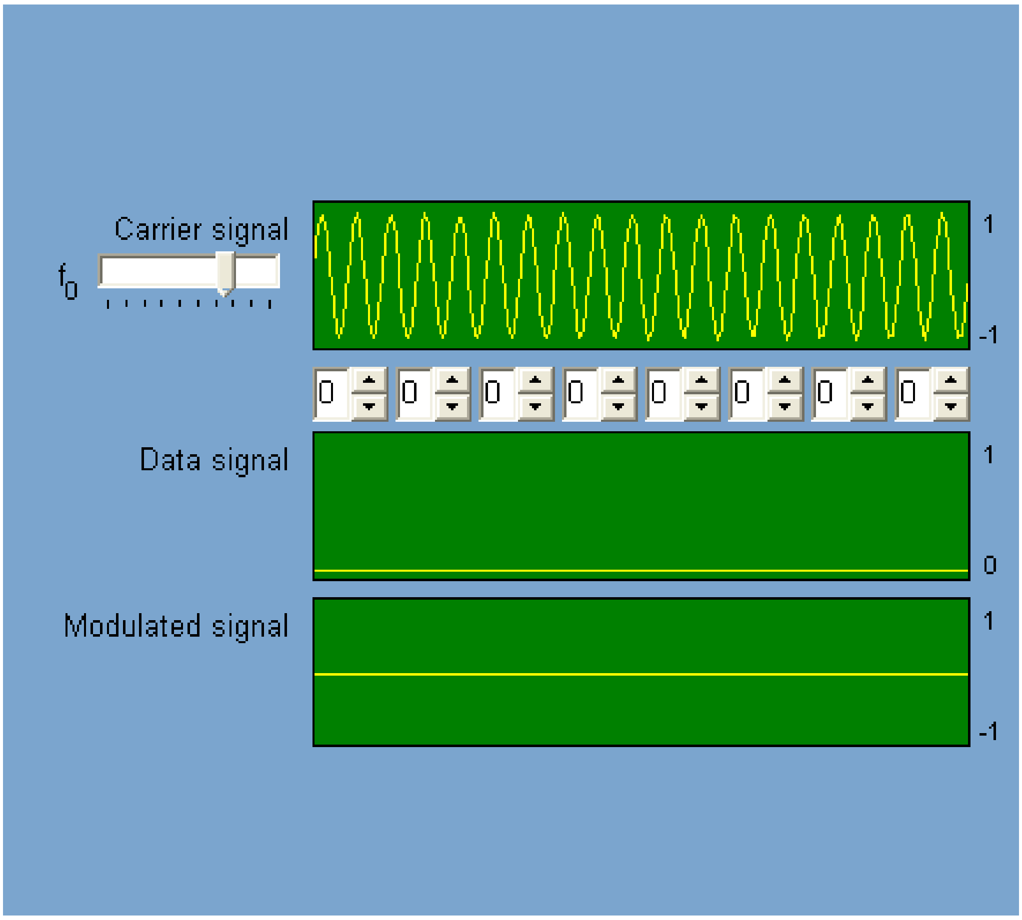
### 2.9 Summary

On the right side you will see a summary of the material covered in this chapter.

**Summary of this chapter**

- Before the binary data are sent, they are first encoded.
- In NRZ coding the signal level depends only on the bit value and remains constant for the entire bit duration (Non-Return-to-Zero).
- In DIFF and Manchester coding the signal level also depends on the preceding signal level.
- Manchester coding is a format with especially advantageous transmission characteristics due to the low DC component and the clear clock frequency in the spectrum.

### 3.1 Time Function

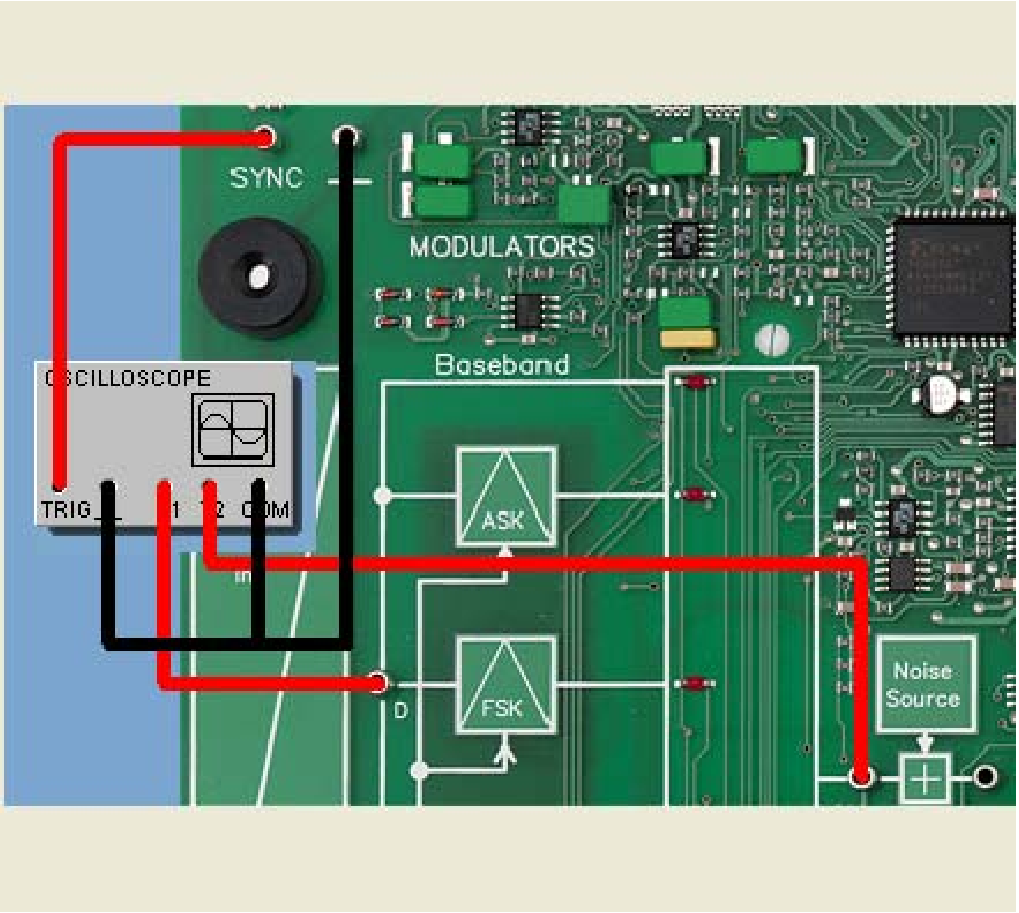



In Amplitude Shift Keying (Amplitude Shift Keying ASK[1] ) a sinusoidal carrier signal having frequency $f_0$ is turned on and off by the data signal (which is why this procedure is also known as ON/OFF keying). If the data signal has the value logical 1 (HIGH), the carrier signal is turned on, and a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

[1] **ASK**

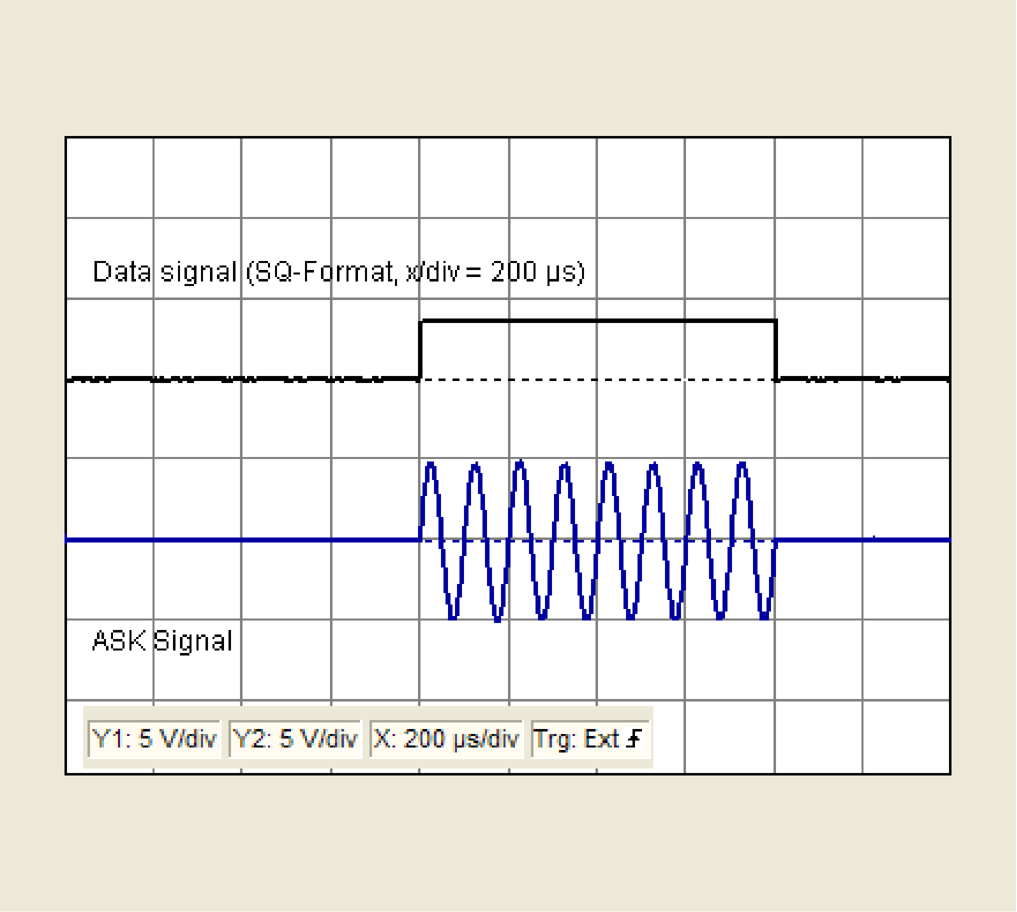
*Amplitude Shift Keying* is a modulation method whereby the amplitude of a sinusoidal carriers signal is changed as a function of the level of the (digital) modulation signal. The carrier signal is usually turned on and off alternately (ON/OFF Keying).

### 3.2 Experiment: Time course for ASK



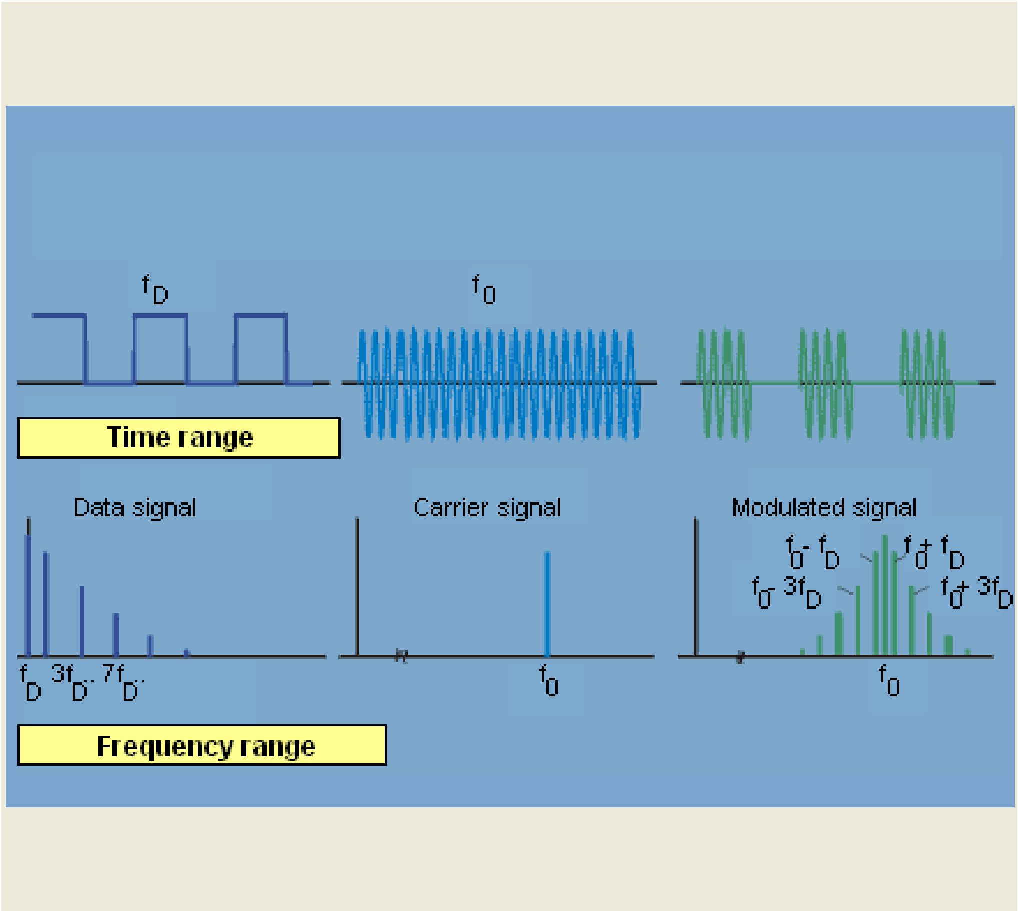

In the following experiment you will first study the modulated signal in amplitude shift keying. Periodically a constant data byte will be sent as a data signal and modulated on to the sinusoidal carrier signal. Both signals will be compared using the oscilloscope.

### 3.3 Result



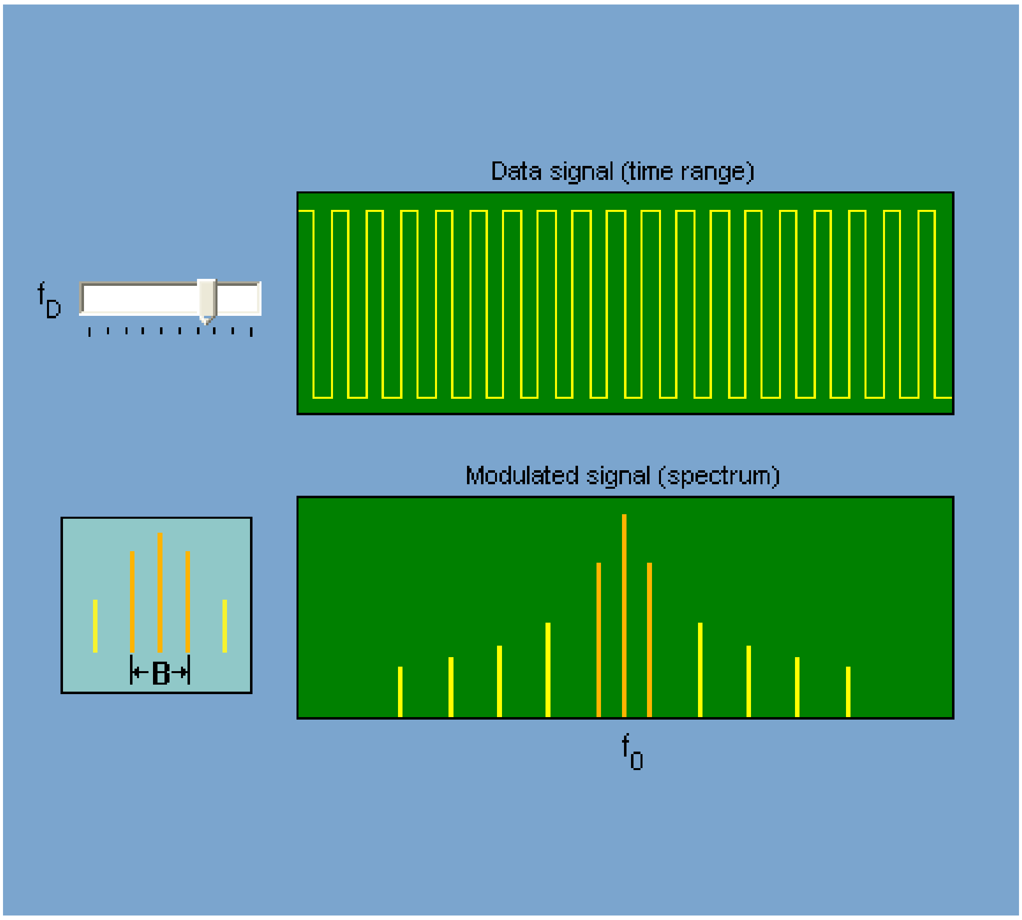

SQ format generates a square-wave signal with a pulse width of 800 µs (upper curve), whereby the pulse width corresponds to the bit width. There are exactly eight oscillations of the carrier signal for each pulse (lower curve). The carrier signal thus has a frequency of $f_0$ = 10 kHz.

### 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

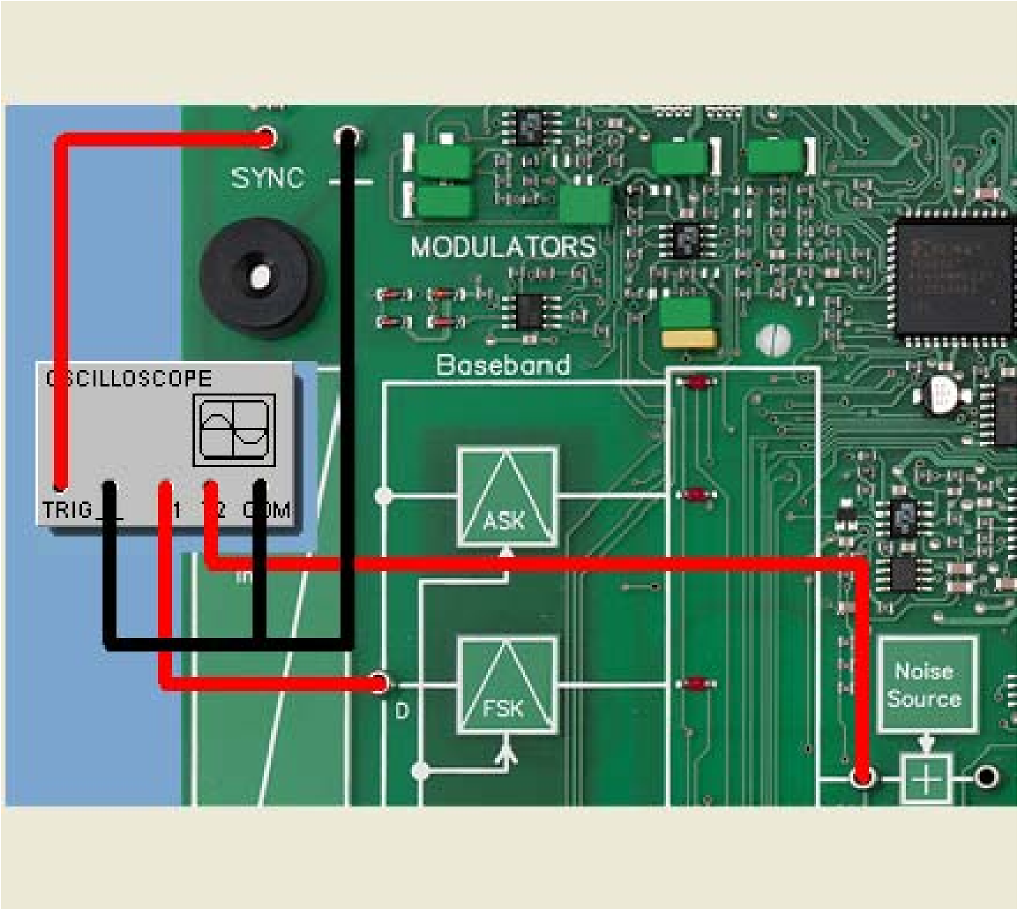
$$B = 2 \cdot f_D.$$

In practice a value of 1.4x is generally used.

[1] **Bandwidth**

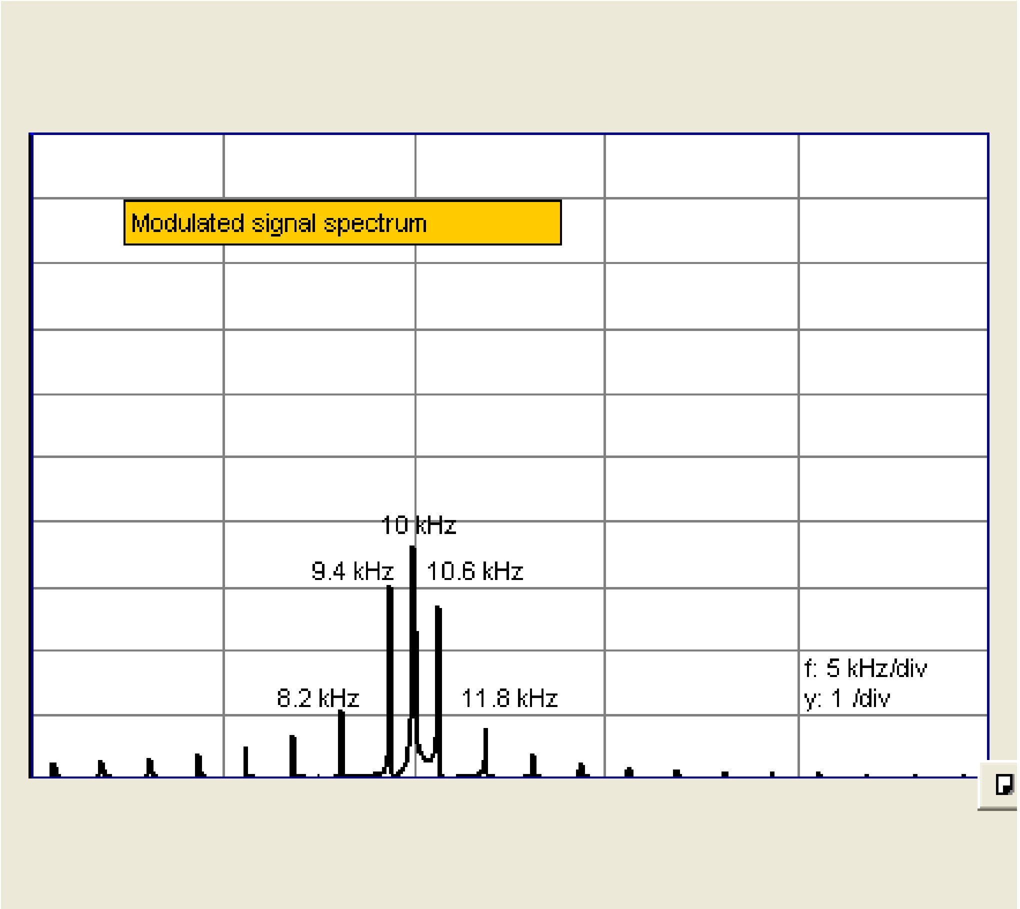
The bandwidth B indicates the width of the frequency range occupied by the modulated signal. The less the bandwidth of a signal, the more signals can be sent side-by-side within a certain frequency range with no overlap.

### 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 .

### 3.7 Result

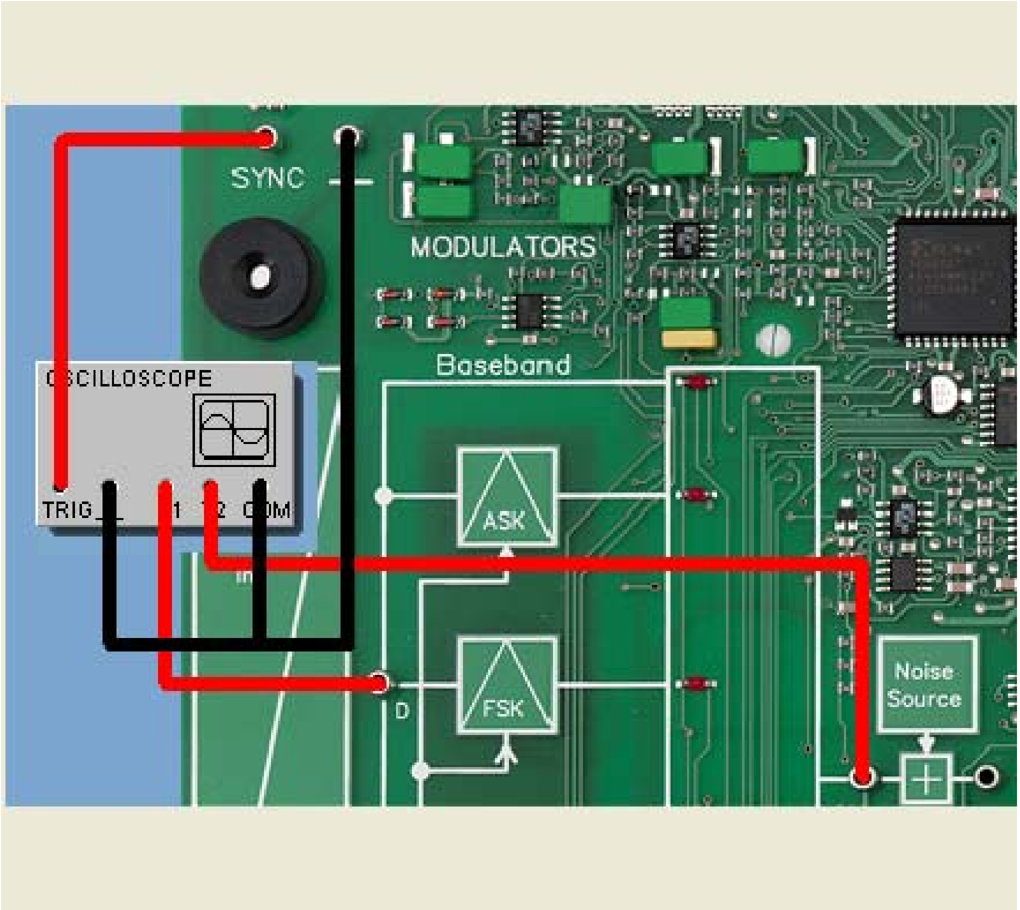



The spectrum of the data signal is shifted by the carrier frequency $f_0$; the individual spectral lines appear mirrored left and right of the carrier. At $f_0$ = 10 kHz the original data signal DC component thus appears, whereas the side-bands occur at the frequencies

$f_n = f_0 \pm (2n+1) \cdot f_D$, $n = 0, 1, 2...$

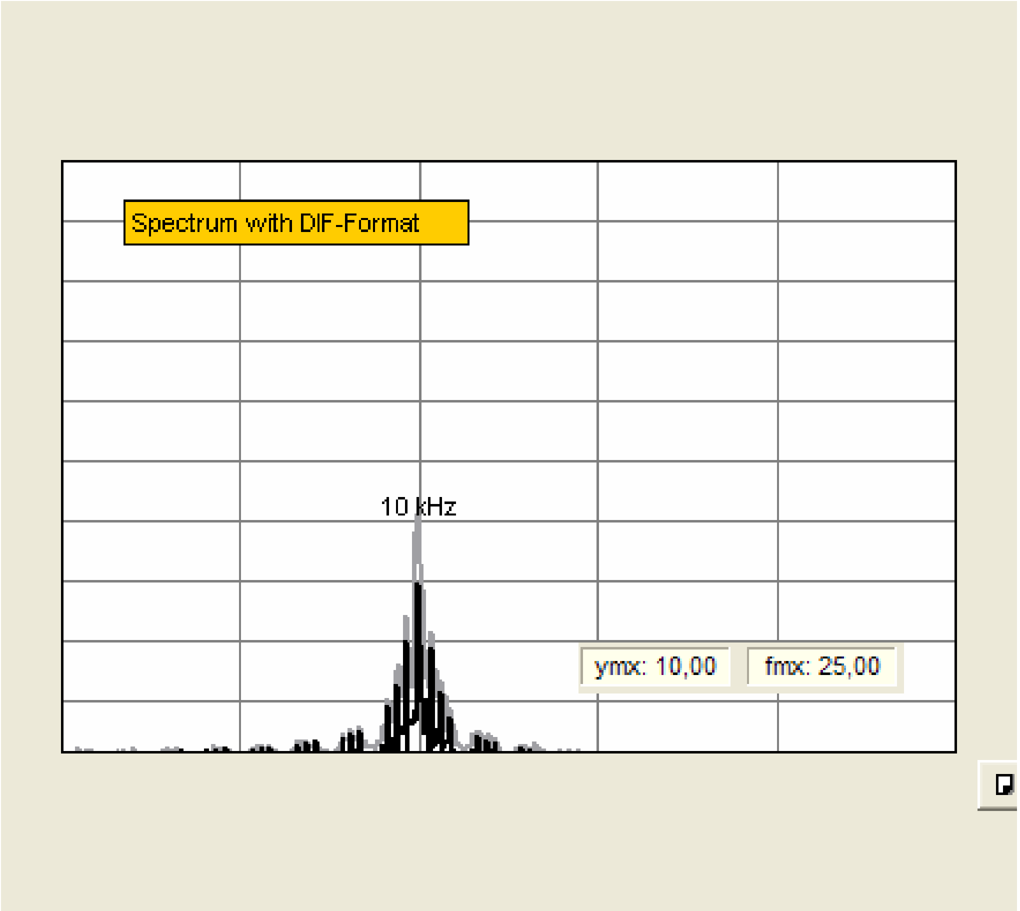
The frequency of the data signal is therefore $f_D$ = 600 Hz.

### 3.8 Experiment: Measuring the ASK spectrum (NRZ/DIF-Format)



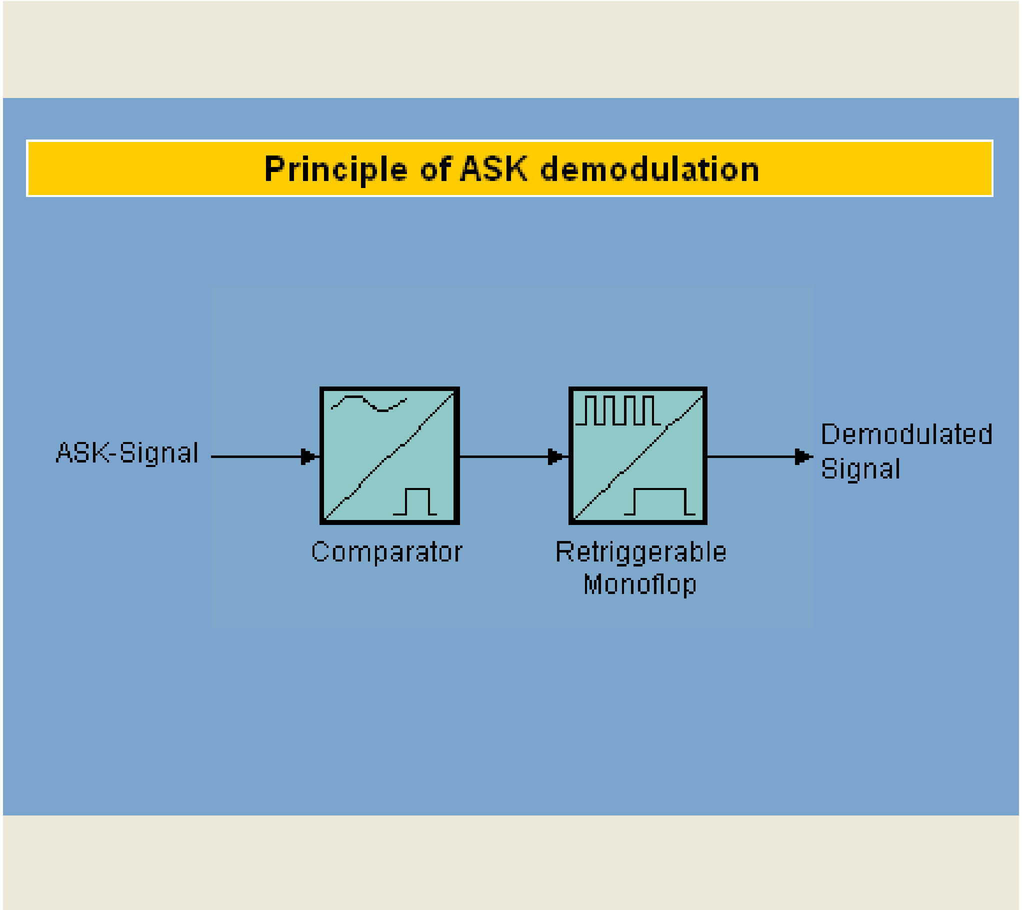

In the following experiment you will again study the amplitude spectrum of the modulated signal with amplitude shift keying, but now continuously different data in NRA or DIFF format will be sent as the data signal. The COM3LAB Spectrum Analyzer will again be used to determine the spectrum

### 3.9 Result




As in the case of square-wave modulation, a line spectrum (in this case due to the ‚MaxHold' function as an overlay of several individual spectra) is formed around the carrier frequency $f_0$ = 10 kHz. The resolution of the spectrum analyzer is insufficient however to separate the individual lines. The structure of the spectrum (particularly the envelope) corresponds rather exactly with that of the spectrum for square-wave modulation, so that the results obtained there can be qualitatively assumed for more general data signals.

### 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.

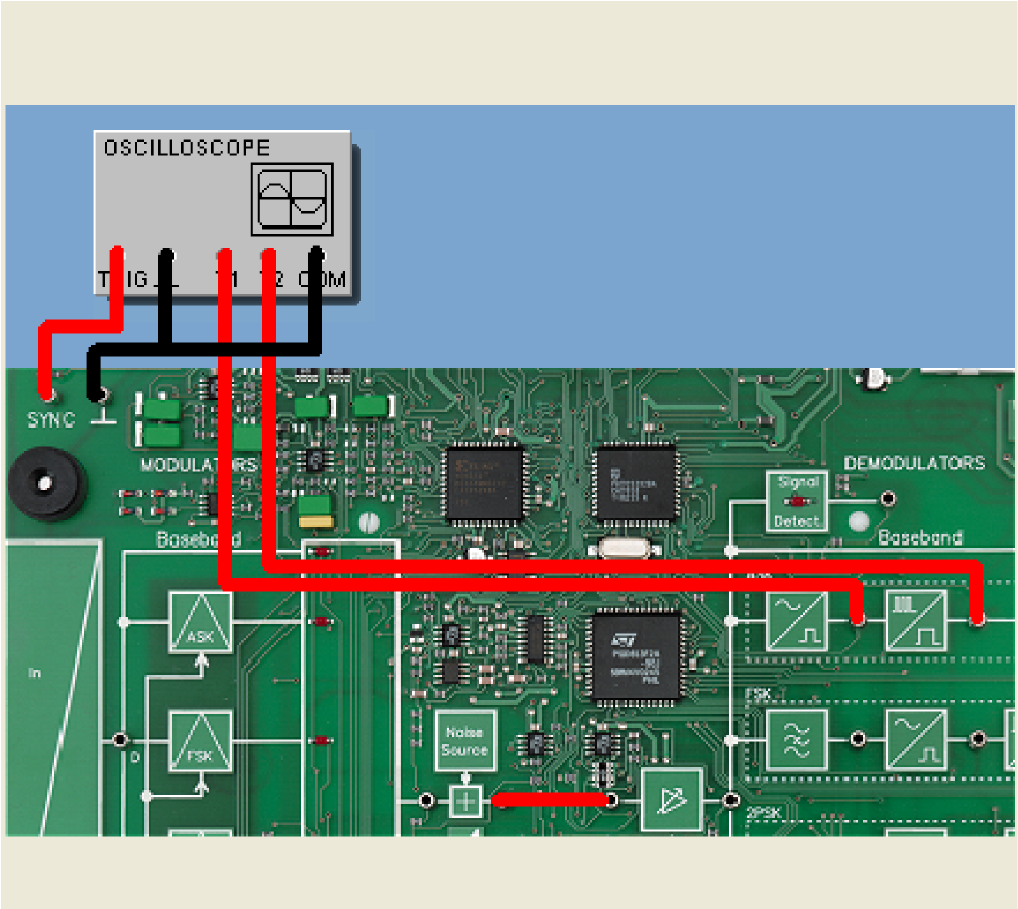
[1] **Demodulator**

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**

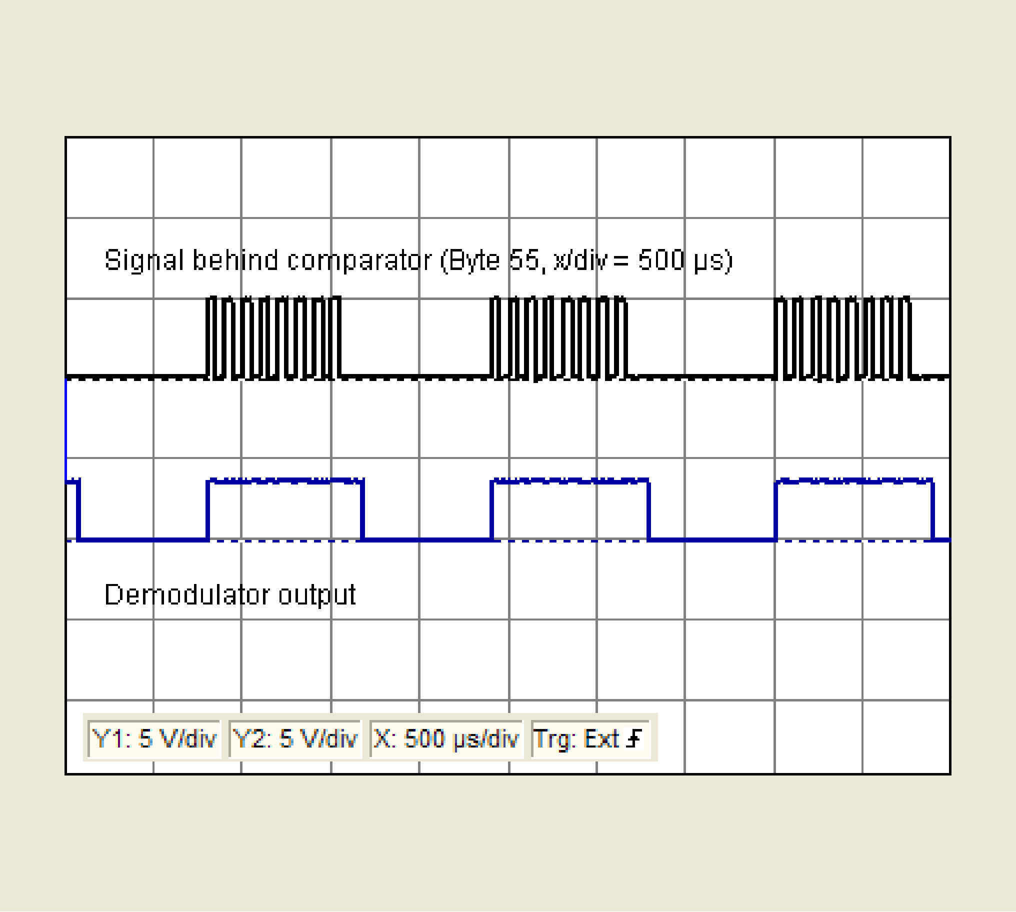
Envelope curve demodulation is a non-synchronous demodulation which does not need explicit provision of the phase-correct carrier signal. In a synchronous demodulator (coherent detector) the phase-synchronous carrier is required. Synchronous demodulators are characterized by low distortion as compared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

**3.12 Result**




The ASK-modulated signal consists - as previous experiments have shown - consists of an amplitude of 0 for a bit at logical 0 and eight sinus oscillations for a bit of logical 1. Behind the comparator there is thus a sequence of eight pulses at TTL level for a bit with logical 1. The re-triggerable monoflop forms the original data bit from these individual pulses.

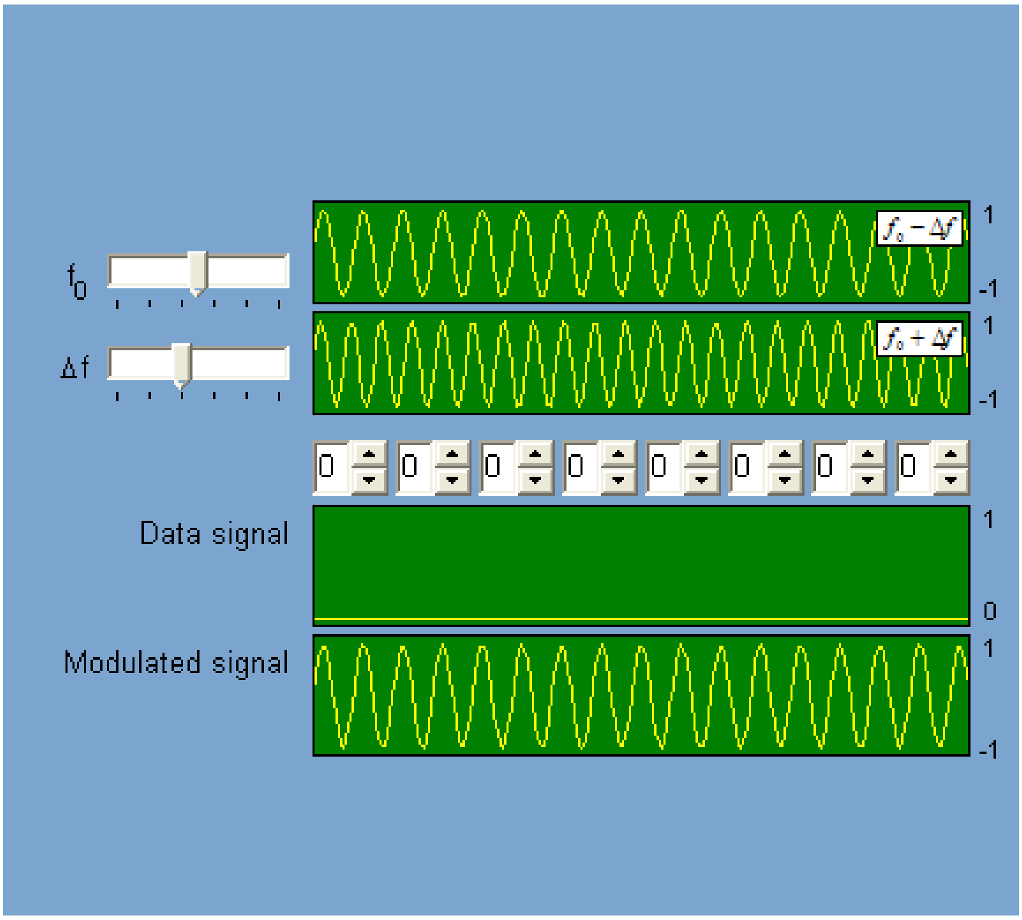
### 3.13 Summary

On the right side you will see a summary of the material covered in this chapter.

**Summary of this chapter**

- In ASK a sinusoidal carrier signal having frequency $f_0$ depending on the data signal is turned on or off.
- In the frequency band ASK causes a shift of the spectrum by the amount of the carrier frequency $f_0$.
- The bandwidth requirement for ASK and a square-wave data signal corresponds to double the data signal frequency.
- In general the bandwidth requirement corresponds to the data bit rate, whereby in practice a value of 1.4x is selected.
- COM3LAB uses a comparator with retriggerable monoflop to demodulate the ASK signal.

### 4.1 Time function




In Frequency Shift Keying (FSK[1]) depending on the data signal the shift is made between two frequencies $f_0 - \Delta f$ (data bit is logical 0) and $f_0 + \Delta f$ (data bit is logical 1). The frequency $f_0$ is termed the center frequency[2], the frequency $\Delta f$ 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.

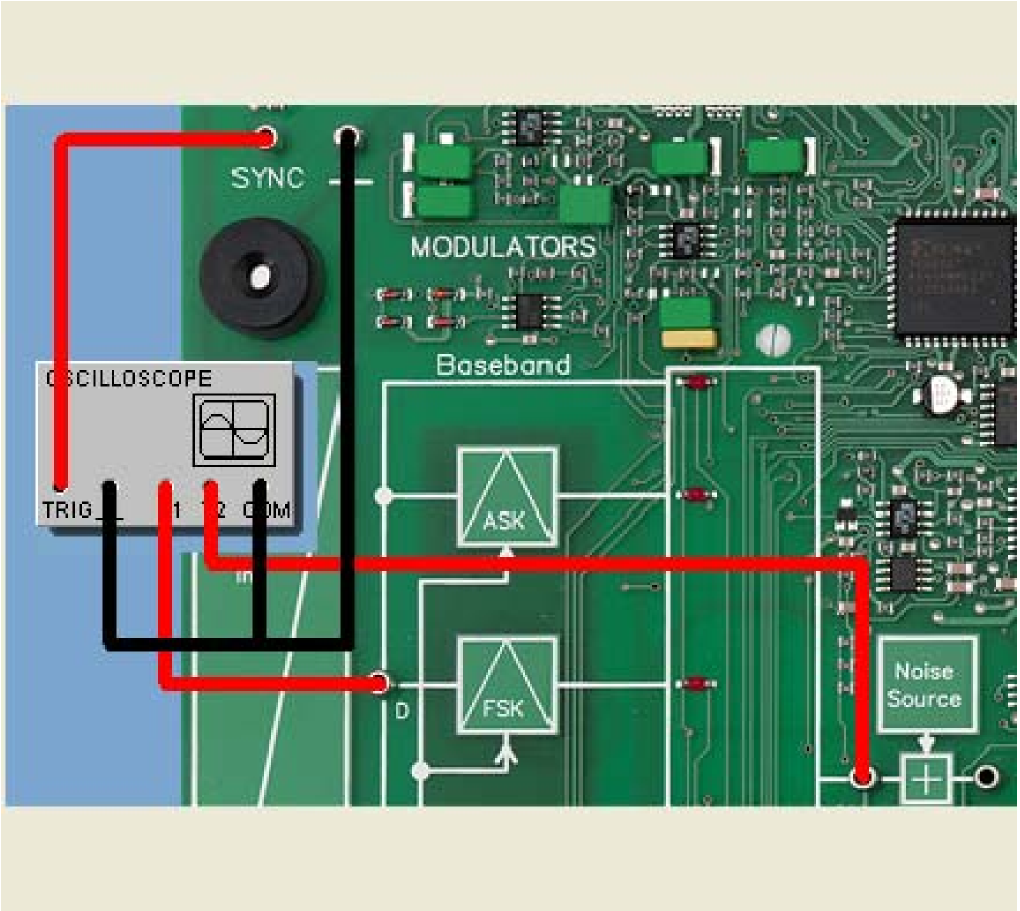
2 **Center frequency**

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**

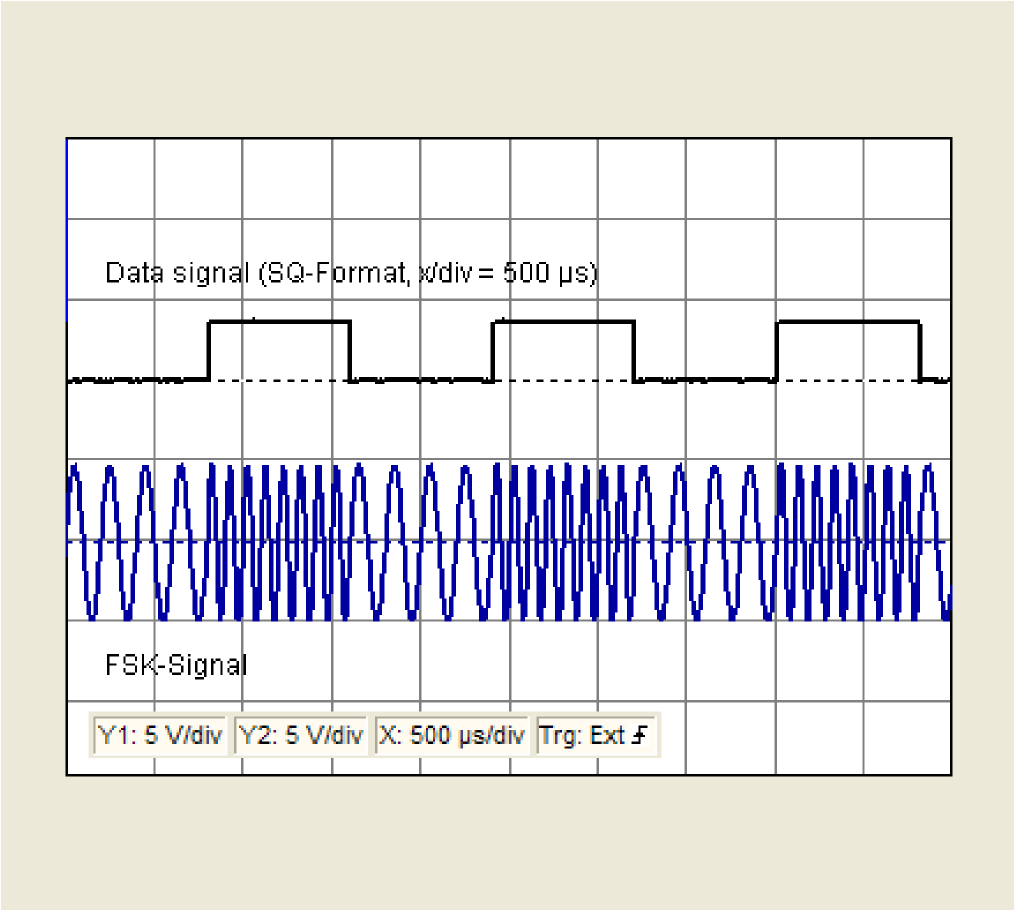
The frequency deviation $\Delta f$ indicates by what value the two characteristic frequencies used in frequency shift keying (FSK) deviate from the center frequency $f_0$.

### 4.2 Experiment: Observing FSK on the oscilloscope



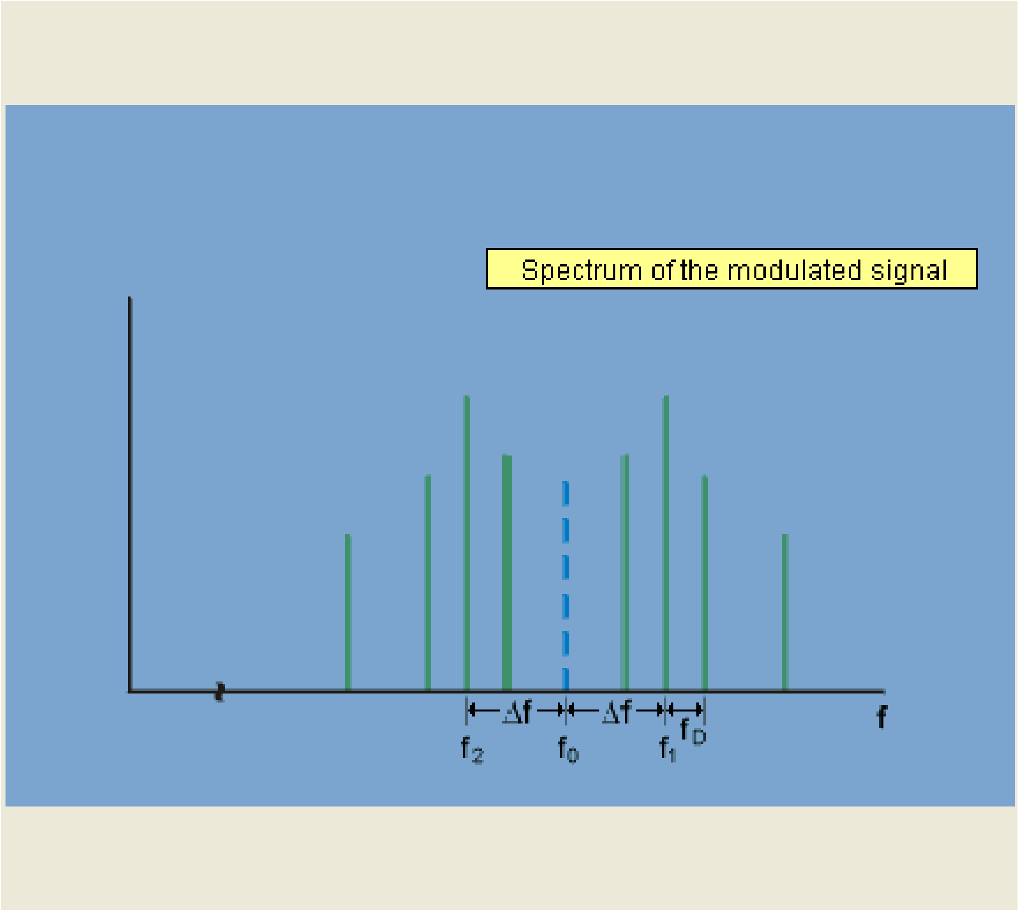

In the following experiment we will first study the modulated signal in frequency shift keying. Periodically a constant data byte will be sent as the data signal and modulated on to the sinusoidal carrier signal. The center frequency and frequency deviation can then be determined from the signals.

### 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**

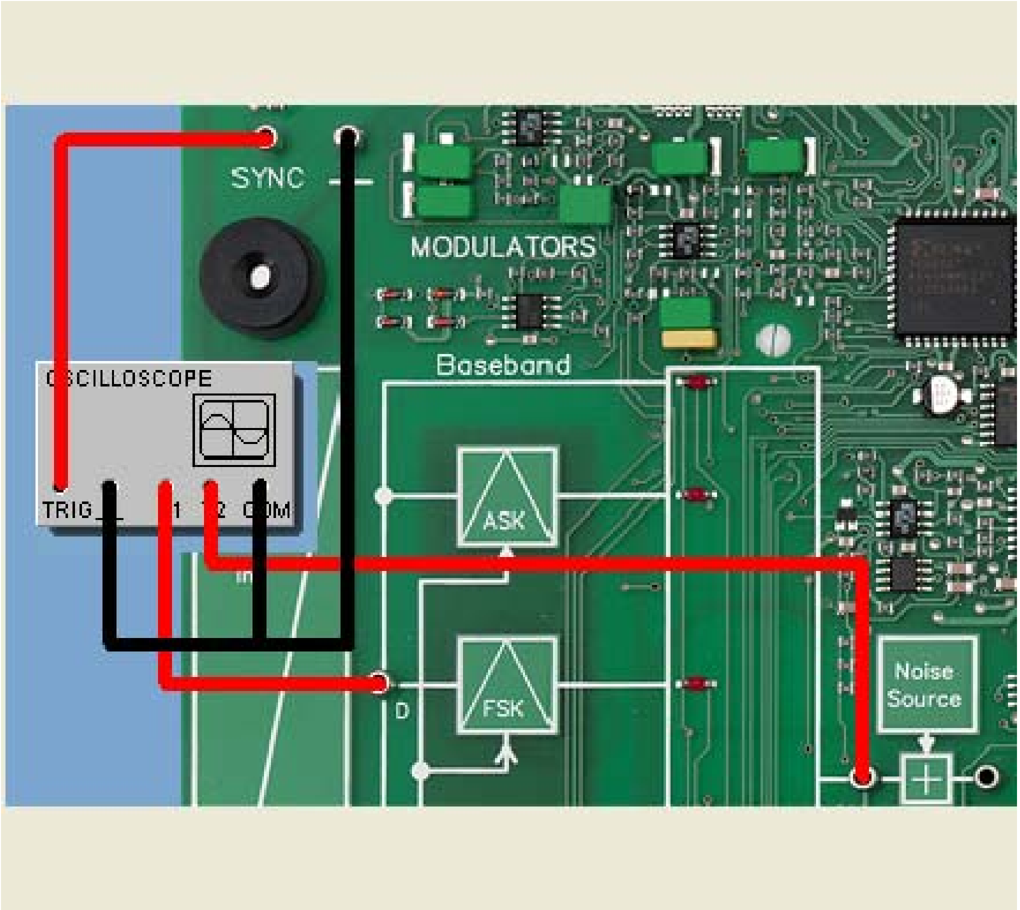



The frequency-shifted signal can be interpreted as the combination of two amplitude-shifted signals having frequencies

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

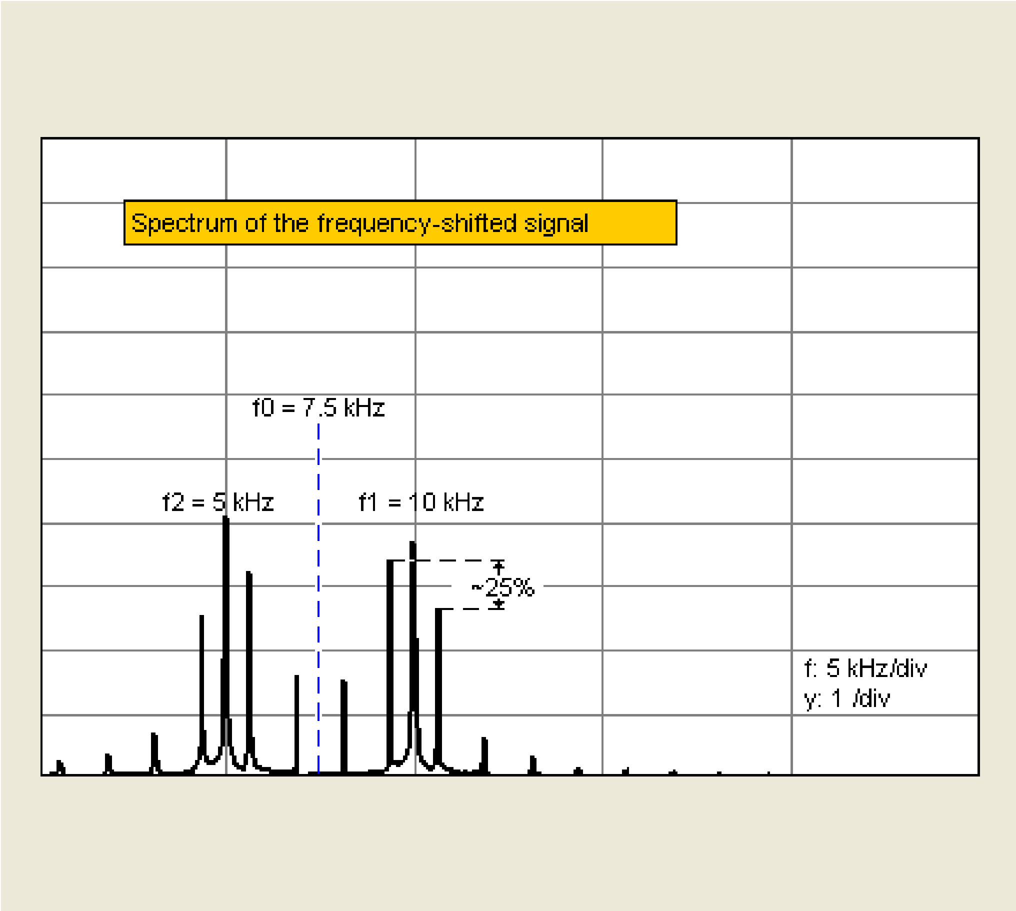
The required bandwidth is therefore significantly greater than in the case of Amplitude Shift Keying. TO reduce the bandwidth the data signal is therefore usually low-pass filtered first. The graphic at right shows the spectrum of the FSK signal with a square-wave data signal having frequency $f_D$.

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



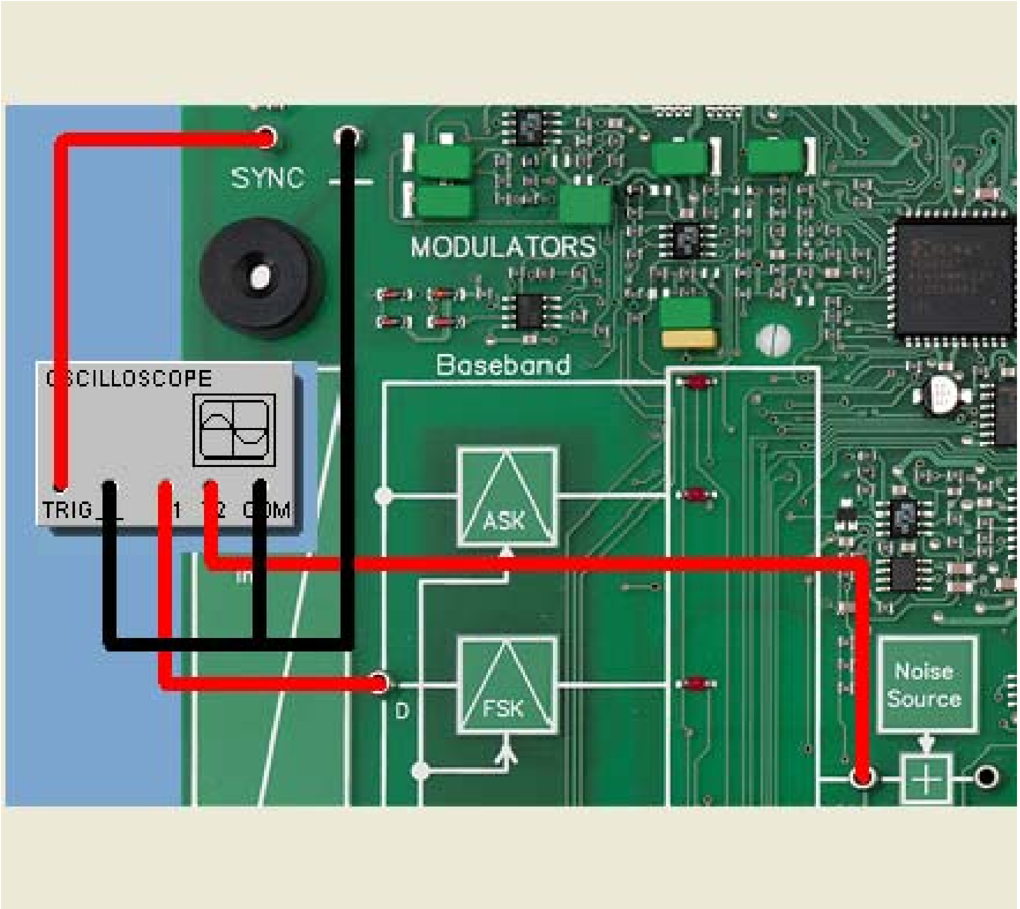

In the following experiment we will investigate the amplitude spectrum of the modulated signal with Frequency Shift Keying. A periodic square-wave signal with a DC component and frequency $f_D$ = 600 Hz will again serve as the data signal.

### 4.6 Result



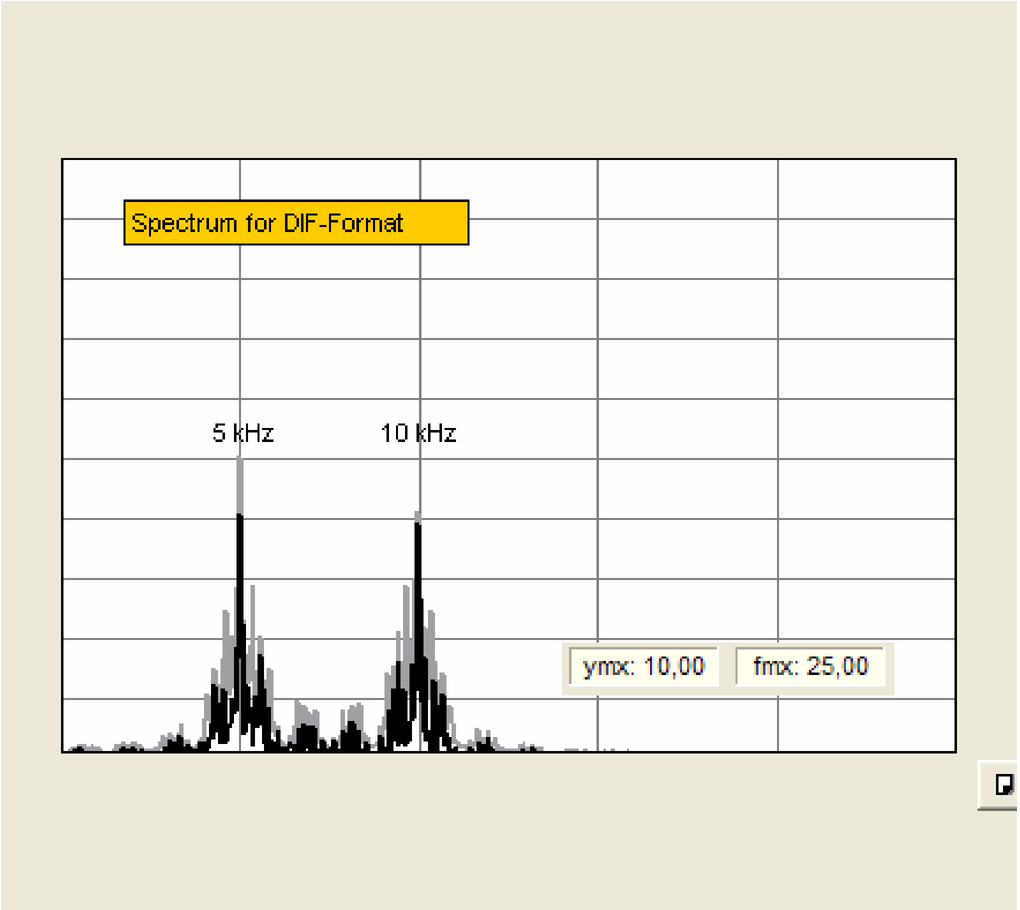

An amplitude spectrum symmetrical with respect to the center frequency of $f_0$ = 7.5 kHz results, whereby the characteristic frequencies are at $f_1$ = 10 kHz and $f_2$ = 5 kHz. To the left and right of the characteristic frequencies are side-bands whose distances from the characteristic frequencies are each odd multiples of the data signal frequency $f_D$. Both "partial spectra' left and right of the center frequency are non-symmetrical with respect to the amplitudes of the side-bands.

### 4.7 Experiment: Measuring the FSK spectrum (NRZ/DIF-Format)



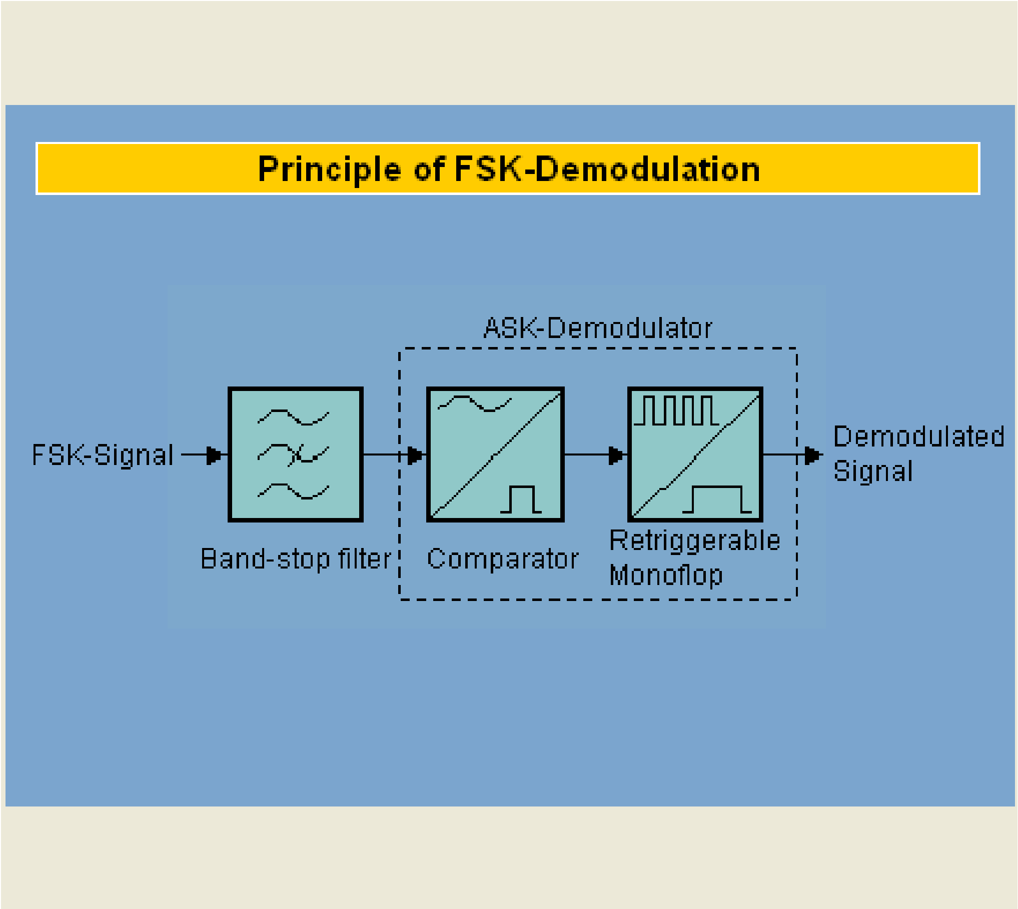

In the following experiment the amplitude spectrum of the modulated signal in Frequency Shift Keying will be studied, but now continuously varying data will be sent as the data signal in NRZ and DIFF format. The COM3LAB Spectrum Analyzer is again used to determine the spectrum.

#### 4.8 Result




As in the case of square-wave modulation, a line spectrum (in this case due to the ‚MaxHold' function as an overlay of several individual spectra) is formed around the two center frequencies $f_1$ and $f_2$. The resolution of the spectrum analyzer is insufficient however to separate the individual lines. The structure of the spectrum (particularly the envelope) corresponds rather exactly with that of the spectrum for square-wave modulation, so that the results obtained there can be qualitatively assumed for more general data signals.

### 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.

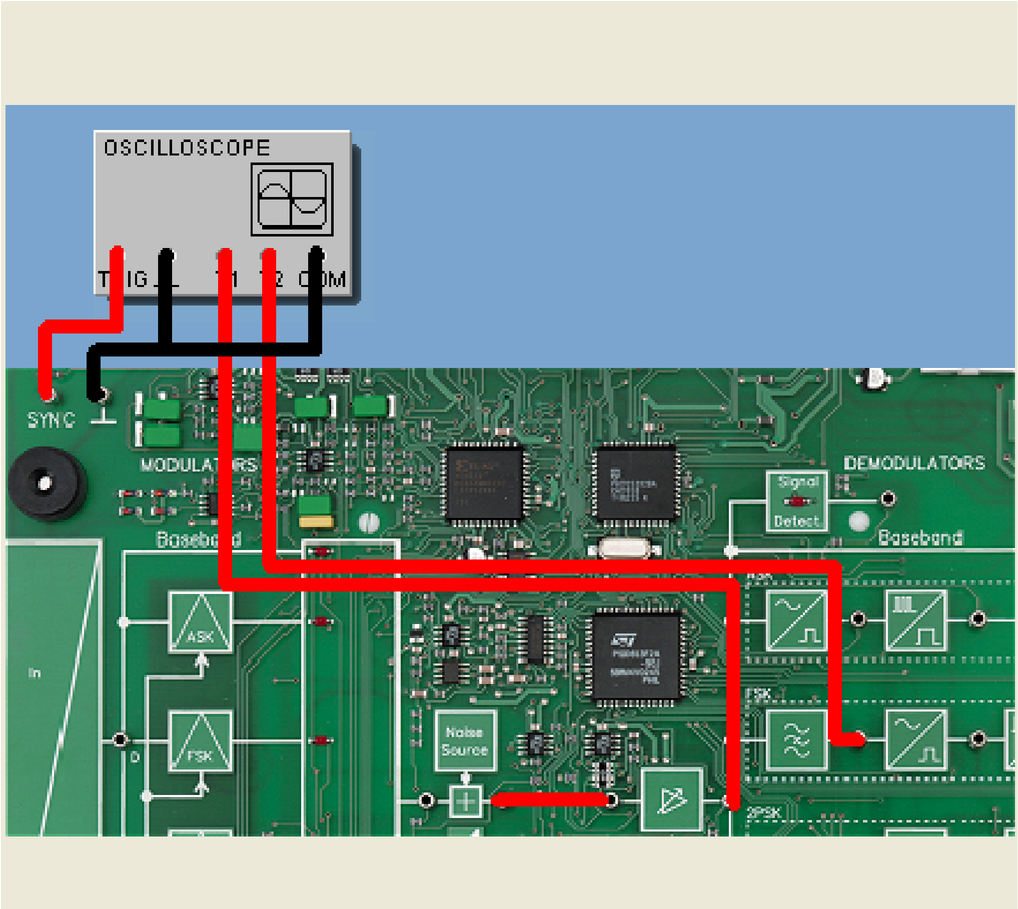
1 **Edge discriminator**

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**

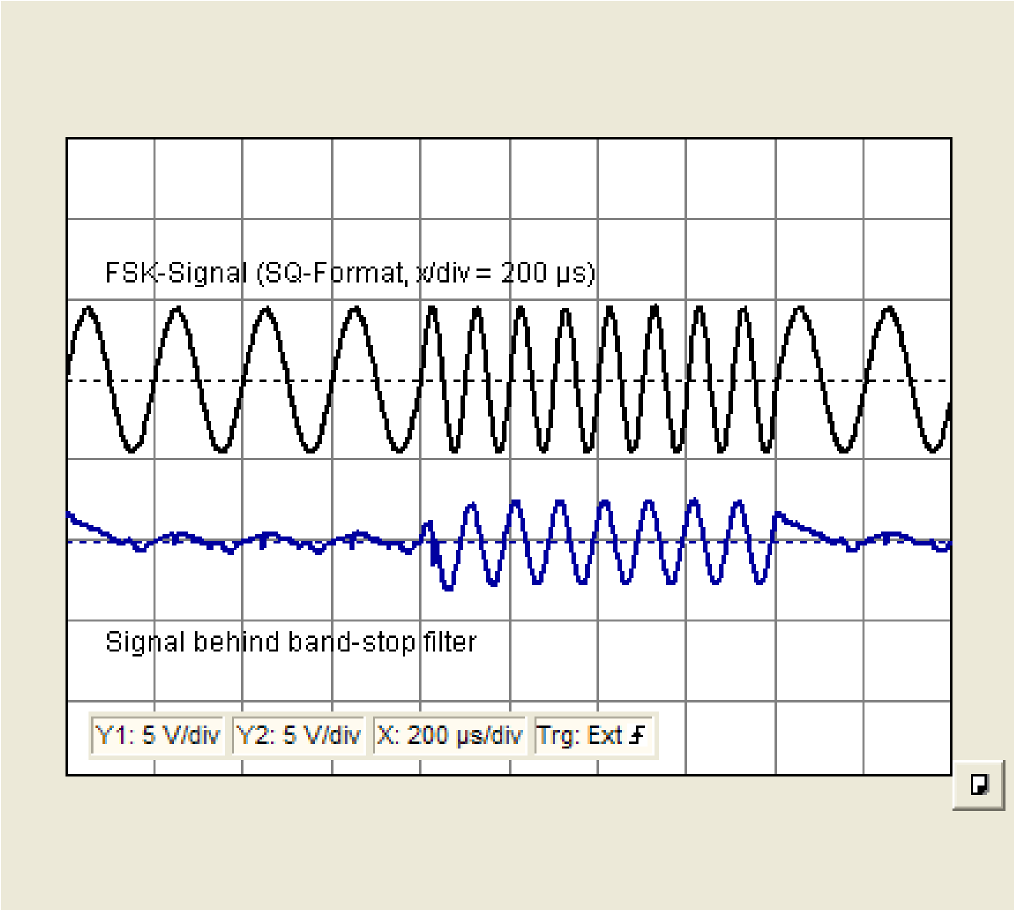
Non-synchronous demodulation differs from synchronous modulation in that the receiver does not need the phase- and frequency-correct carrier (example: envelope demodulator).

#### 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.

### 4.11 Result




You can clearly see the effect of the band-stop filter: Whereas the upper frequency is only weakly damped, the amplitude of the lower frequency drops considerably. The band-stop filter also causes a phase shift in the signal however. Therefore there is a time delay of approx. 100 µs between the original data signal and the demodulated signal at the output of the FSK demodulator.

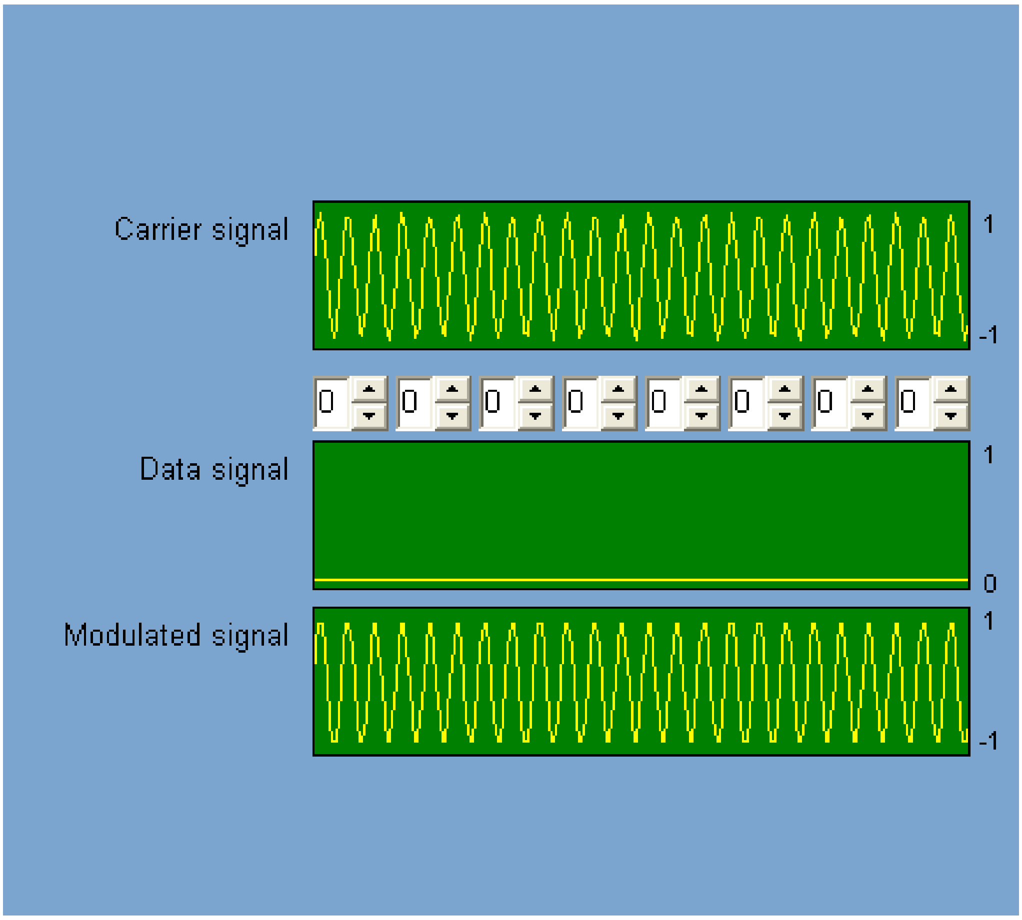
### 4.12 Summary

On the right side you will see a summary of the material covered in this chapter.

**Summary of this chapter**

- In FSK there is a switch between two frequencies, $f_1 = f_0 - \Delta f$ and $f_2 = f_0 + \Delta f$, depending on the data signal.
- The difference $\Delta f$ is referred to as the frequency deviation, $f_0$ is called the center frequency.
- In general, FSK is more noise-immune than ASK.
- The spectrum of FSK is symmetrical with respect to $f_0$ and more extended the greater the frequency deviation is.
- For FSK demodulation, COM3LAB first converts the FSK signal into an ASK signal, which is then fed to an ASK demodulator.

### 5.1 Time function

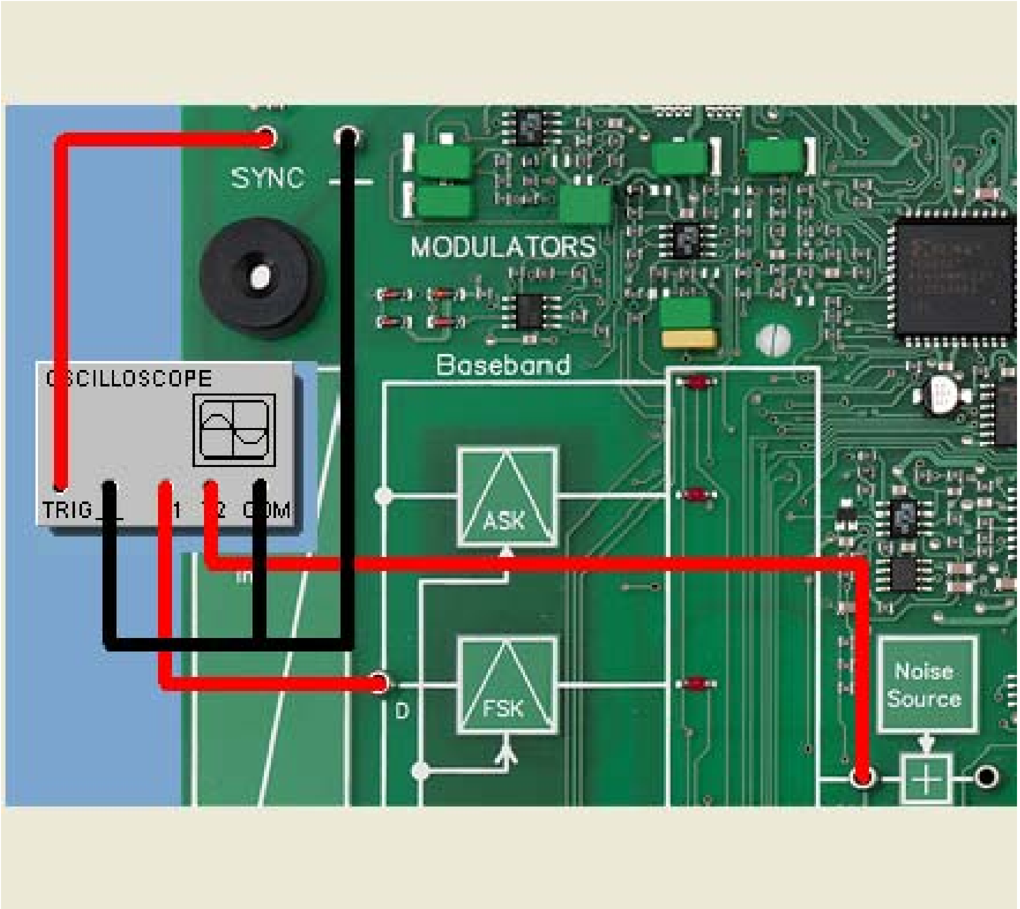



In two-phase shift keying (2PSK[1]) a sinusoidal carrier signal with frequency $f_0$ is toggled between two different phase positions depending on the data signal. Since disturbances generally affect only the amplitude of the signal and not its phase position, Phase Shift Keying is very noise-immune.

1 **PSK**

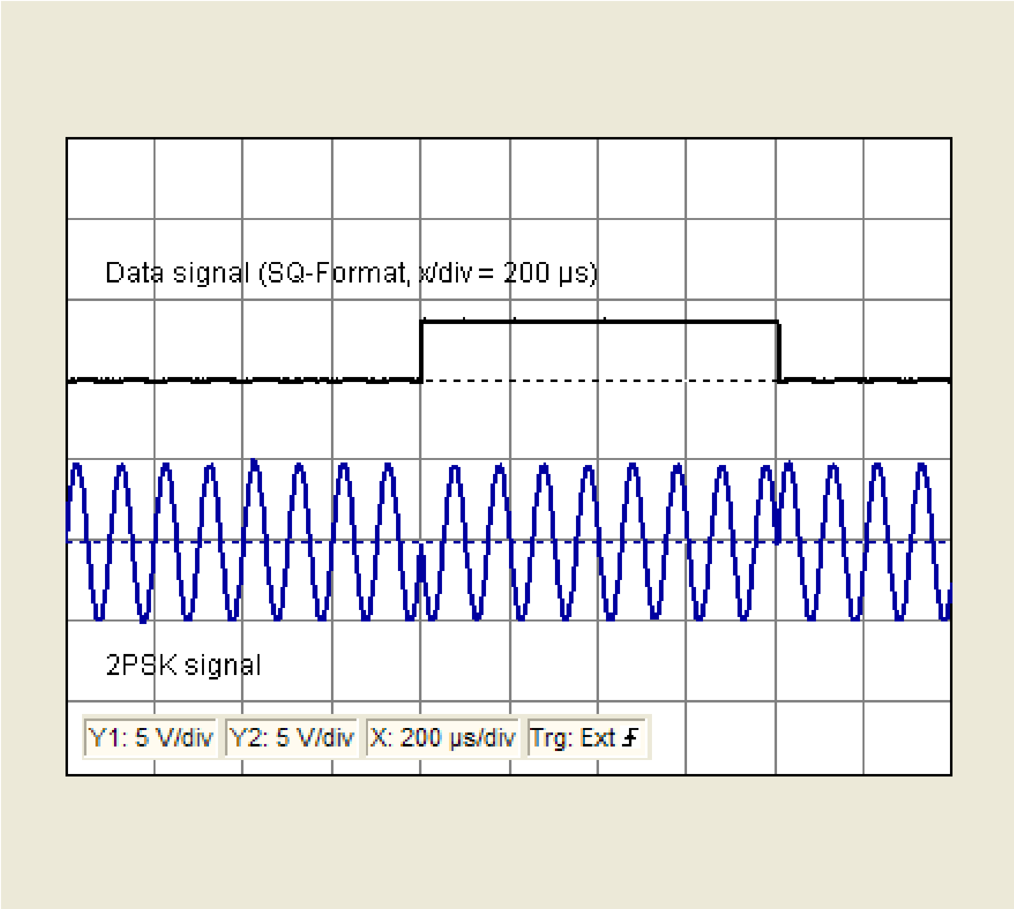
*Phase Shift Keying* is a modulation procedure whereby the phase position of a sinusoidal carrier signal is changed depending on the level of the (digital) modulation signal. In 2PSK two and in 4PSK four different phase positions are toggled. There are also variations with more phase positions.

**5.2 Experiment: Displaying 2PSK on the oscilloscope**



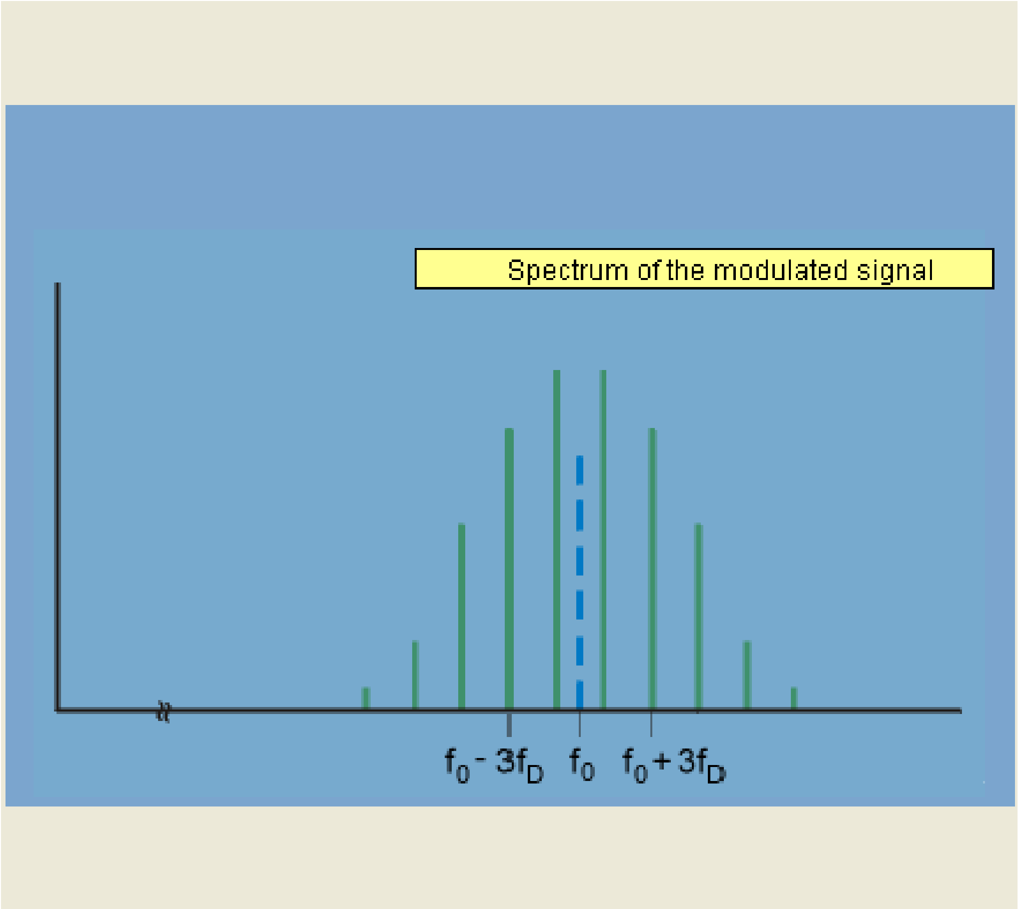

In the following experiment we will first study the modulated signal in two-phase shift keying. A periodic square-wave signal (SQ format) will be sent as the data signal and modulated on to the sinusoidal carrier signal. Both signals will be compared on the oscilloscope. Both the phase positions for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

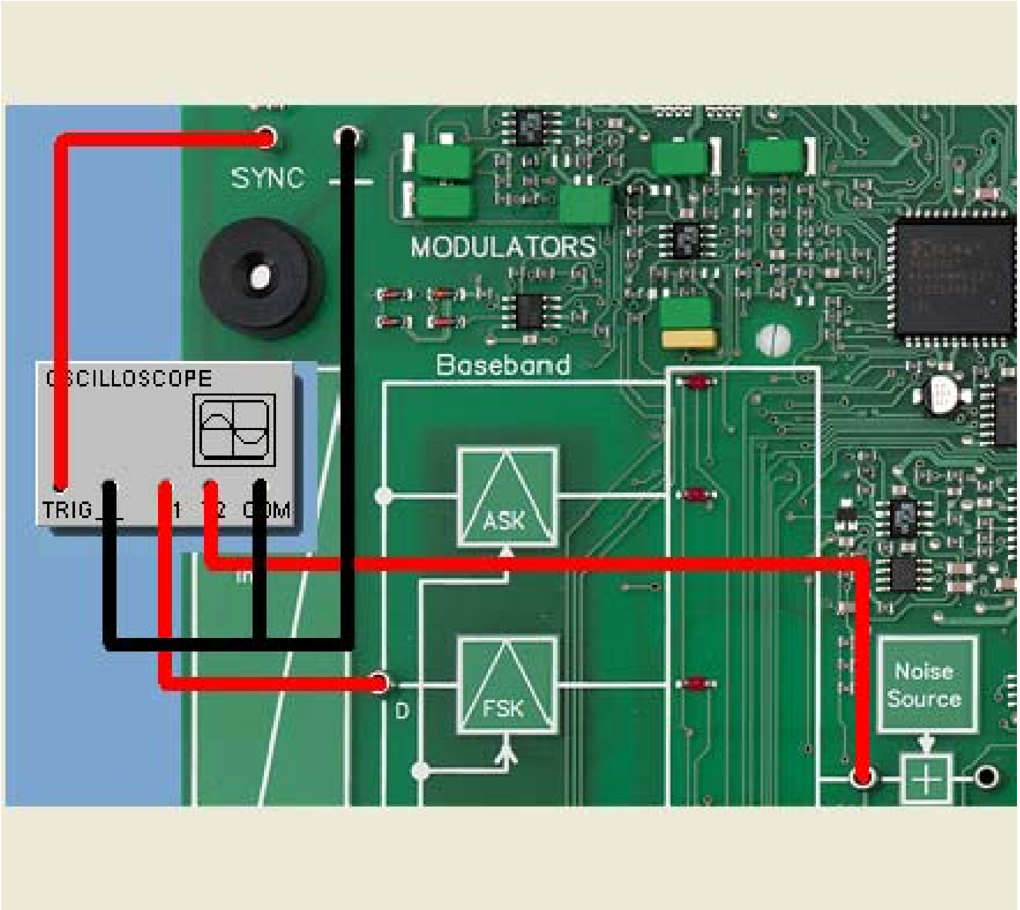



The spectrum of the 2PSK signal corresponds to amplitude modulation with suppressed carrier. The adjacent graphic shows the spectrum for modulation with a square-wave data signal having frequency $f_D$. As in the case of ASK, the minimum required transmission bandwidth is therefore

$B = 2 \cdot f_D$.

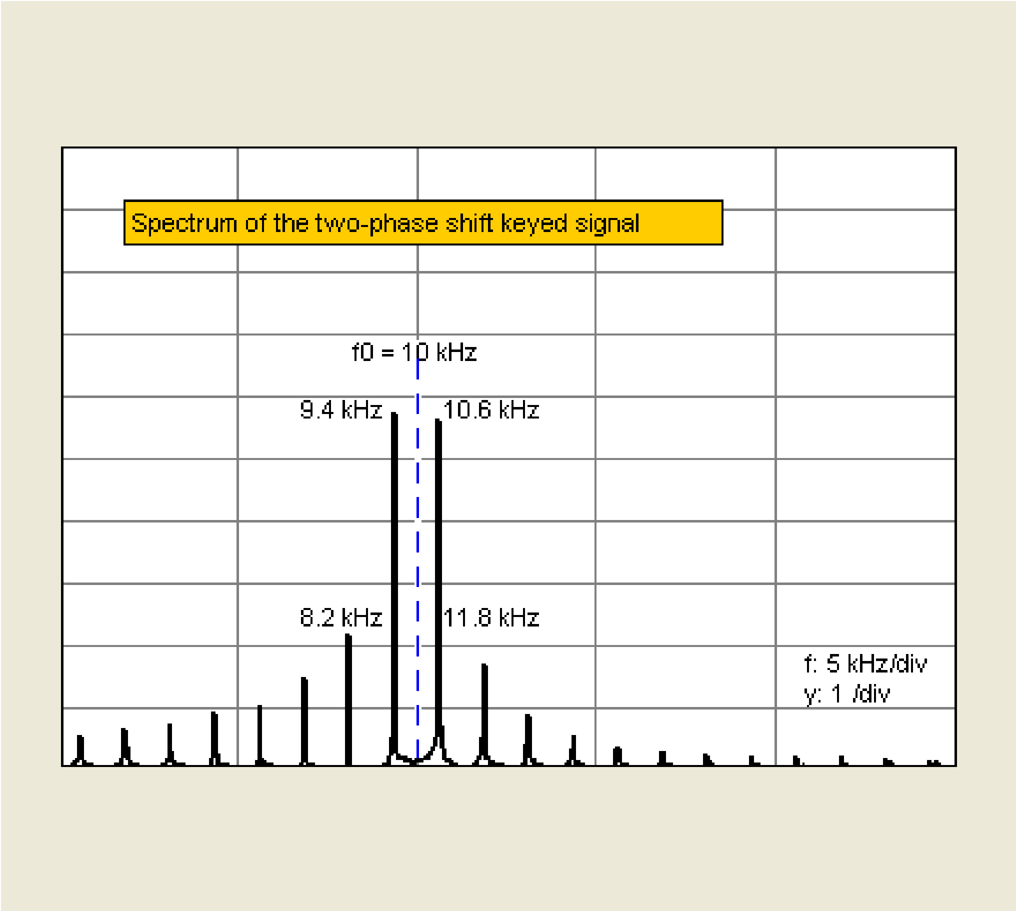
In practice a value of 1.4x is generally used.

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



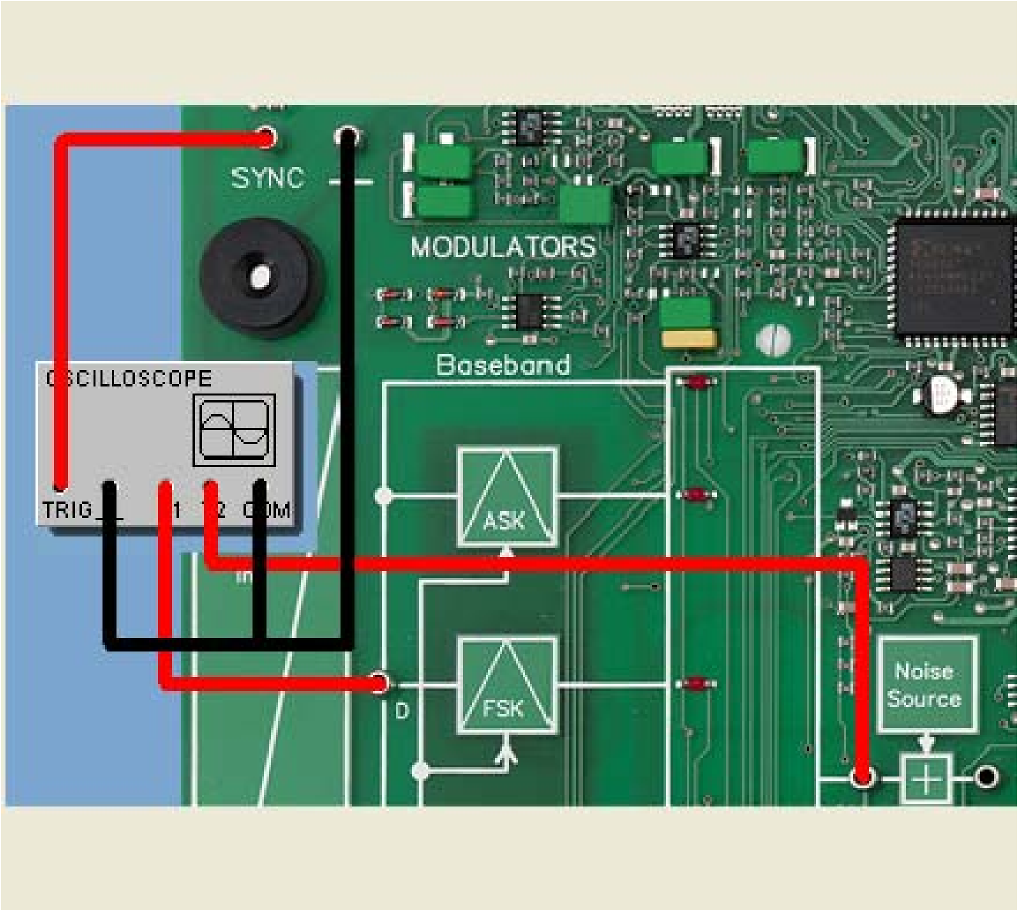

In the following experiment we will study the amplitude spectrum of the modulated signal in two-phase shift keying. As the data signal we will again use a periodic square-wave signal having a DC component (SQ format) and frequency $f_D$ = 600 Hz.

### 5.6 Result



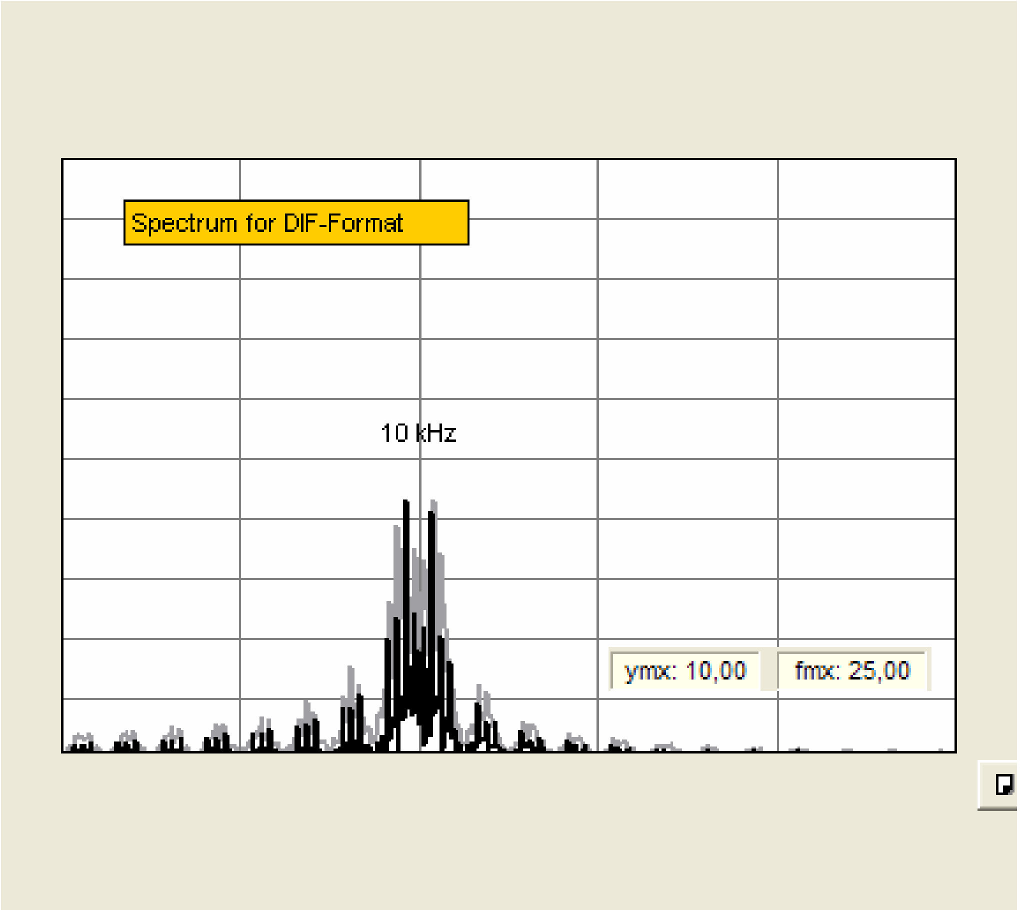

The result is an amplitude spectrum which is symmetrical with respect to the carrier frequency of $f_0$ = 10 kHz, whereby the carrier itself no longer appears in the spectrum. To the left and right of the carrier frequency are side-bands whose separations are each an odd multiple of the data signal frequency $f_D$ and whose amplitude decreases with increasing separation.

### 5.7 Experiment: Measuring the 2PSK spectrum (NRZ/DIF-Format)



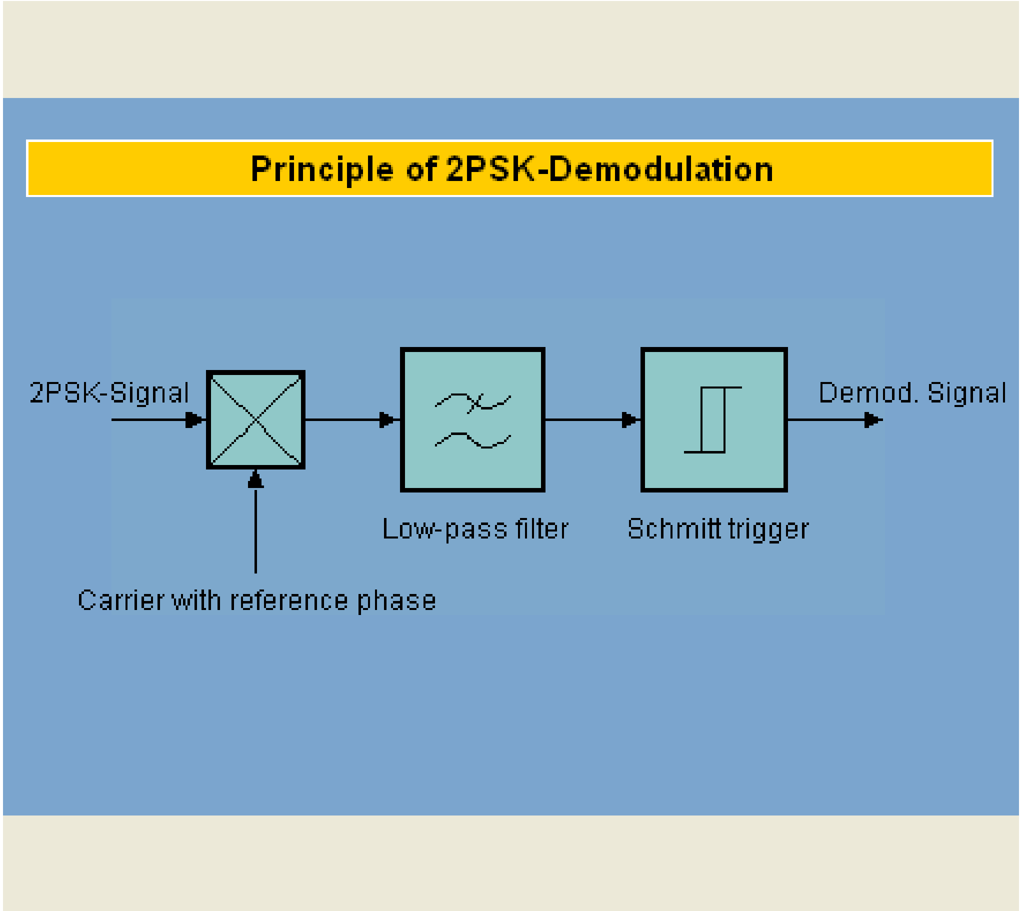

In the following experiment we will again study the modulated signal in two-phase shift keying, whereby the data signal will now consist of continuously varying data in NRZ and DIF format. The COM3LAB Spectrum Analyzer is again used to determine the spectrum.

### 5.8 Result



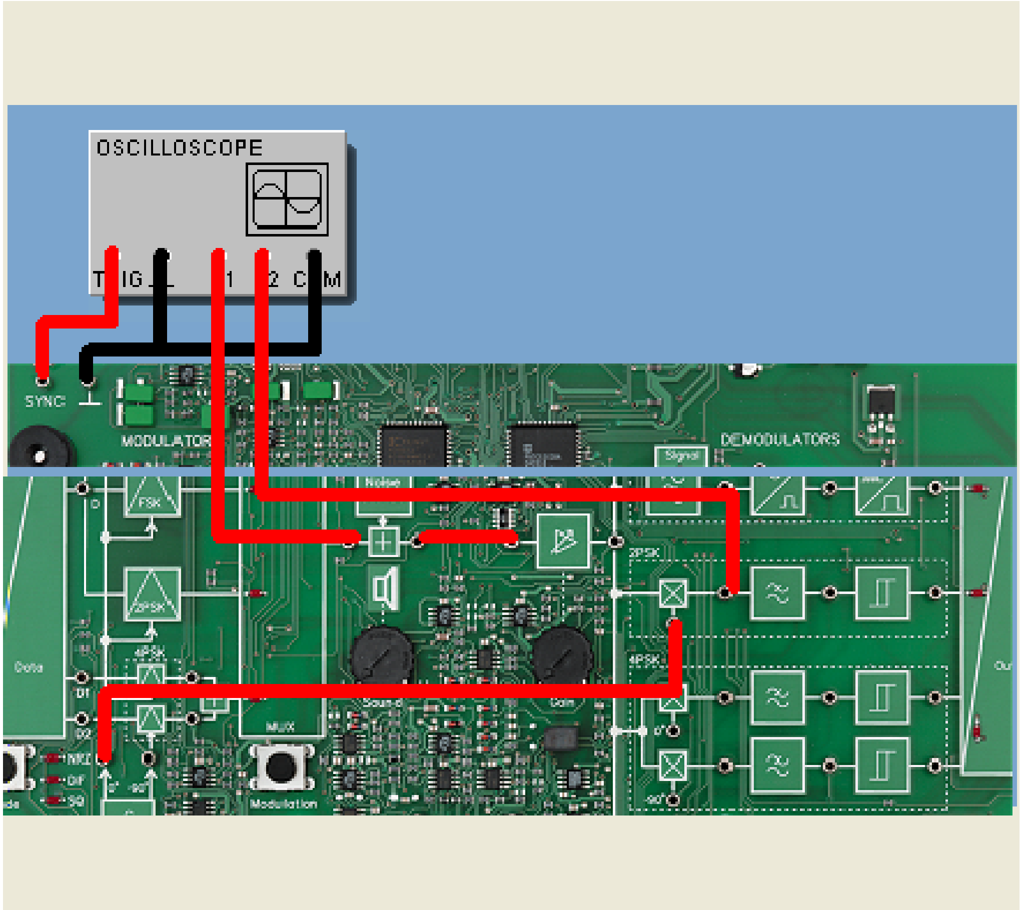

As in the case of square-wave modulation, a line spectrum (in this case due to the ‚MaxHold' function as an overlay of several individual spectra) is formed around the carrier frequency $f_0$ for NRZ and DIFF format. The resolution of the spectrum analyzer is insufficient however to separate the individual lines. The structure of the spectrum (particularly the envelope) corresponds rather exactly with that of the spectrum for square-wave modulation, so that the results obtained there can be qualitatively assumed for more general data signals.

### 5.9 Demodulation



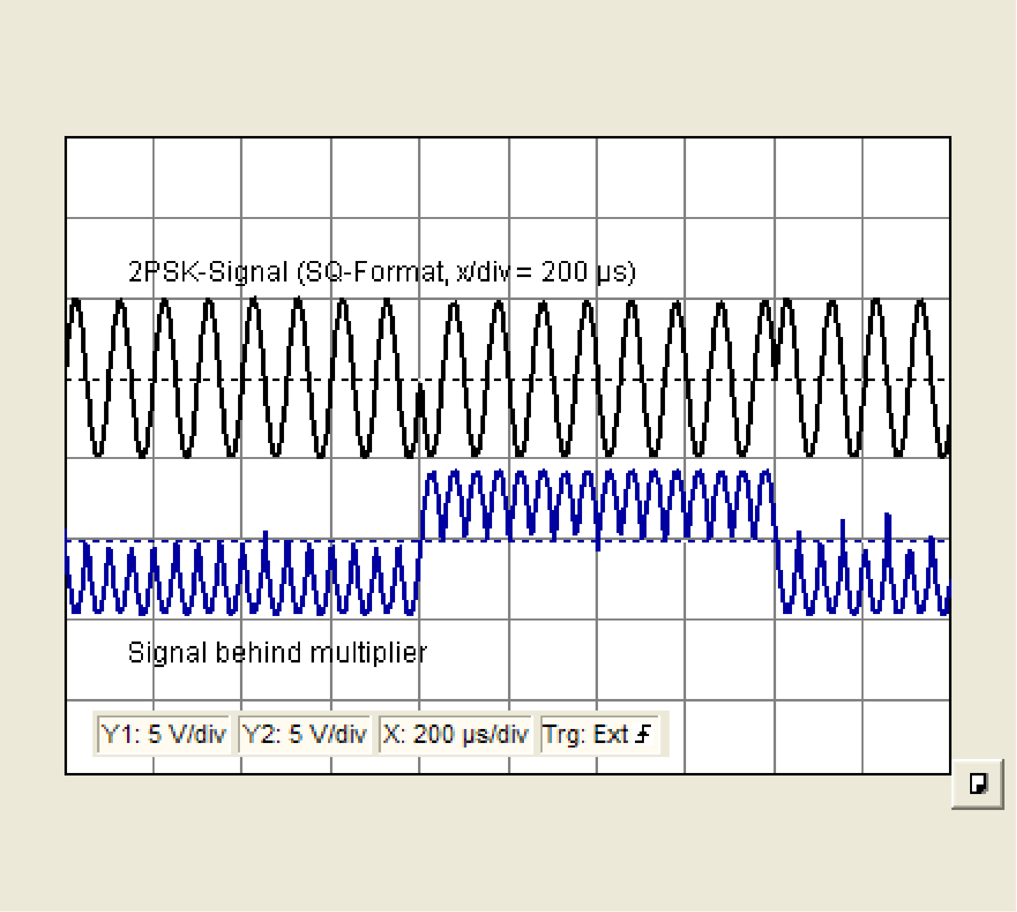

For synchronous demodulation of the 2PSK signal the carrier signal with the reference phase position is required. By multiplying with the 2PSK signal, the result is first a signal with double the carrier frequency whose center value over a bit width varies with the actual data bit. A downstream low-pass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

### 5.10 Experiment: Synchronous demodulation with 2PSK



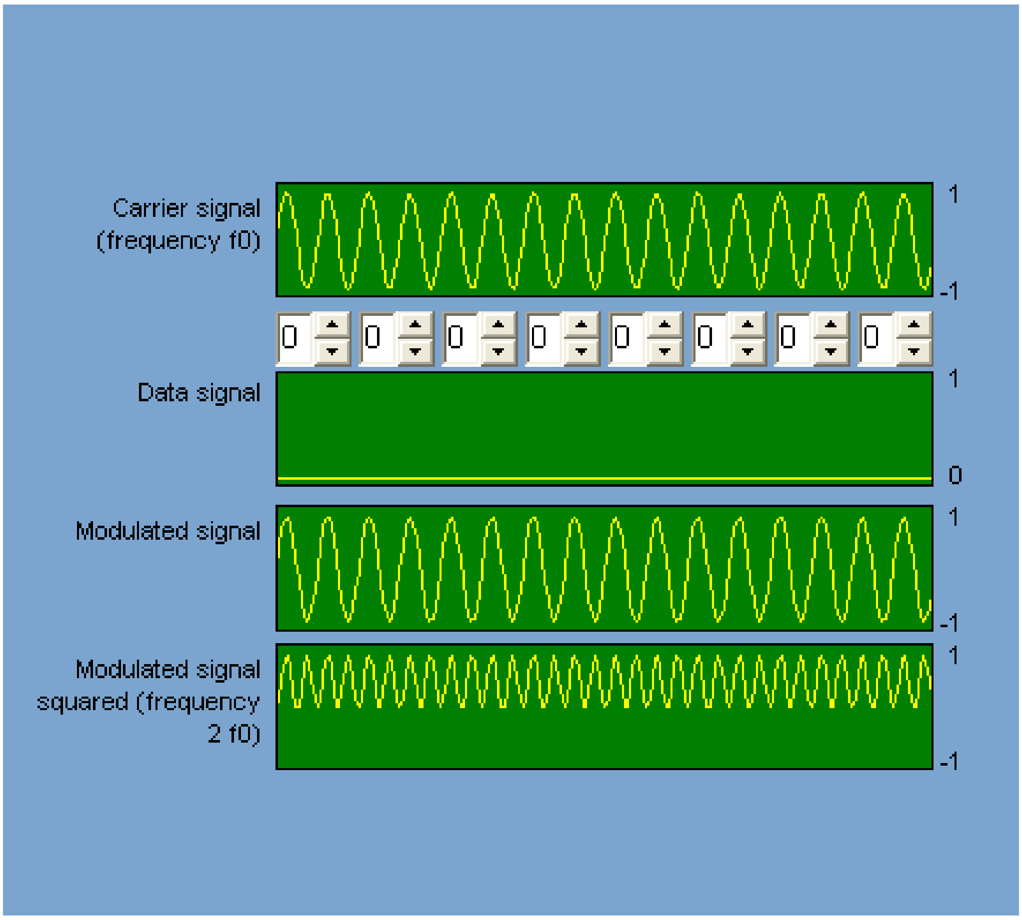

In the following experiment we will investigate in greater detail the demodulation of a 2PSK modulated signal with NRZ formatting. A periodic square-wave signal (SQ format) will be sent and the course of the signal recorded in the various stages of the PSK demodulator. The original data signal and demodulated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

### 5.11 Result



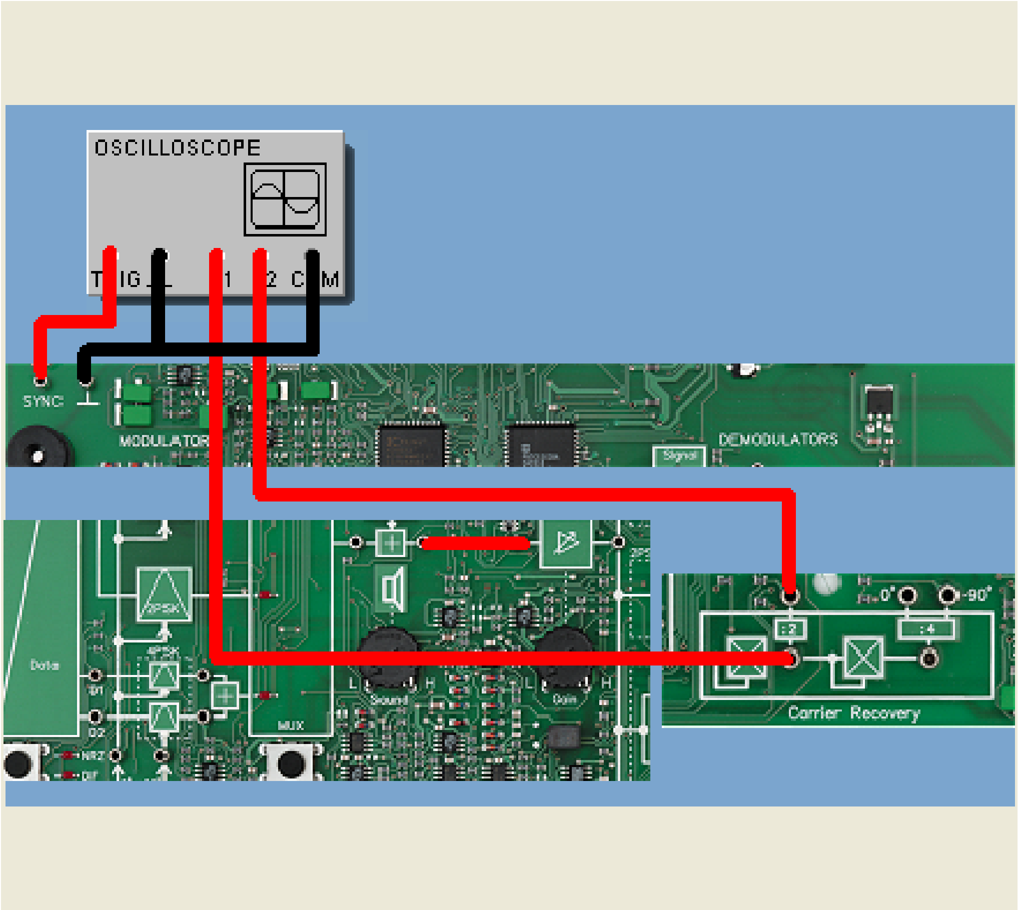

The first thing you notice is the effect of the multiplication by the frequency- and phase-identical carrier signal. The low-pass filter results in a signal with an e-shaped, rising (bit logical 1) or falling (bit logical 0) edge. The Schmitt trigger generates the actual data signal from that, which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

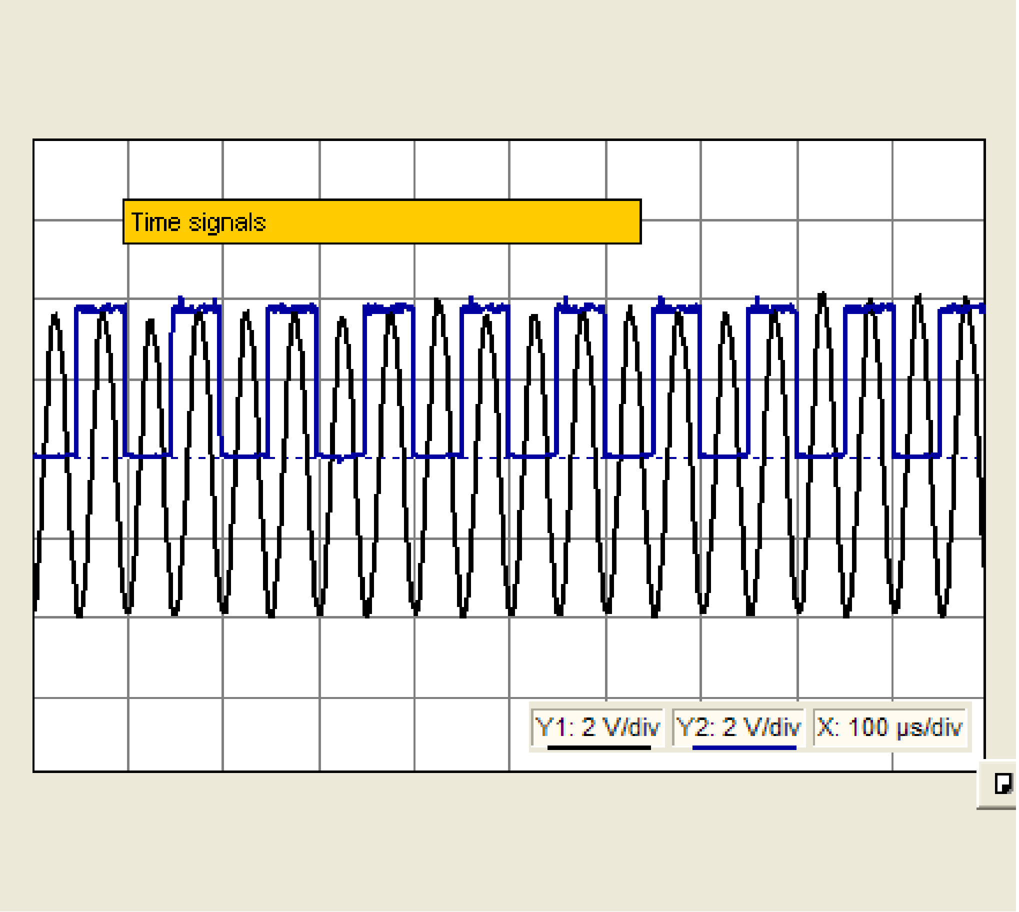
### 5.13 Experiment: Measurements on carrier recovery with 2PSK




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.

### 5.14 Result




Multiplying the 2PSK signal by itself results in a purely sinusoidal signal with a frequency of 2 $f_0$ = 20 kHz, whose DC component is filtered out on the COM3LAB board. The frequency divider forms this signal into a square-wave signal with frequency $f_0$, which due to the square shape also contains harmonics at odd multiples of the carrier frequency, in other words at, 30 kHz, 50 kHz, 70 kHz etc.

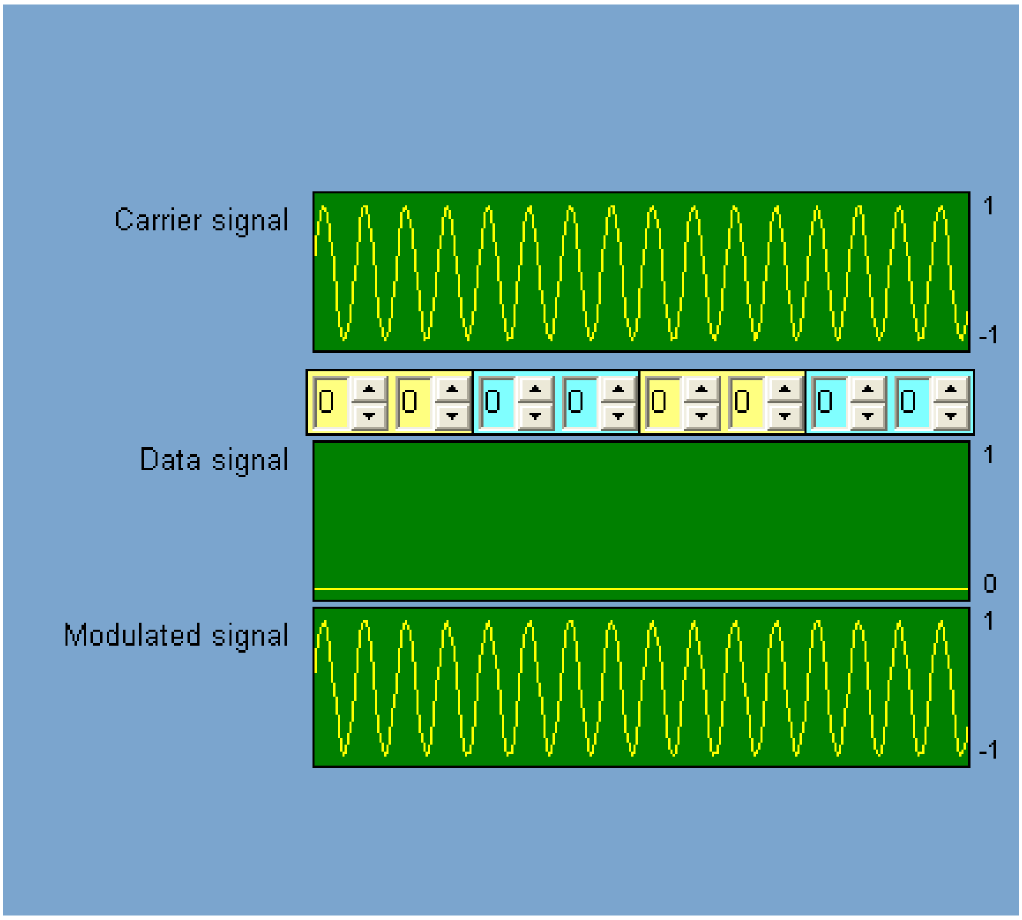
### 5.15 Summary

On the right side you will see a summary of the material covered in this chapter.

**Summary of this chapter**

- In 2PSK the phase of a carrier signal of constant frequency is toggled depending on the data signal between the phase positions 0 and 180°.
- 2PSK is generally more noise-immune than ASK or FSK.
- The spectrum of 2PSK and thus the bandwidth requirement are comparable with ASK, but the carrier is suppressed in 2PSK and must be recovered by means of a suitable circuit on the receive side.
- With carrier recovery a phase uncertainty of 180° occurs. This can - as will be shown later - lead to problems in data recovery.

### 6.1 4PSK time function




In four-phase shift keying (4PSK[1]) a sinusoidal carrier signal having frequency $f_0$ is toggled depending on the data signal among four phase positions (45°, 135°, 225° and 315°). Since **two** bits are required for distinguishing four phase positions, in 4PSK each phase position is specified by a pair of successive bits (Dibit[2]) and therefore is retained for each doubled bit duration. If the transmission channel has the same properties, 4PSK allows double the bit rate compared with 2PSK, or the same bit rate with half the bandwidth requirement.

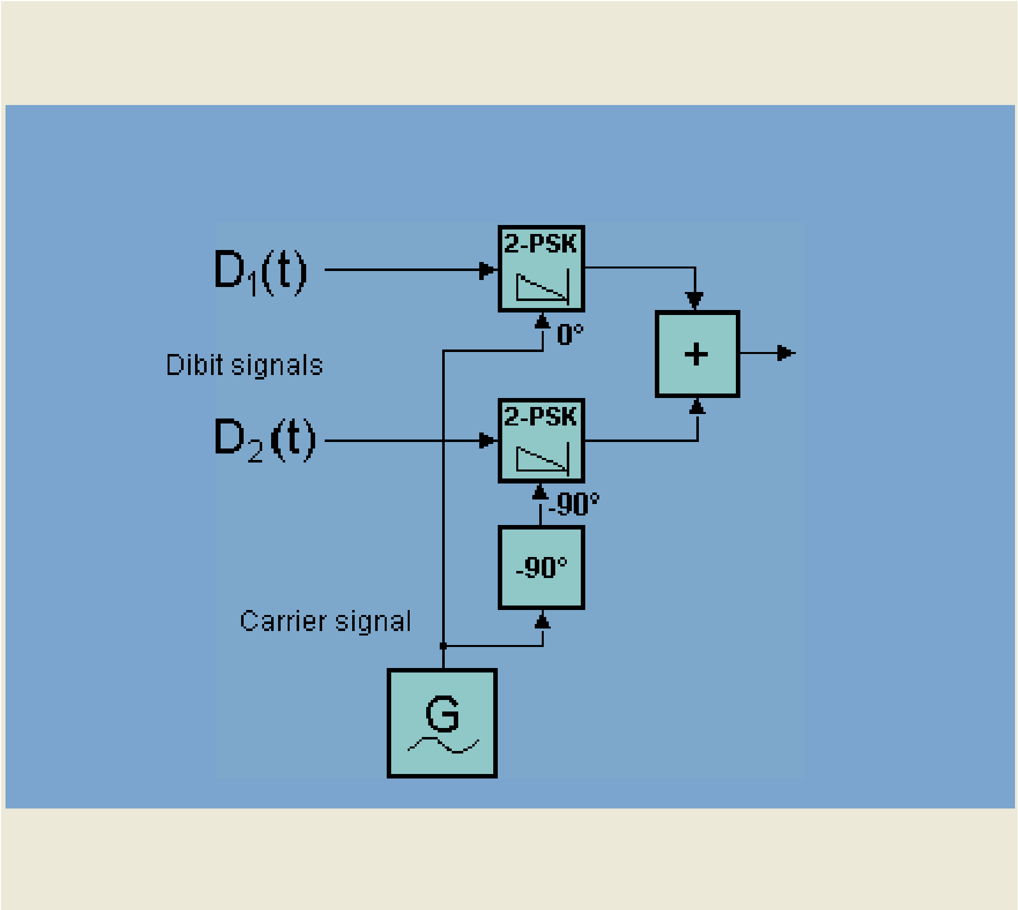
1 **PSK**

*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.

2 **Dibit**

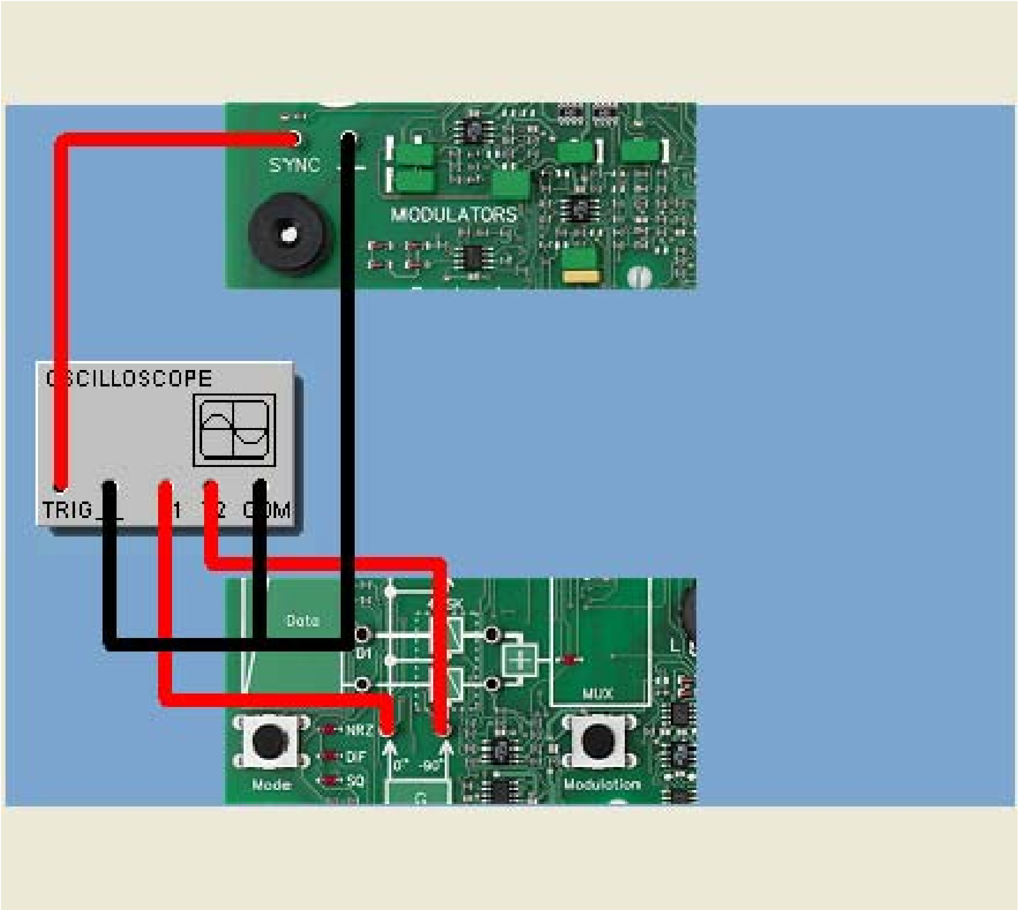
A dibit is a pair of successive data bits. The term is used for example in connection with four-phase shift keying (4PSK).

### 6.2 4PSK generation



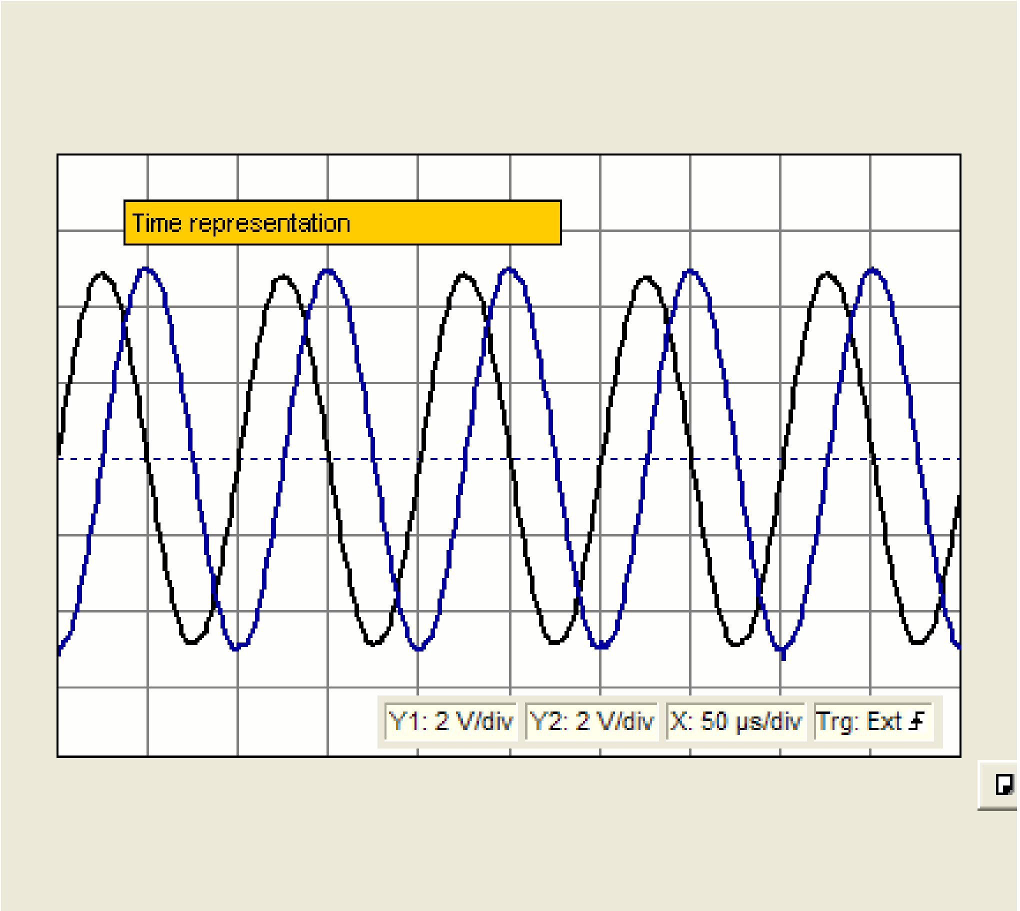

Four-phase Shift Keying is implemented with double, parallel Two-phase Shift Keying of the Dibit signals $D_1$(t) and $D_2$(t) with orthogonal carrier signals (phase position 0° and -90°) and summing of both signals. The 4PSK signal obtained in this way then has, depending on the bit combination present, phase positions of 45°, 135°, 225° and 315°.

### 6.3 Experiment: Carrier signals in 4PSK



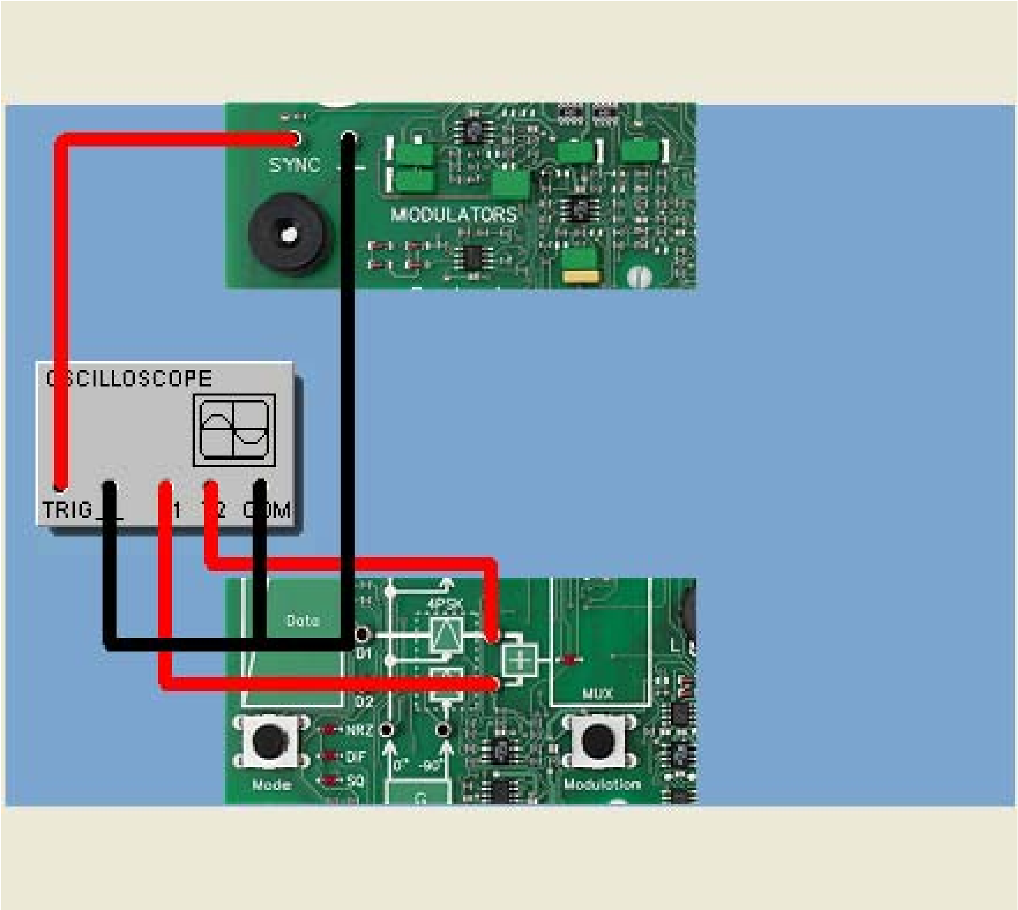

In the following experiment we will first study the courses of the two orthogonal carrier signals used in 4PSK. The courses will be captured by the oscilloscope and recorded both over time and in XY coordinates.

**6.4 Result**



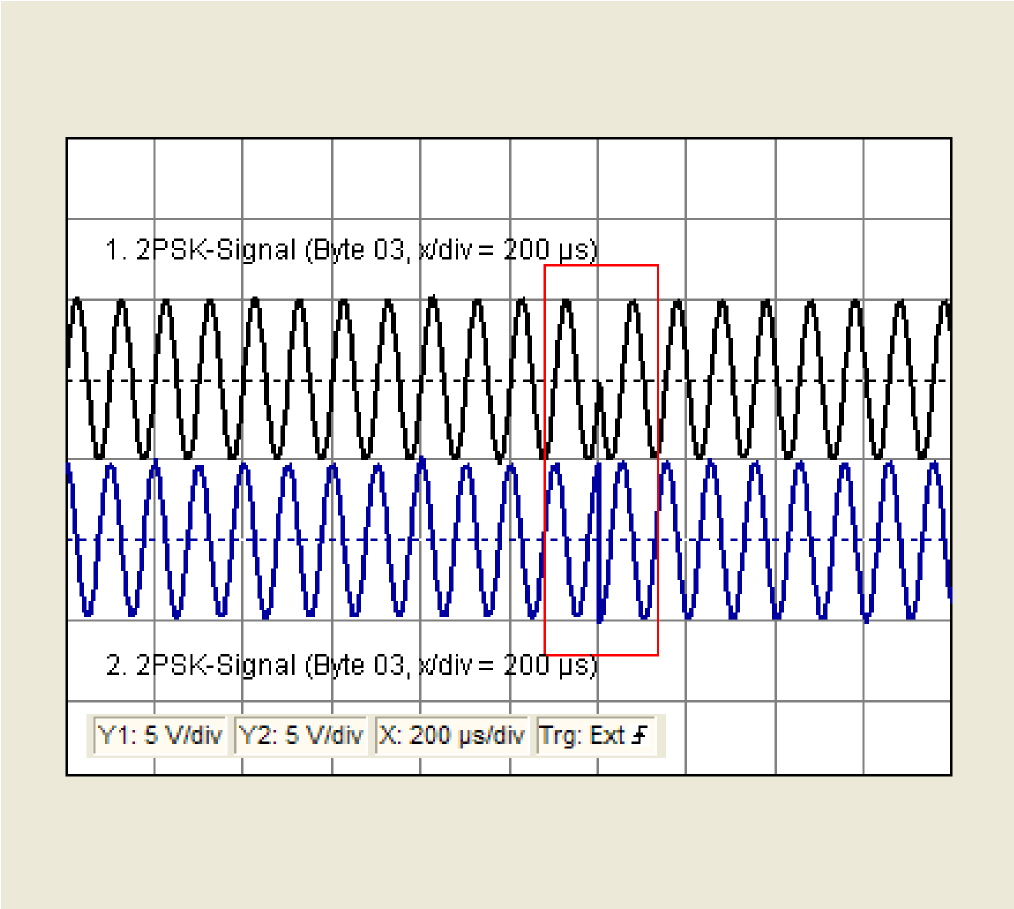

The oscillograms show clearly in the time representation the phase shift of -90° between the two carrier signals in the upper and lower 2PSK branch of the 4PSK modulator. In the XY representation there is (depending on the scaling) an ellipse or (if the axes have the identical scale) a circle, since the carrier signals each represent a sinusoidal resp. cosinusoidal function.

### 6.5 Experiment: Elements of the 4PSK signal



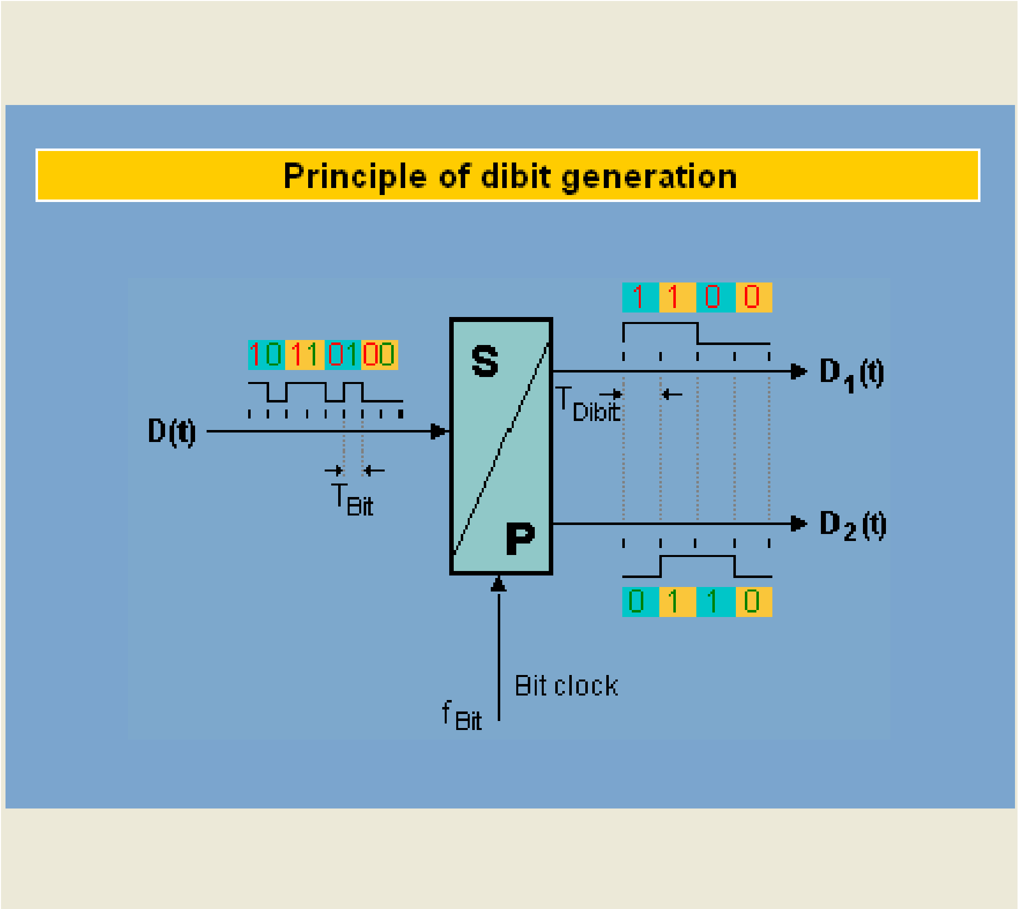

In the following experiment we will analyze the composition of the 4PSK signal made up of the two 2PSK signals. A data byte of 03 will be sent periodically. The courses of the two 2PSK signals will be captured with the oscilloscope.

### 6.6 Result



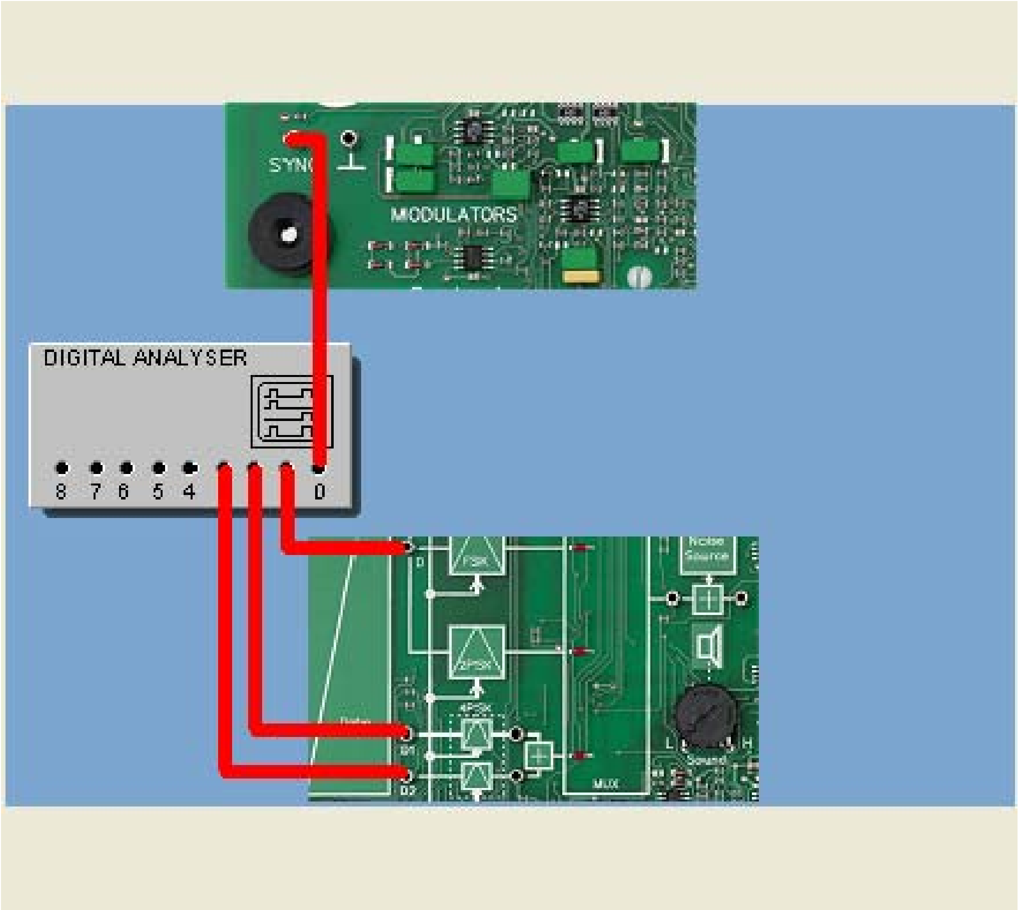

The oscillograms show clearly the phase shift of -90° between the two carrier signals in the upper and lower 2PSK branch of the 4PSK modulator. Since both branches perform "normal" 2PSK modulation, the result for 0-1- and 1-0- edges of the data signal are jumps of 180° each.

### 6.7 Dibit-generation



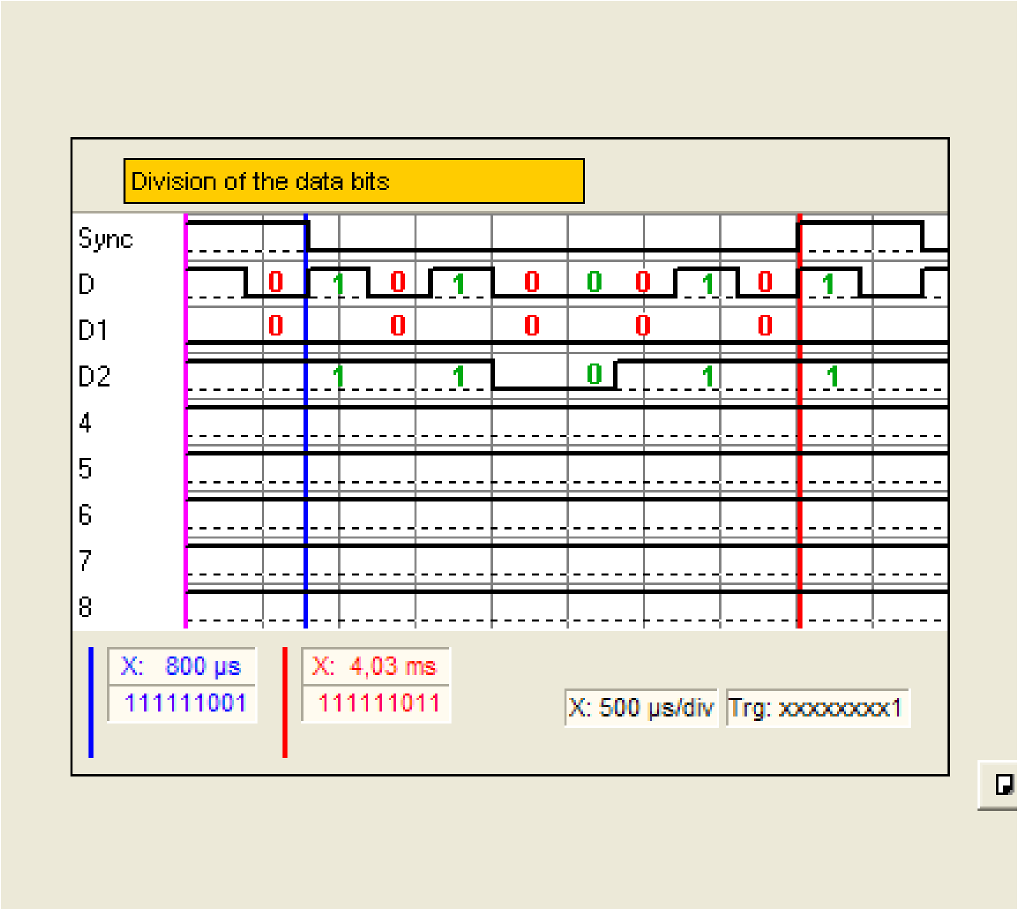

The digit signals $D_1$(t) and $D_2$(t) obtained by means of a serial-parallel conversion from the original bit sequence D(t). In principle this is an extension of the bit to the duration $T_{Dibit} = 2T_{Bit}$ and a division into two separate signal sequences. The first bit in a bit pair is delayed by the time duration of one bit in order to bring both dibit signals to the same clock start.

### 6.8 Experiment: Measuring dibit signals D1 and D2




In the following experiment we will investigate the principle of dibit generation through serial-to-parallel conversion. A suitable data byte will be periodically generated and the resulting dibit signals $D_1(t)$ and $D_2(t)$ recorded with the help of the digital analyzer. From the courses we will then determine the transmission rate for four-phase shift keying.

### 6.9 Result

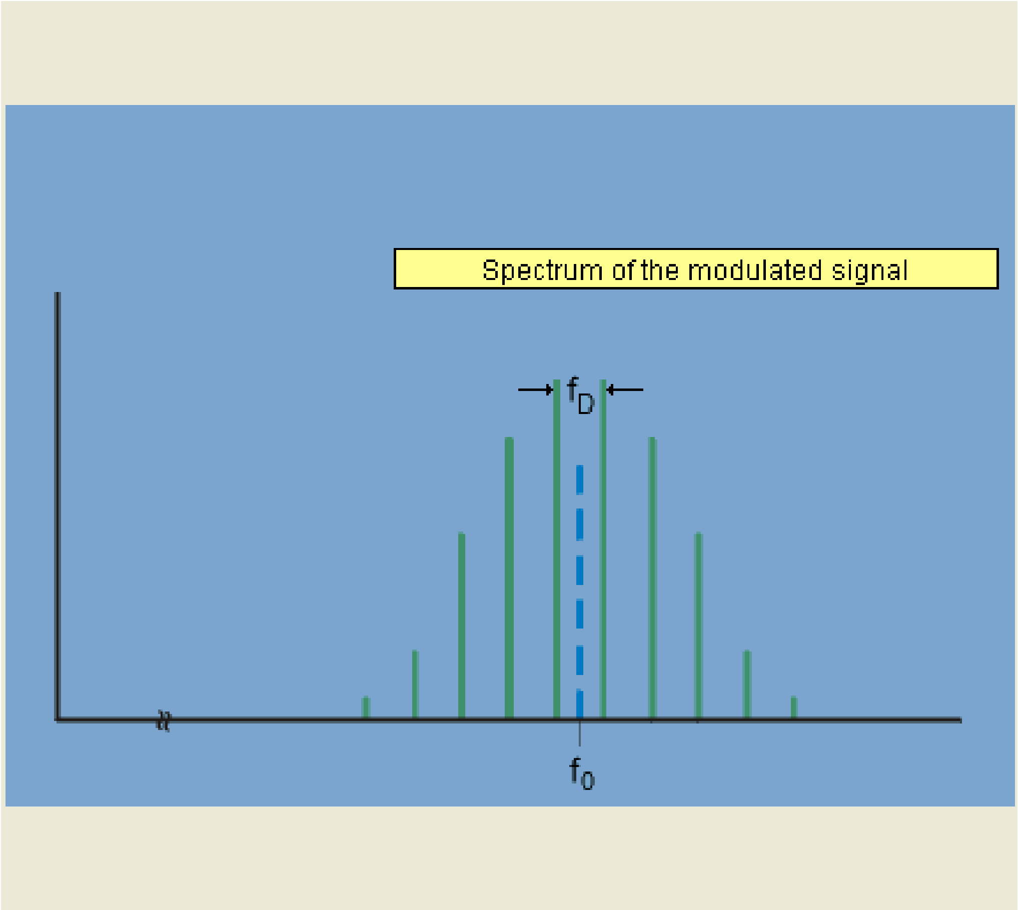



To the right of the blue cursor is the data signal D with first the digit 5 of the data byte 45 (LSB first), then the four bits of the digit 4. These end at the stop/start block at the same time as the sync signal (red cursor). You can see how the start bit, the eight data bits (between blue and red cursor) and the stop bit are "divided" over the two dibit signals. In this case 3.2 ms are required for transmitting the data bit. The bit rate is therefore

8 • 1000 / 3.2 = 2500 bps,

which is twice as fast as with the other modulation types.

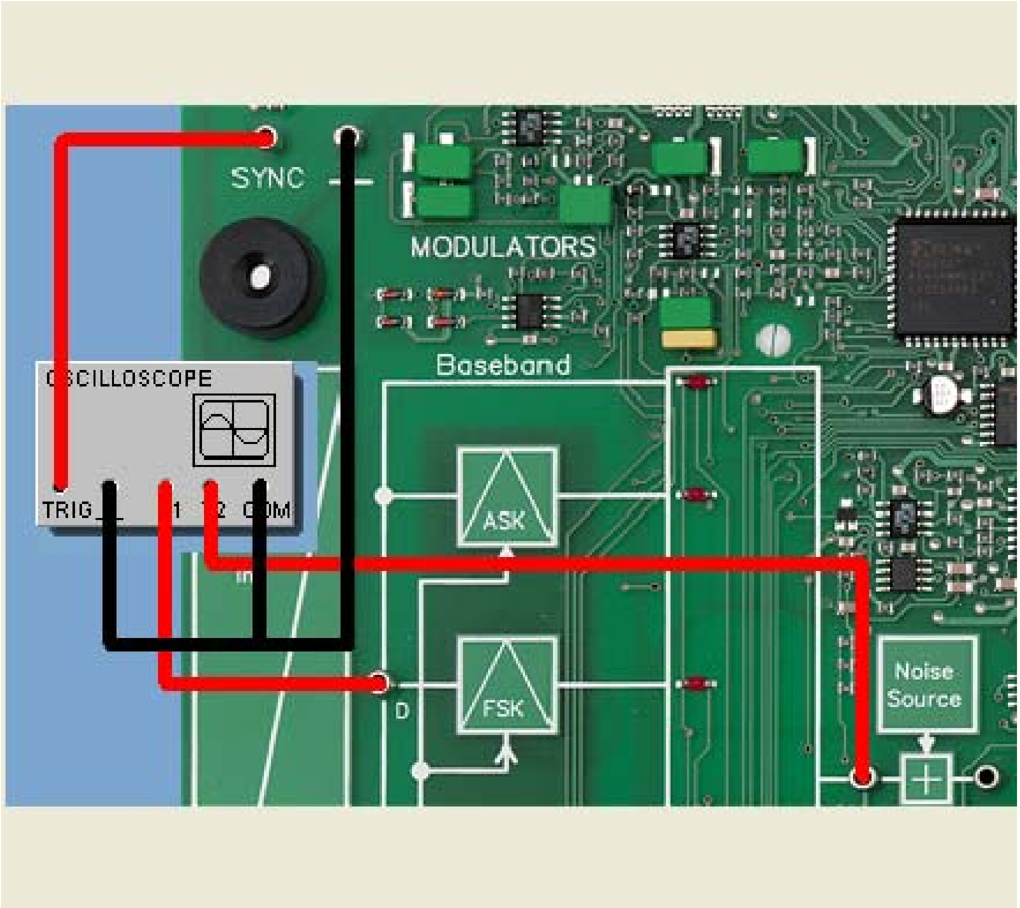
**6.10 4PSK in the frequency range**




If four-phase shift keying is operated at the same bit rate as two-phase shift keying, a signal step has twice the duration. This reduces the spectrum as compared with 2PSK to half the width, as shown in the adjacent graphic for a square-wave data signal having frequency $f_D$. The minimum required transmission bandwidth is thus only

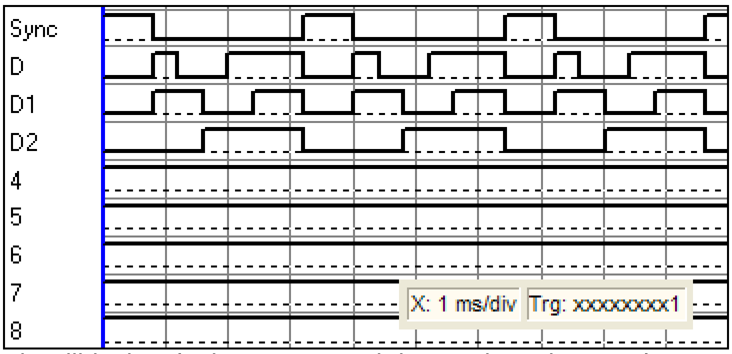
$$B = f_D.$$

### 6.11 Experiment: Measuring the 4PSK spectrum



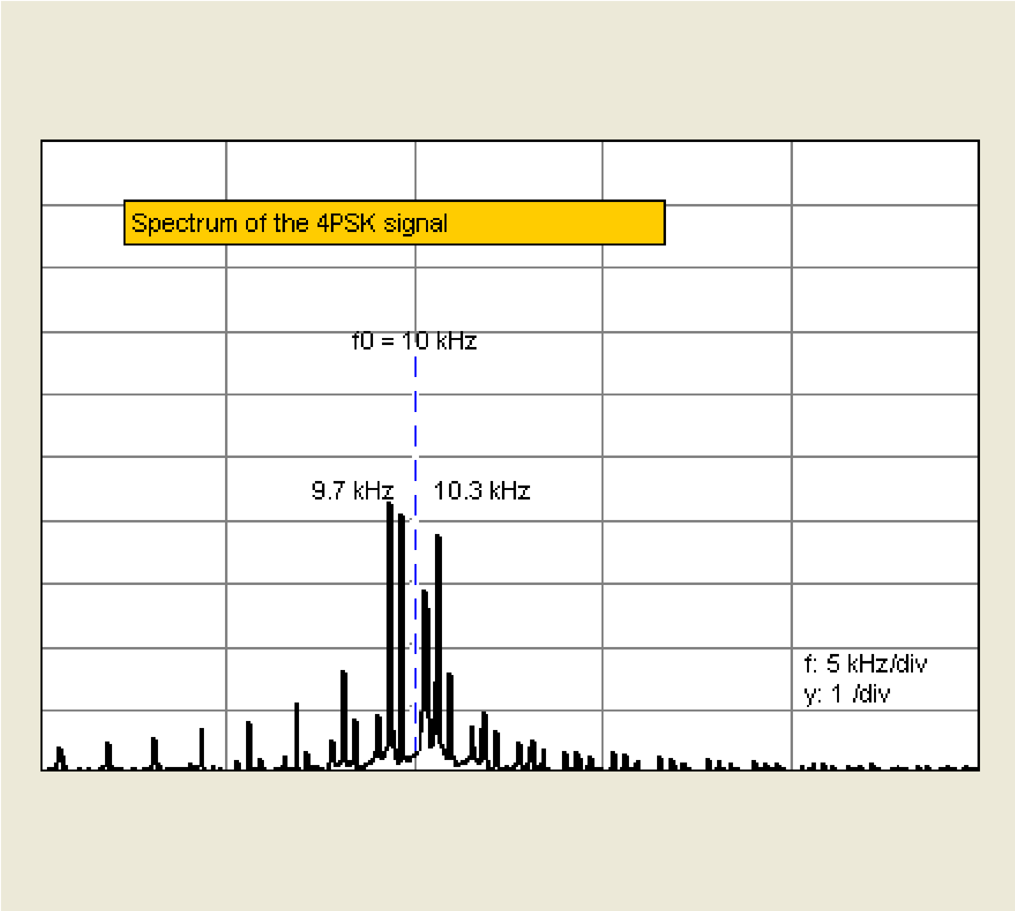

In the following experiment we will investigate the amplitude spectrum of the modulated signal in Four-phase Shift Keying. The data signal will again be a periodic square-wave signal[1] with a DC component and a frequency $f_D$ = 600 Hz.

[1] When square-wave (SQ) is turned on, a signal is applied to data output D which after appropriate conversion generates dibit signals having a symmetrical square-wave form on D1 and D2. The frequency of these square-wave signals is in a ratio of 2:1 (as with divider outputs); see graphic below.




The dibit signals thus generated do not show the usual start and stop bits as in normal, asynchronous transmission. This means even the in-phase and quadrature modulator get signals having a time-constant duty cycle. This is the prerequisite for the creation of discrete line spectra with separable lines.

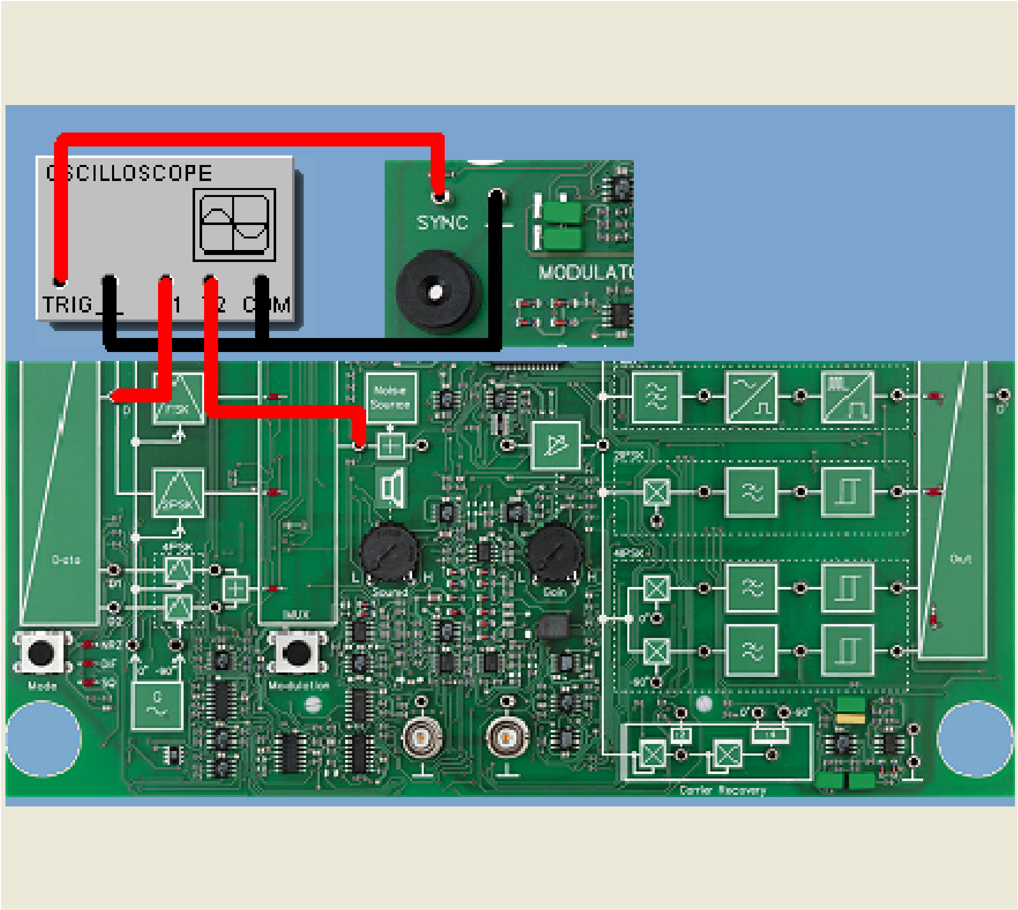
### 6.12 Result




Four-phase shift keying works with double the bit rate as 2PSK, but the spectrum has about the same spread, in other words with the same bandwidth requirement 4PSK lets you send at double the bit rate. The carrier itself does not appear in the spectrum in 2PSK.
Remark[1]

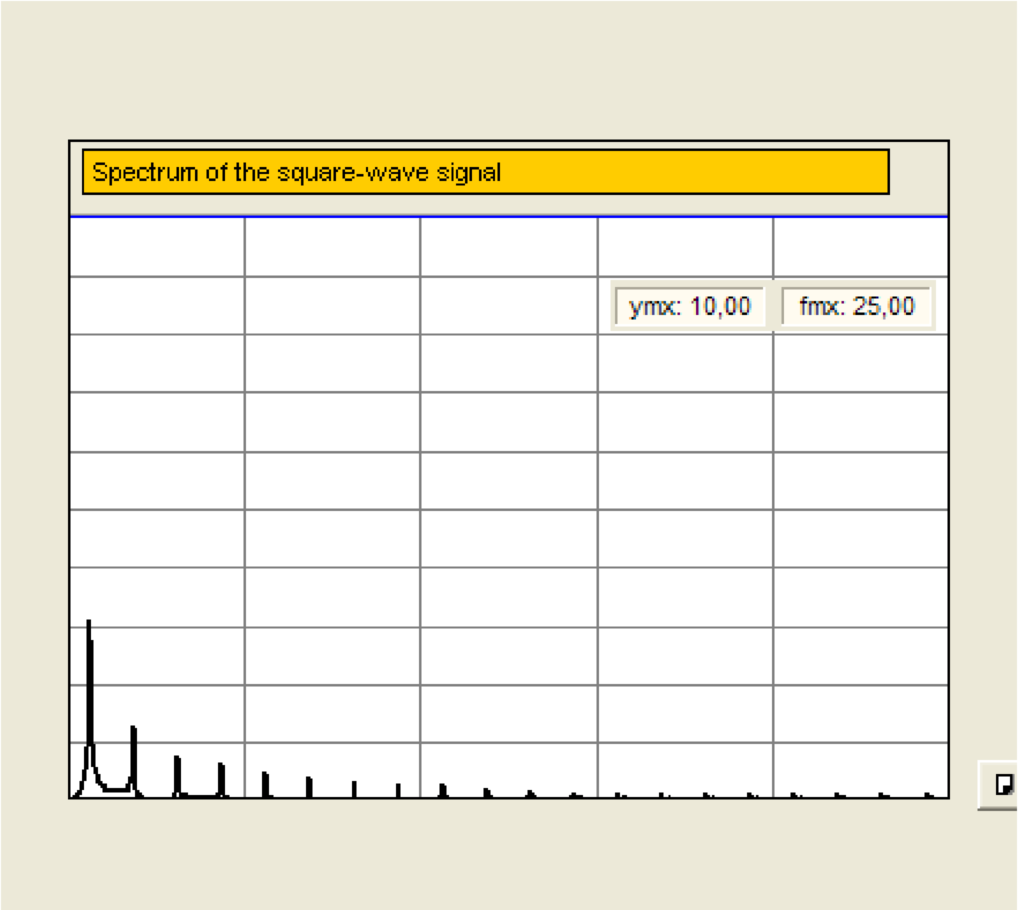
[1] A 4PSK consists of two 2PSK which are added together. The two 2PSK do have a different phase position (0° / 90°). But since spectrum analyzers do not take this into account, the amplitude of the 4PSK spectrum is shown incorrectly.

### 6.13 Experiment: Composition of the 4PSK spectrum



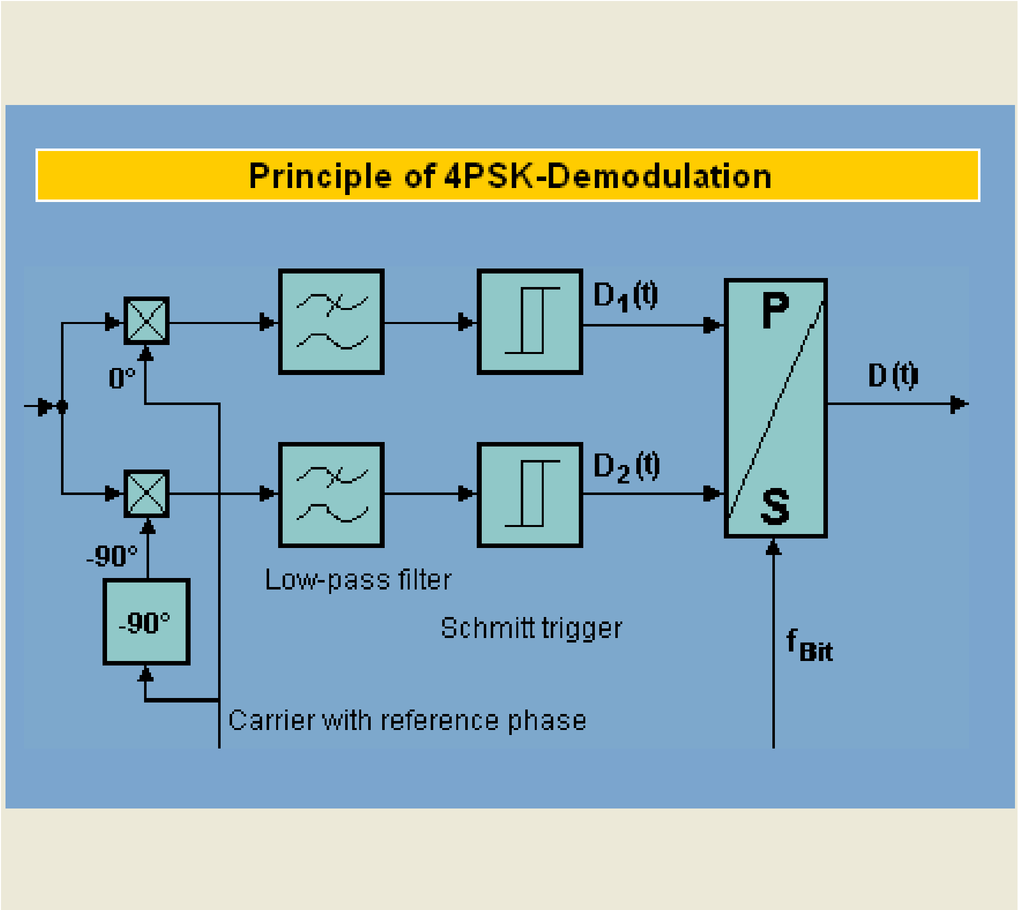
In the following experiment we will deepen our understanding of the 4PSK spectrum with square-wave modulation by investigating the composition of the spectrum made up of the two 2PSK spectra, in other words the spectra of the carrier signals modulated over the dibit signals $D_1$ and $D_2$ and shifted by 90° (in-phase modulator and quadrature phase modulator). A square-wave signal (SQ format) will again be used as the modulating signal.

### 6.14 Result



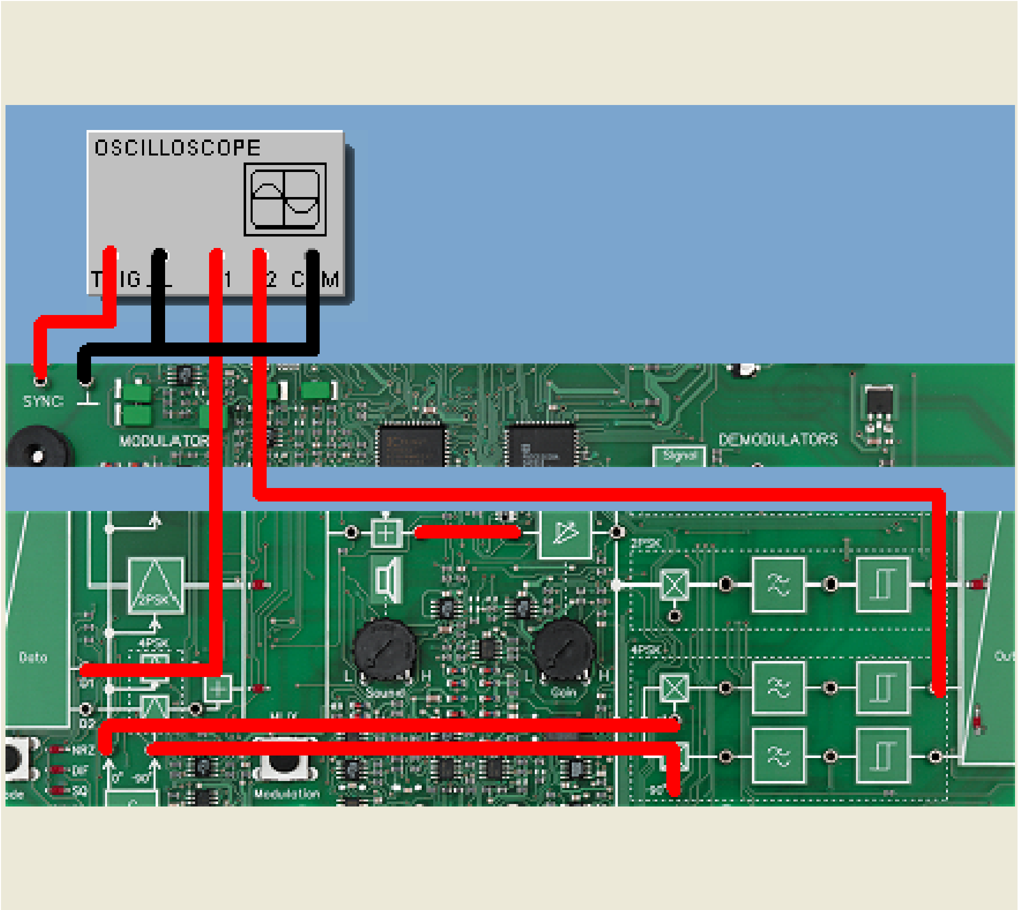

Because the frequency of the $D_1$-square-wave signal is twice as high compared with the $D_2$-square-wave signal, the output of the in-phase modulator shows a spectrum with about twice the line separation (namely 1200 Hz). The 4PSK spectrum is then created by additive overlay of both spectra and has twice the spread of the 2PSK spectrum in spite of the doubled data transfer speed. The measurement of the 4PSK spectrum on the multiplexer output is however incorrect with respect to amplitudes due to the phase uncertainty of the FFT.

### 6.15 Demodulation



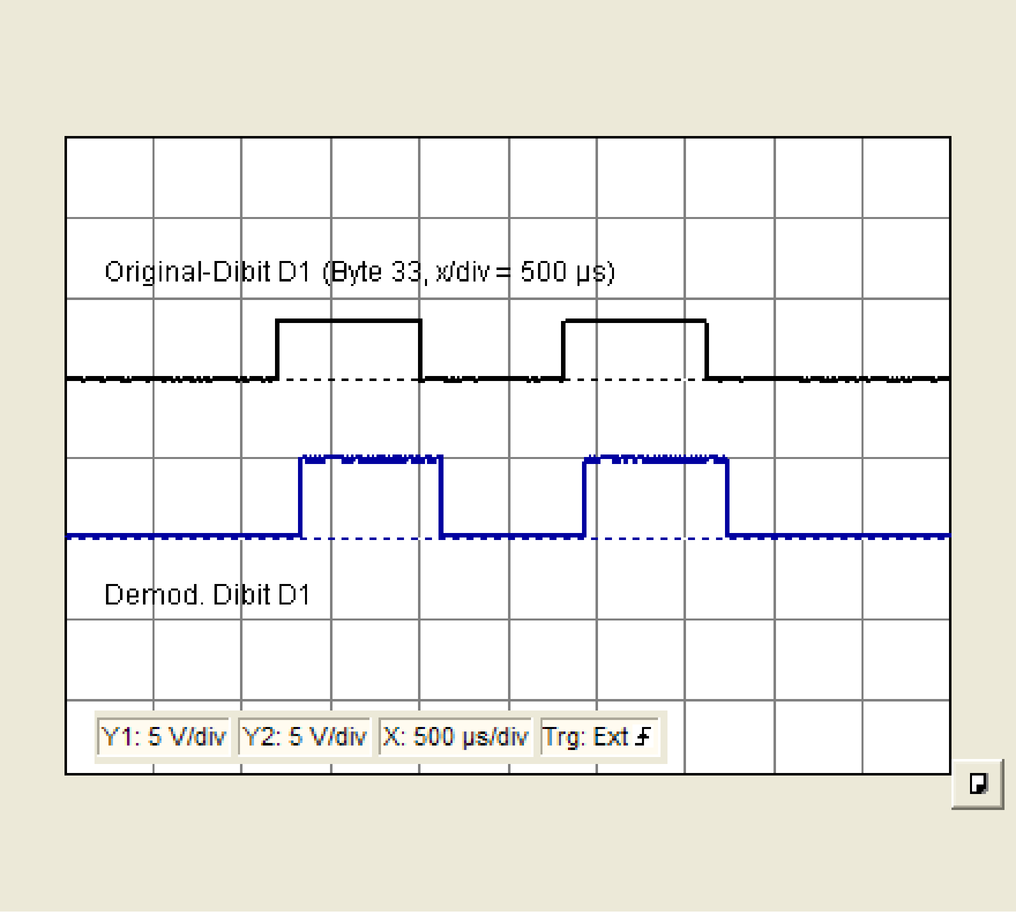

For synchronous demodulation of the 4PSK signal, two parallel 2PSK synchronous demodulators are used which work with –90° shifted carrier signals. The resulting dibit signals $D_1$(t) and $D_2$(t) are restored to the total data signal D(t) in a parallel/serial converter.

### 6.16 Experiment: Investigating 4PSK demodulation with the oscilloscope



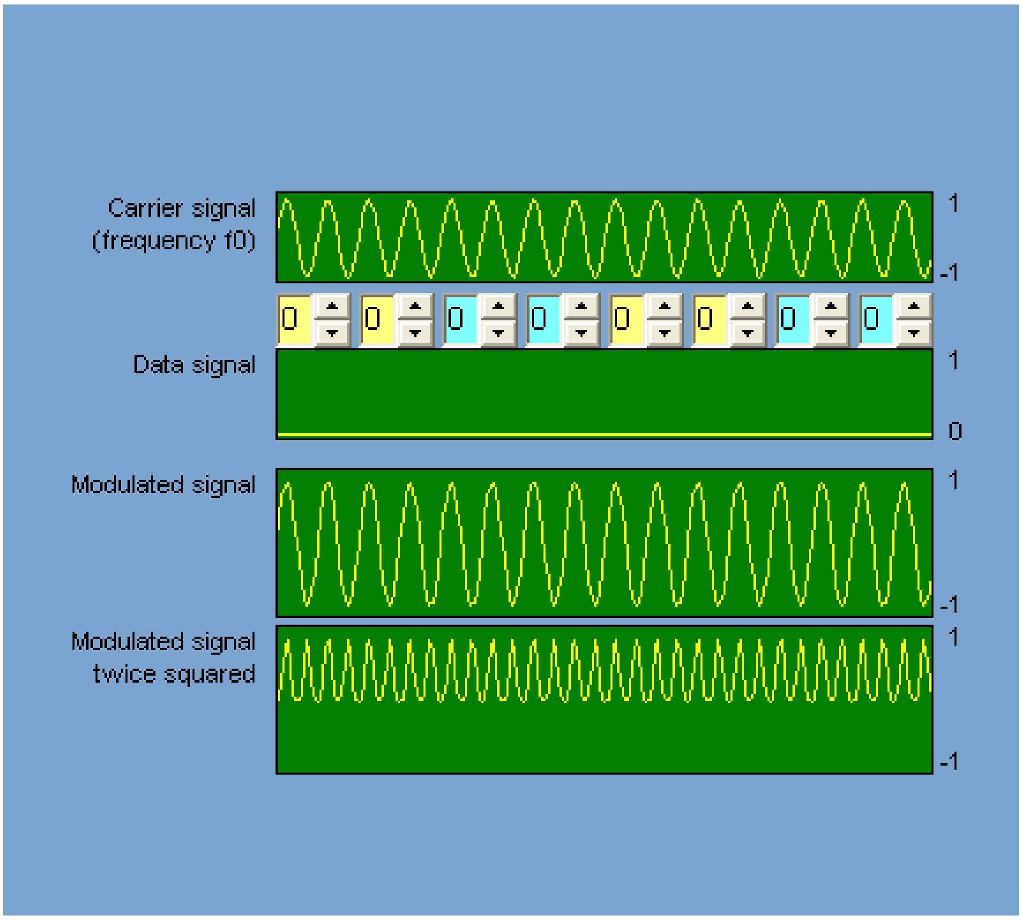

In the following experiment we will see that the 4PSK demodulator consists essentially of two separate 2PSk demodulators which each work with 90° shifted carriers. We will also investigate the demodulation of a 4PSK modulated signal in NRZ format, whereby periodically a data byte of 33 is sent. The original data signal and demodulates data signal will then be compared.

### 6.17 Result



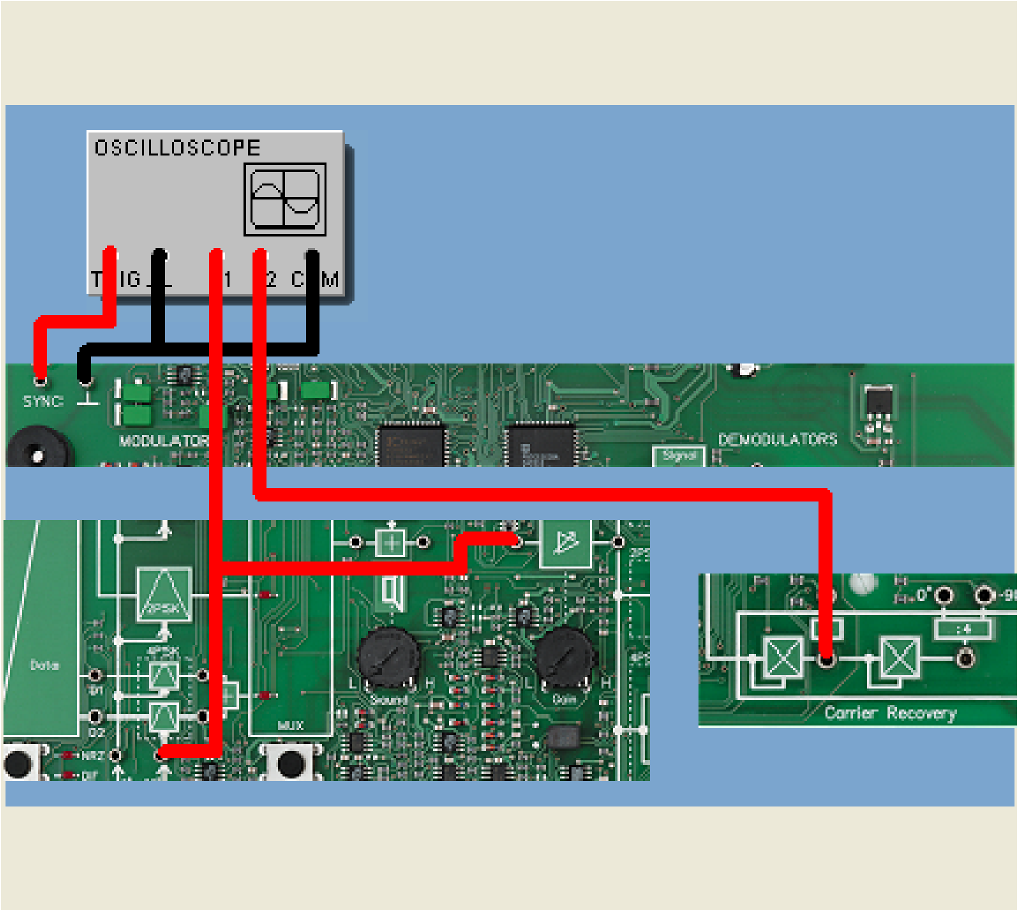

Since 4PSK demodulation consists essentially of two separate 2PSK synchronous demodulators, you get for the individual dibits identical ratios and signal courses as for 2PSK demodulation. The original and demodulated dibit are each shifted by around 120 µs due to the effect of the low-pass filter and Schmitt trigger.

### 6.18 Carrier recovery



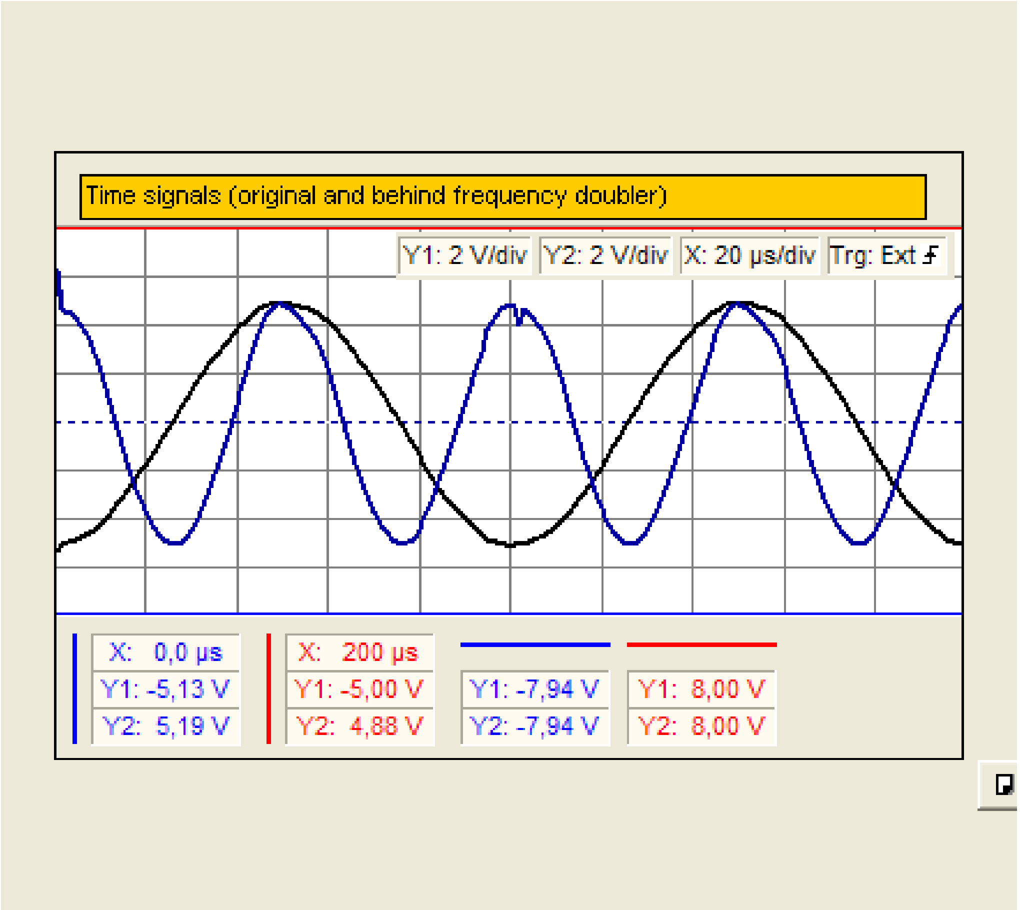

Also with four-phase shift keying the carrier needs to be recovered at the receiving location. For this purpose the modulated signal is squared twice; the result is an oscillation with a DC-component and frequency components at 2 $f_0$ (caused by the first quadrupling) and 4 $f_0$ (caused by the second quadrupling). The carrier can be recovered from this by filtering out the fourth harmonic (in other words the frequency component at 4 $f_0$) and then dividing the frequency by four - though with a phase uncertainty of i • 90º. The 2x squared modulated signal does not change when the data signal changes.

### 6.19 Experiment: Measuring carrier recovery with 4PSK



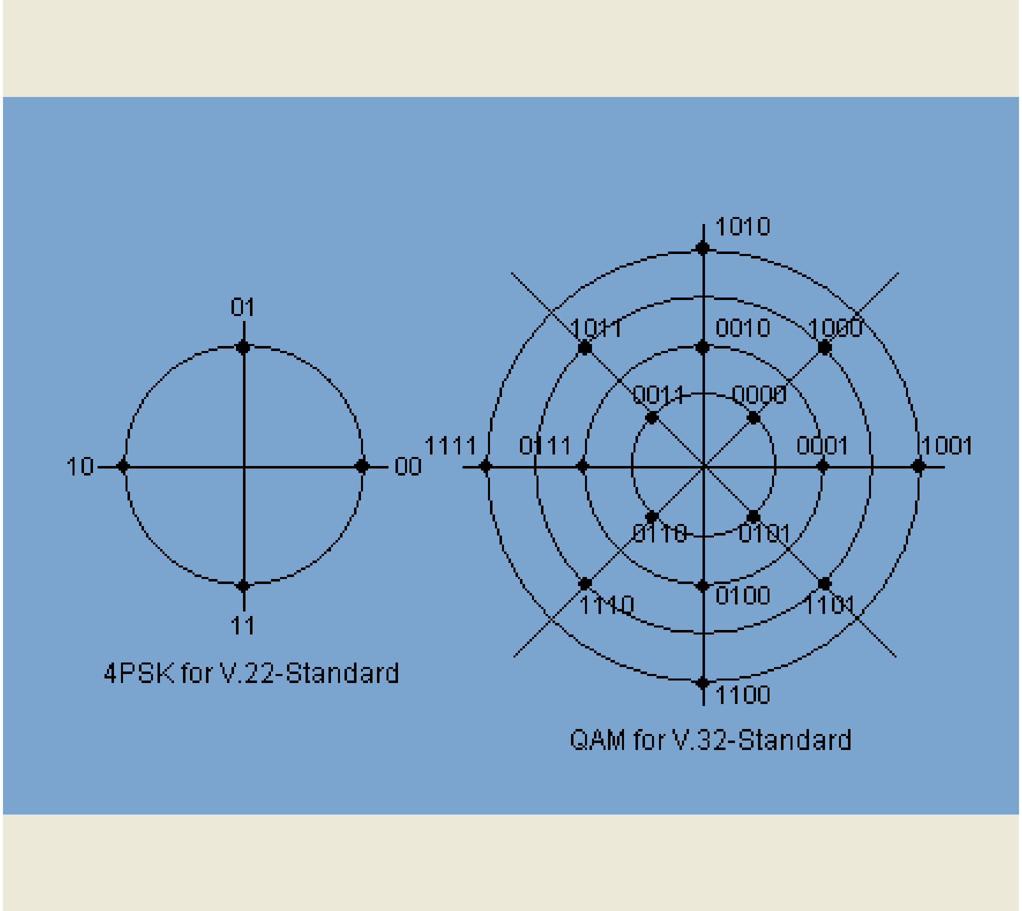

In the following experiment we will investigate carrier recovery with 4PSK whereby the modulated signal is squared twice. The analysis will be carried out in both the time and frequency range. Of particular interest are the signal spectra in front of and behind the frequency divider. To make the connections especially clear, the original carrier in 90°-position will be used as the "data signal".

**6.20 Result**




The first quadrupling results in a sinusoidal signal having frequency 2 $f_0$ = 20 kHz, the second quadrupling in a signal with a frequency of 4 $f_0$ = 40 kHz; the corresponding spectra thus consist only of a single line. The frequency divider reconstructs the signal into a (square-wave) signal having frequency $f_0$, which also has low-amplitude harmonics at odd multiples of the carrier frequency, in other words at 30 kHz, 50 kHz, 70 kHz etc.

### 6.21 Representation of phase shift keying in the vector diagram



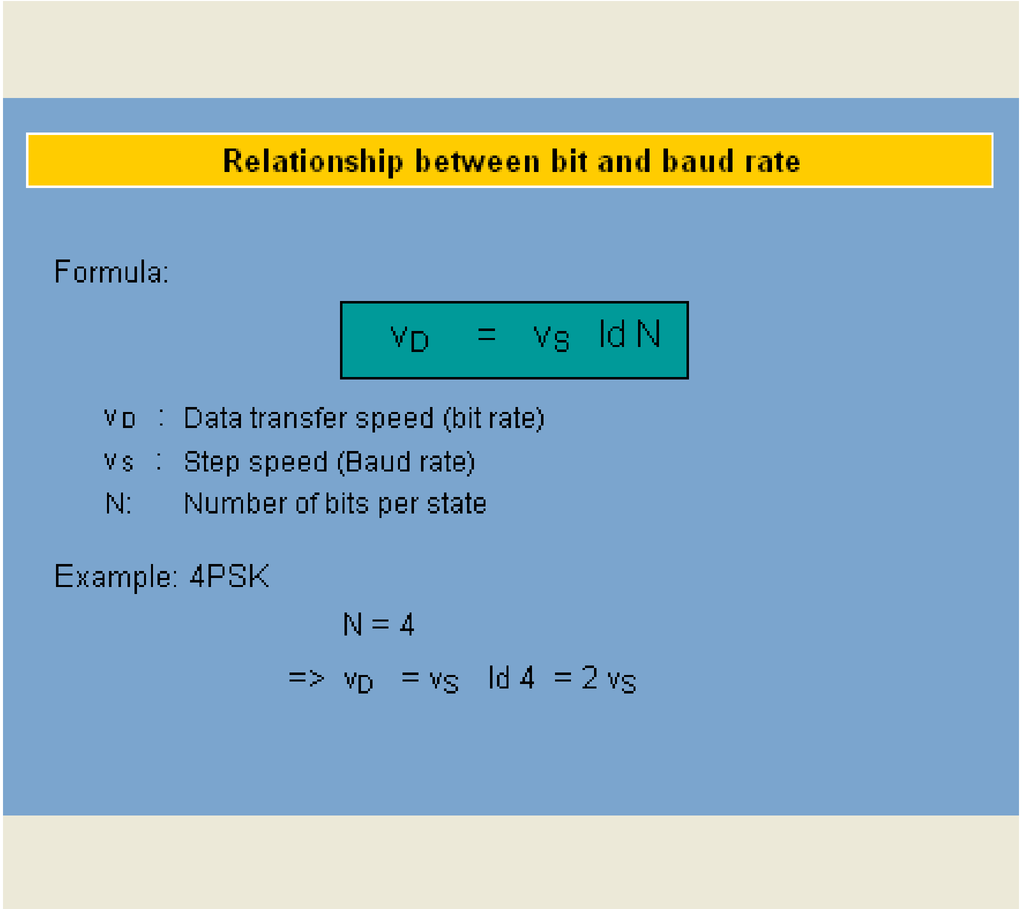

The various states in phase shift keying can also be shown very clearly in the form of vector diagrams, in which the angle of a vector represents the phase position of a state (for example of a dibit in 4PSK) and the length of the vector the amplitude (for example in quadrature amplitude modulation[1] ). The adjacent graphic shows two examples.

[1] **QAM**

QAM stands for *Quadrature Amplitude Modulation*. In QAM digital signals are represented by a combination of for example four phases and four amplitudes. The data are represented in the resulting matrix. This procedure is used for example in transmitting faxes.

See also: Modulation, V.32

### 6.22 Bit- and baud rate




The bit rate represents the number of bits per second (data transfer speed $v_D$) an is measured in bit/s or bps. In contrast, the baud rate (also Step speed $v_S$) indicates the number of states of the sent signal per second and is measured in baud units. If you multiply the number of bits per state by the baud rate, you will get the bit rate. Only if the number of states is exactly two (meaning exactly one bit is encoded with a state) is the baud rate the same as the bit rate. In general the relationship between both speeds is described by

$v_D = v_S \cdot \mathrm{ld}$[1] $N$,

whereby N is the number of bits per state.

[1] ld = logarithmus dualis
(binary logarithm $\log_2 n$)

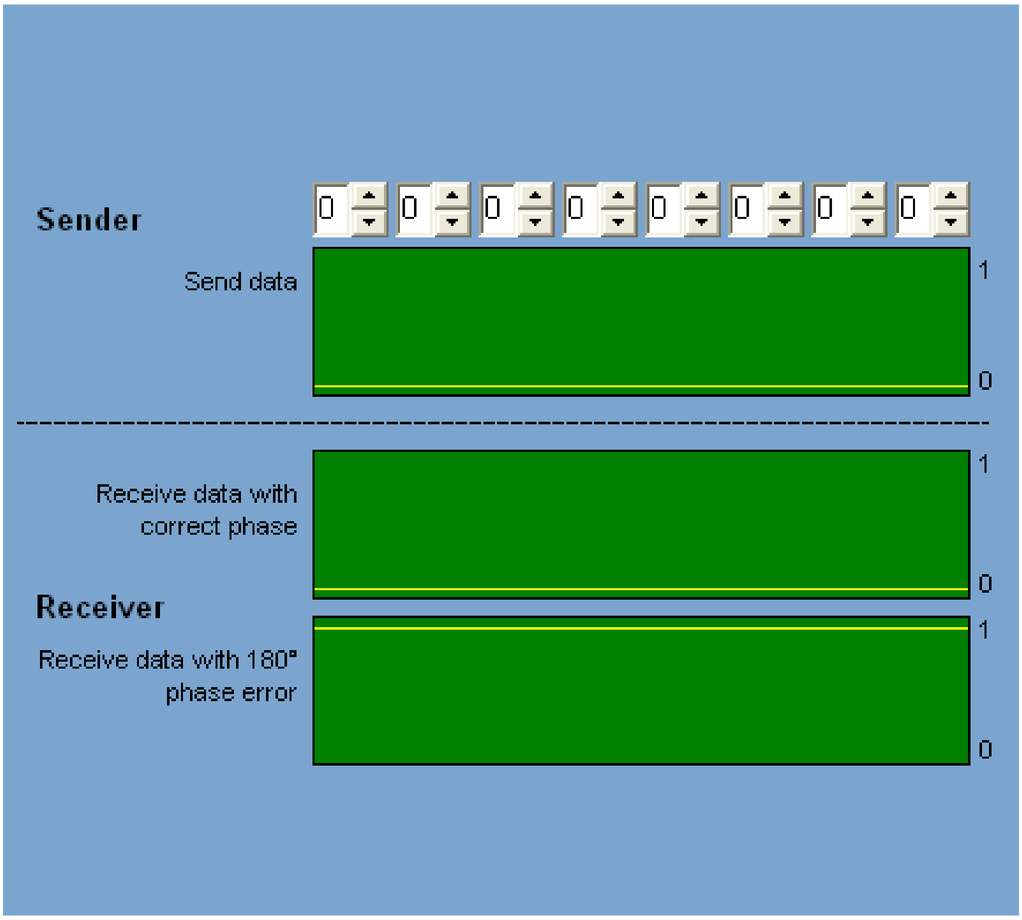
### 6.23 Summary

On the right side you will see a summary of the material covered in this chapter.

**Summary of this chapter**

- In 4PSK the carrier is toggled among four different phase positions depending on the data signal.
- Each of the four positions encodes respectively two successive data bits (one dibit) at the same time.
- 4PSK allows double the bit rate as the same bandwidth compared with 2PSK or transmission of the same bit rate at half the bandwidth.
- With 4PSK as well the carrier needs to be recovered on the receiving end, whereby there is a phase uncertainty of i • 90°.
- With 4PSK the bit rate is twice the baud rate.

### 7.1 Time course of DPSK




In carrier recovery with 2PSK there is a phase uncertainty of 180°, which can result in a mixup of the demodulated data bits (see illustration at right). This can be prevented by encoding a bit value not with the absolute value of the phase, but rather the phase differential from the previous value. This is referred to as Differential Phase Coding (DPSK[1] ). Now a phase shift between sender and receiver carrier no longer plays a role.

[1] **DPSK**

In *Differential Phase Shift Keying* a data bit is encoded not by the absolute phase position of the carrier, but rather by the phase difference from the preceding value. A phase shift between sender and receiver can therefore be ignored.

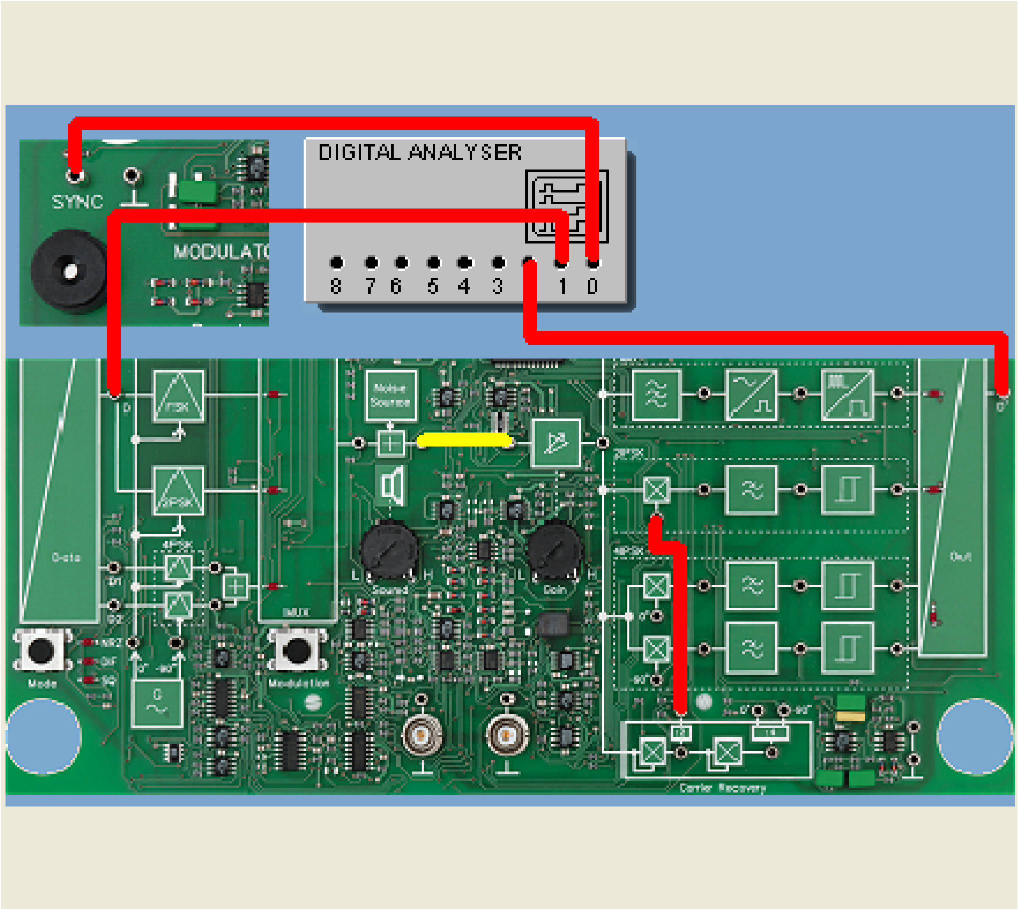
### 7.2 2DPSK

**Example for 2DPSK**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Send bit sequence | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 |
| Carrier phase angle (sender-side) | $\alpha$ | $\alpha$ +180° | $\alpha$ +180° | $\alpha$ | $\alpha$ +180° | $\alpha$ +180° | $\alpha$ +180° | $\alpha$ |
| | On receiver side with reference carrier of the phase $\alpha+\Delta\varphi$ recognized as | | | | | | | |
| at $\Delta\varphi = 0°$ | 0° | 180° | 180° | 0° | 180° | 180° | 180° | 0° |
| at $\Delta\varphi = 180°$ | 180° | 0° | 0° | 180° | 0° | 0° | 0° | 180° |
| Difference of successive phase states | ? | 180° | 0° | 180° | 180° | 0° | 0° | 180° |
| Receive bit sequence | ? | 0 | 1 | 0 | 0 | 1 | 1 | 0 |

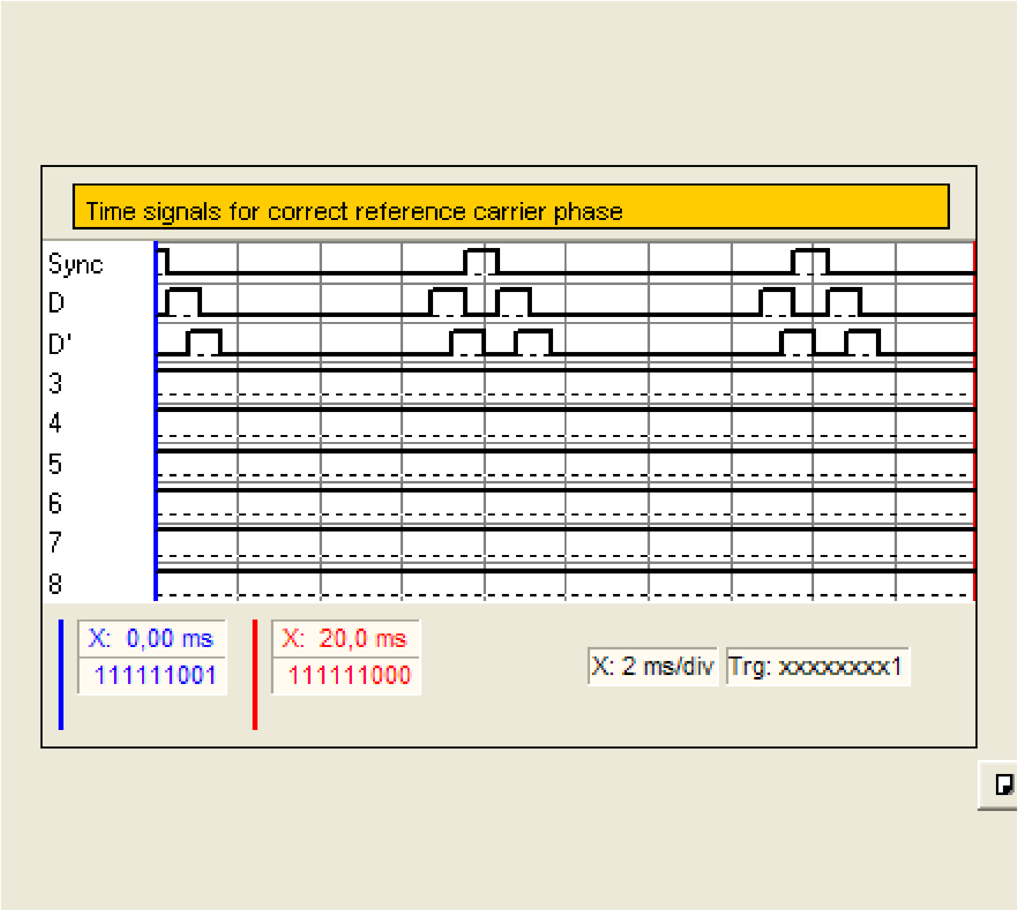
In 2PSK with a send bit of 1 the carrier phase of the previous bit is retained, and with a send bit of 0 it is shifted by 180°. On the receiver side the phase difference of successive bit values is evaluated and the data signal reconstructed from that. The table at right explains this in an example. The differential formation means that when the phase position of the reference carrier is wrong ($\Delta\varphi$ = 180°) there is no longer an error; only the first bit received is uncertain.

**7.3 Experiment: Faults in the 2PSK**



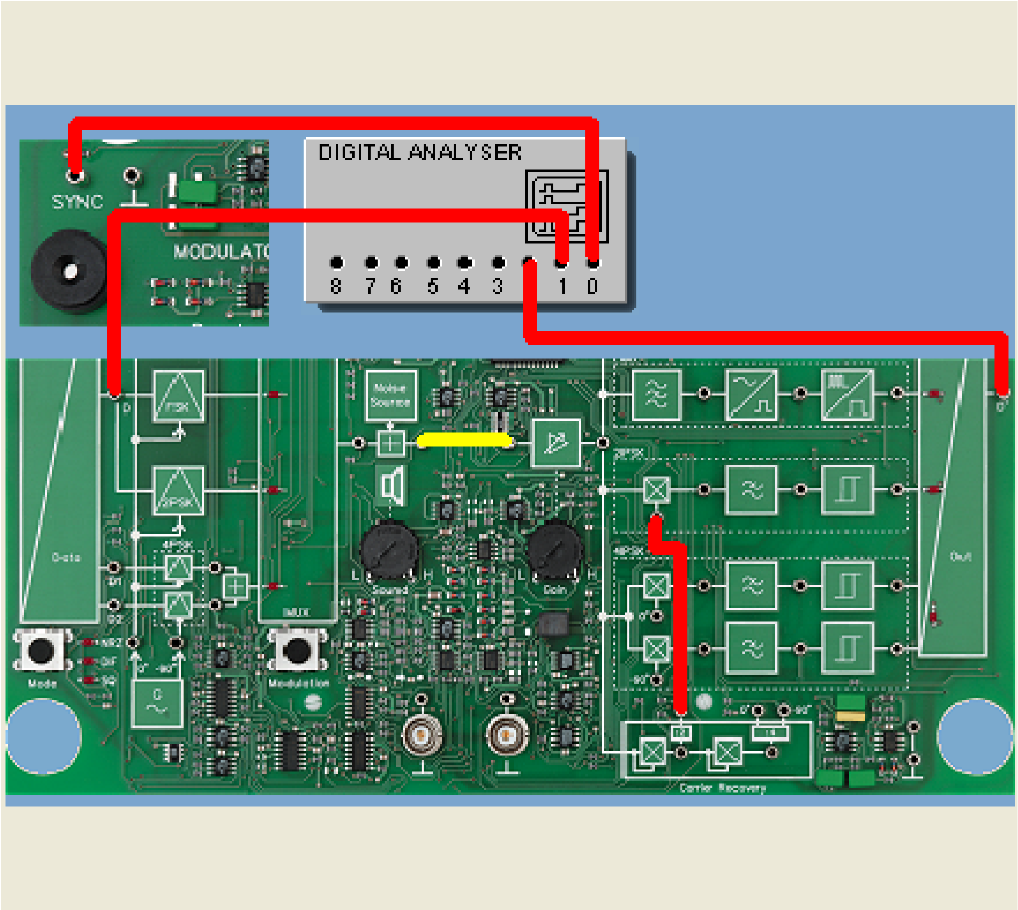

In the following experiment we will investigate the demodulation of a 2PSK modulated signal, whereby the reference carrier is recovered from the modulated signal on the receiver side. A data byte of 01 will be sent periodically and the course of the signal recorded on the send and receive side.

### 7.4 Result



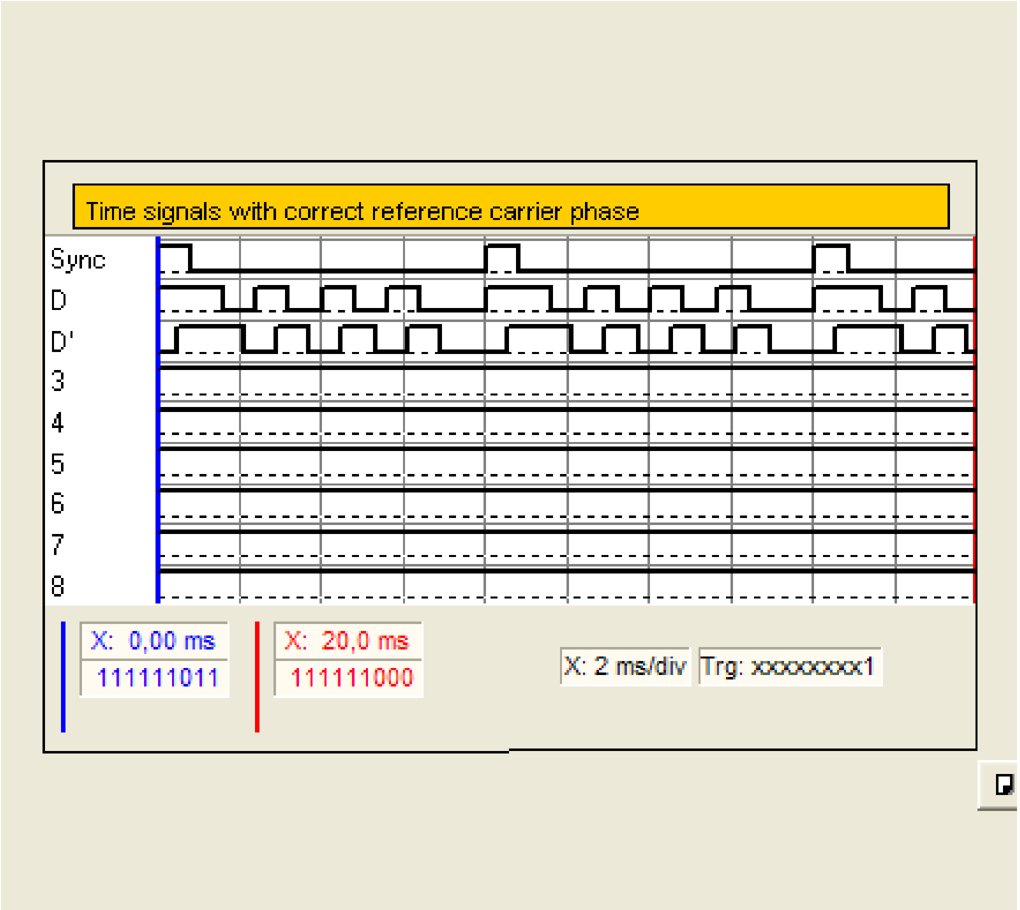

Due to the phase uncertainty of the reference carrier of 180° there is a statistical phase error of just this 180° every second time the connection is opened. This results in the decoded data signal being exactly inverted on the receive side compared with the sent data signal.

### 7.5 Experiment: Disturbances in the line network with 2DPSK



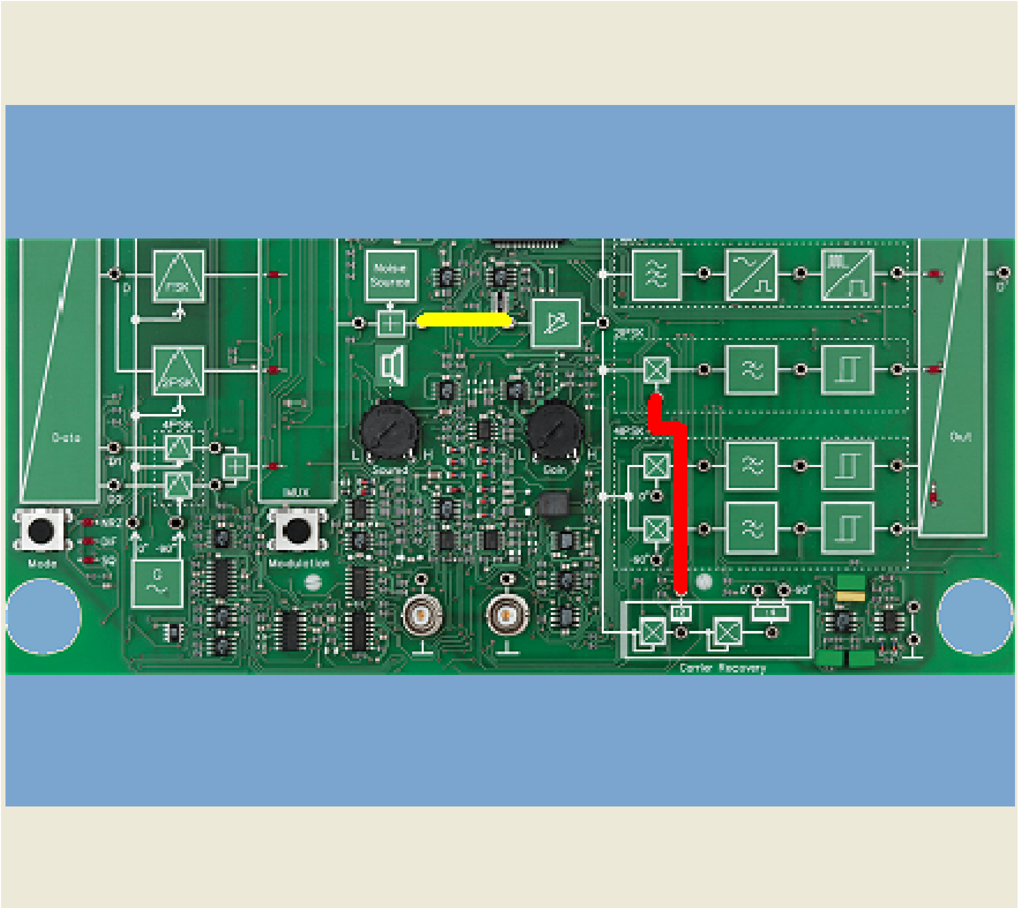

In the following experiment we will by way of comparison investigate the demodulation of a 2DPSK modulated signal, whereby the reference carrier is again recovered from the modulated signal on the receiver side. A data byte of 01 will be sent periodically and the course of the signal recorded on the send and receive side.

**7.6 Result**




Here again, due to the phase uncertainty of the reference carrier of 180° there is a statistical phase error of just this 180° every second time the connection is opened. This results in the decoded data signal being exactly inverted on the receive side compared with the sent data signal. But with Differential Phase Coding this phase shift plays no role in data recovery, as will be shown in the following experiment.

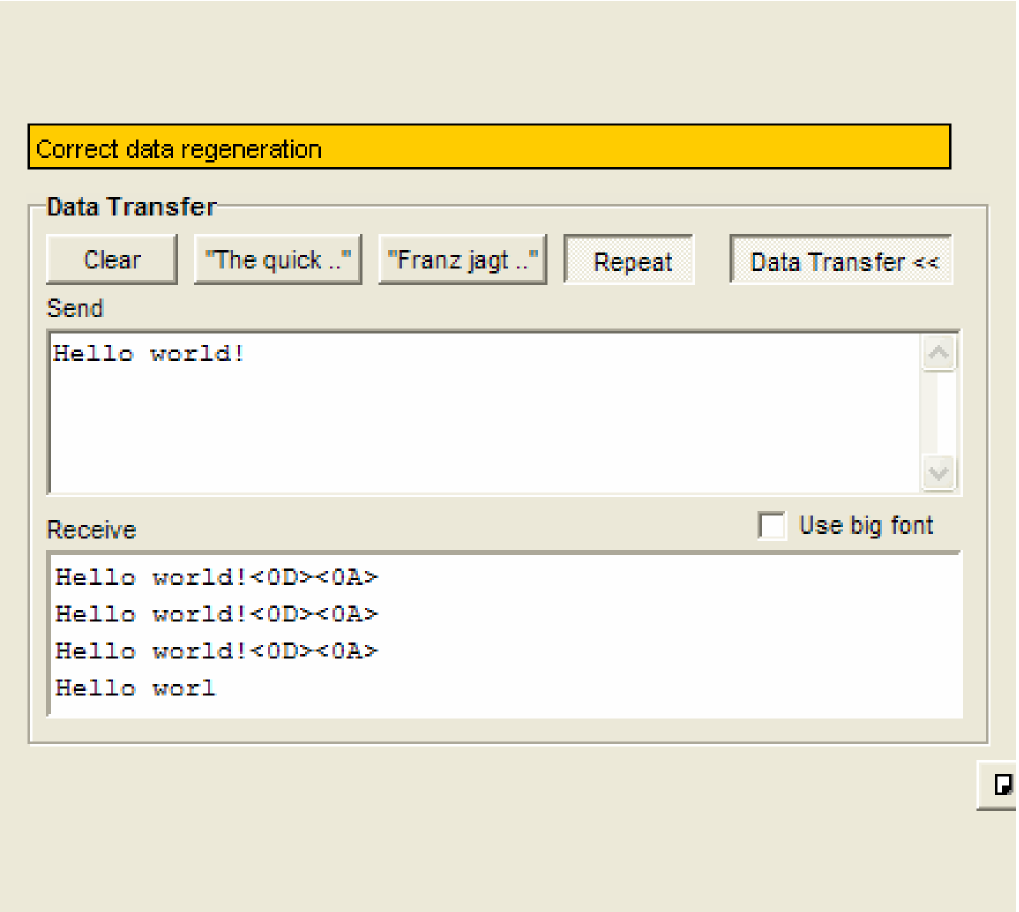
### 7.7 Experiment: Text transmission with 2PSK/2DPSK and disturbances in the line



network

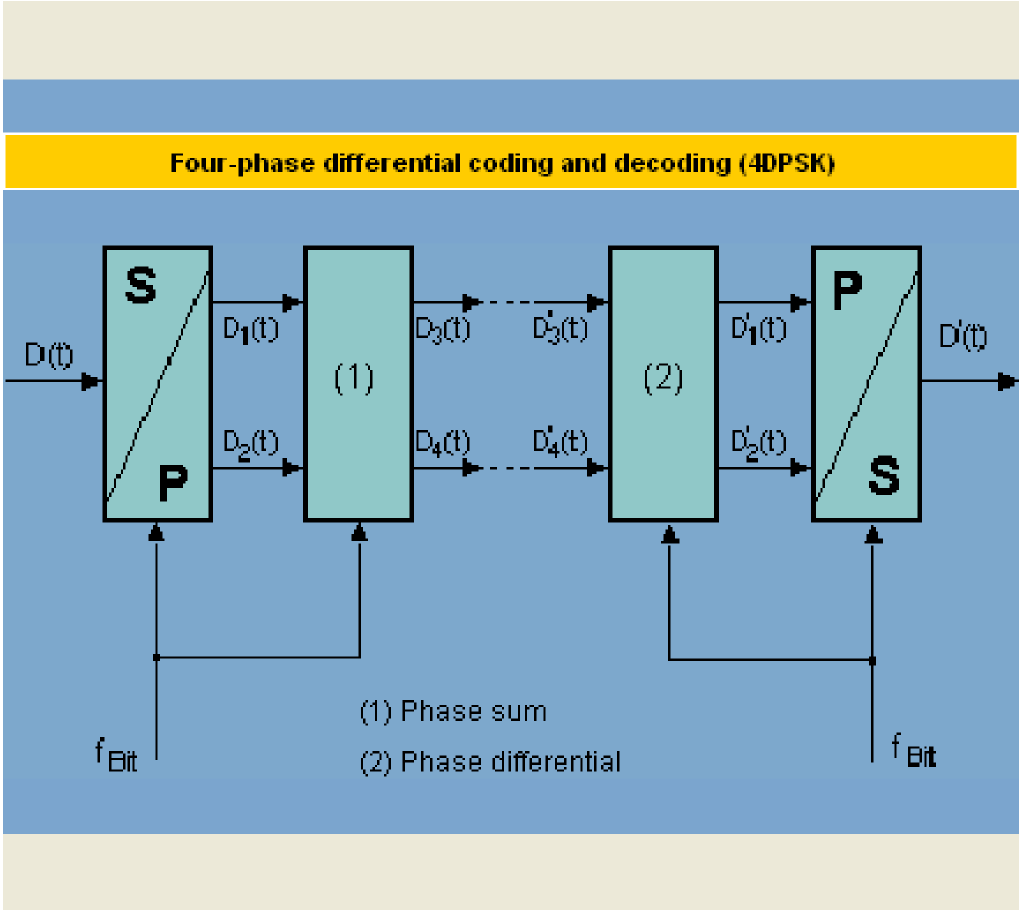
In the following experiment we will compare data transfer with "normal" 2PSK with that of 2DPSK, whereby the reference carrier is recovered from the modulated signal on the receive side. A constant character string is sent periodically and the decoded string compared on the receive side with the sent string.

### 7.8 Result




With Differential Phase Coding the receive data for 2DPSK are also regenerated perfectly when the reference carrier phase is incorrect. But in simple two-phase shift keying about every second time a connection is opened there are incorrectly decoded receive data due to the incorrect reference carrier phase; the received text thus becomes completely unreadable.

### 7.9 4DPSK




The phase uncertainty of the reference carrier of i • 90° with 4PSK can also be circumvented by using Differential Phase Coding, which in general functions in the same manner as 2DPSK. A digital phase adder (1) converts the dibit signals $D_1(t)$ and $D_2(t)$ into the differential encoded signals $D_3(t)$ and $D_4(t)$. On the receive side a phase difference calculator (2) performs decoding of the dibit signals $D'_3(t)$ and $D'_4(t)$ into $D'_1(t)$ and $D'_2(t)$ .

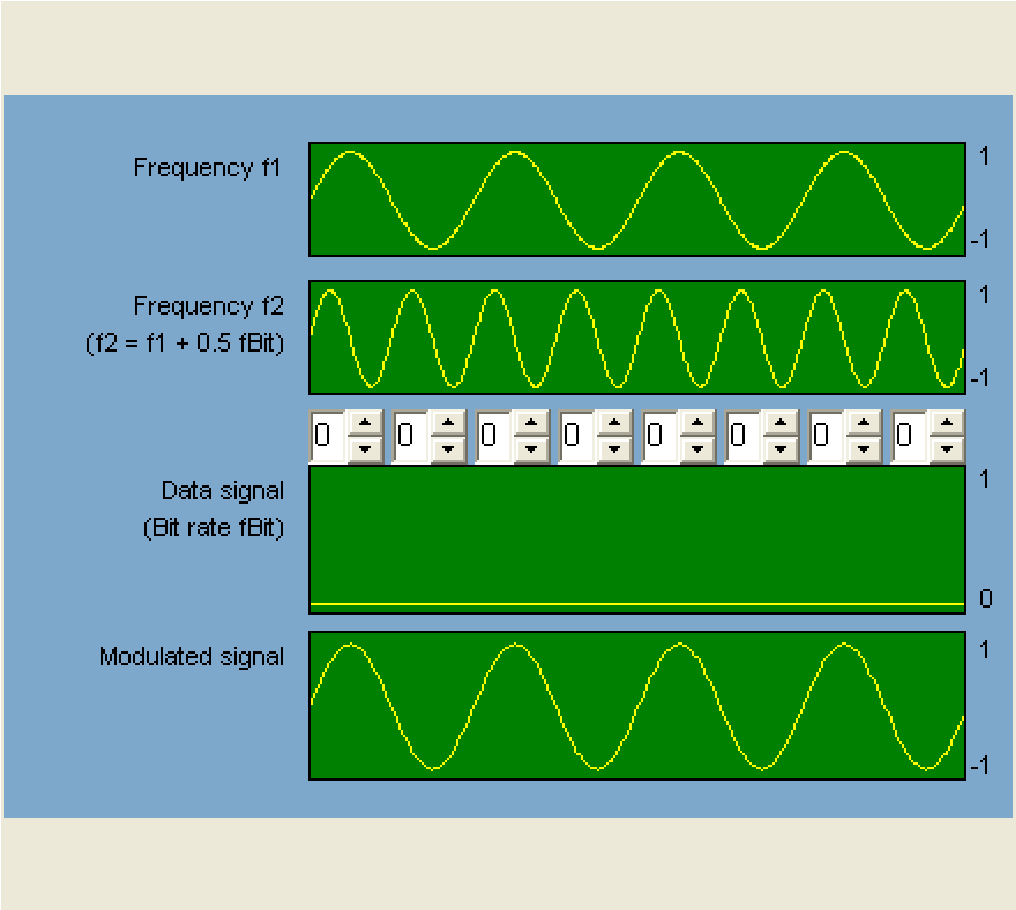
### 7.10 Summary

On the right side you will see a summary of the material covered in this chapter.

**Summary of this chapter**

- Differential Phase Coding (DPSK) is a special form of phase shift keying.
- In DPSK a bit value is not encoded by the absolute value of the phase, but rather by the phase differential from the previous value.
- DPSK circumvents the problem of phase uncertainty in carrier recovery.
- The first sent bit cannot be unambiguously recognized by DPSK, since there is not yet a "predecessor" to it.
- There is Differential Phase Coding for two- and four-phase Shift Keying (2DPSK resp. 4DPSK).

### 8.1 Minimum Shift Keying

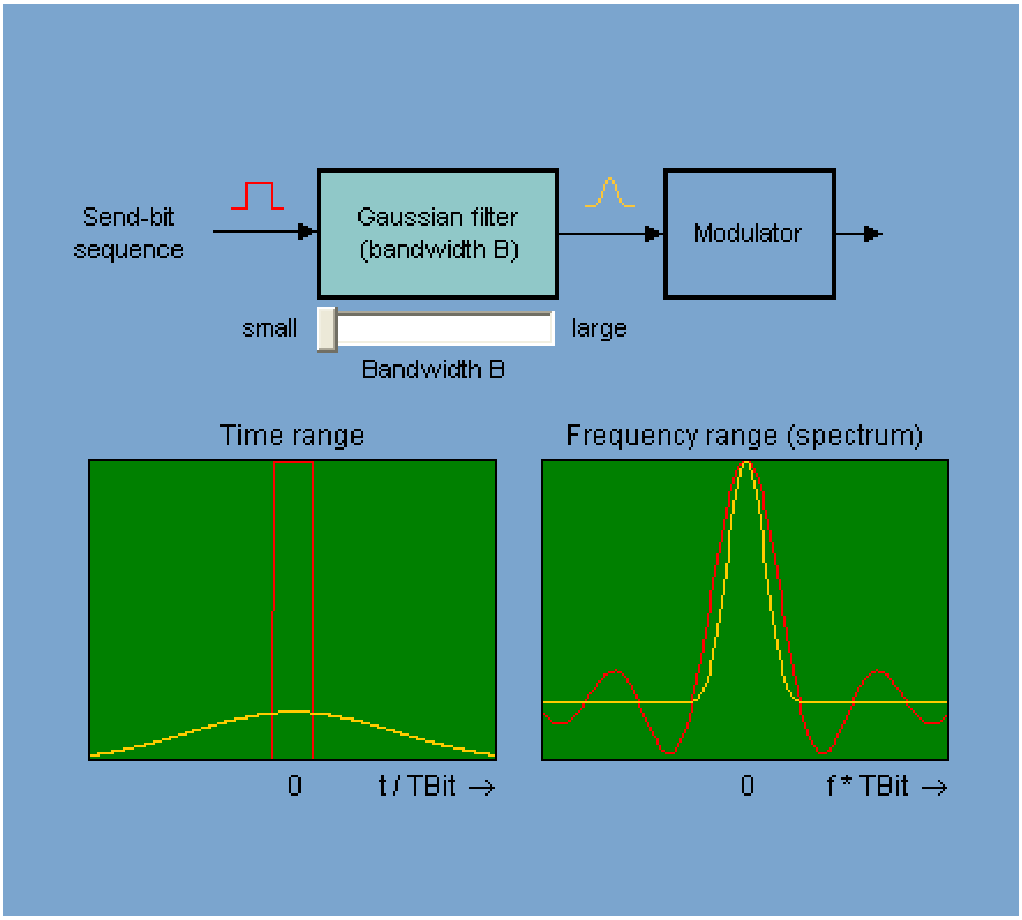



Minimum Shift Keying (MSK[1] ) or Fast Frequency Shift Keying (FFSK) is a special type of Frequency Shift Keying, whereby the modulation index has a value of 0.5. The carrier frequency is changed between discrete values, so that for both frequencies $f_1$ and $f_2$ the relationship $f_2 = f_1 + 0.5 \bullet f_{Bit}$ applies; $f_2$ results during a bit duration of only half an oscillation more than $f_1$. The phase is continuous when the discrete values are changed. Compared with standard FSK, the MSK signal required significantly less bandwidth.

1 **MSK**

*Minimum Shift Keying* is a special, bandwidth-optimized form of frequency shift keying in which the upper characteristic frequency $f_2$ performs just half an oscillation more within a bid width than the lower characteristic frequency $f_1$.

### 8.2 Gaussian Minimum Shift Keying

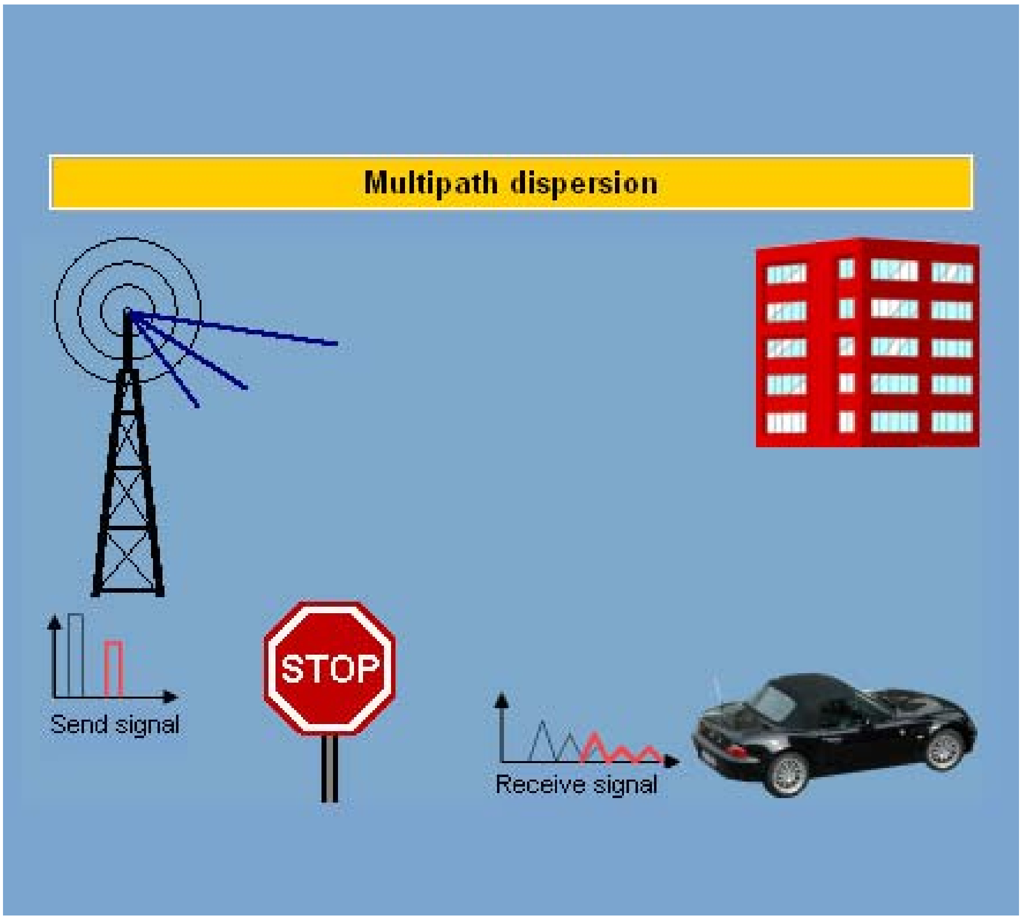



In Gaussian Minimum Shift Keying (GMSK[1]) further bandwidth limiting is accomplished by freeing the bit pulses from their steep pulse edges before modulation by means of a Gaussian low-pass filter (shape filter). Pulses filtered in this way then have the shape of a Gaussian bell curve, which can result in overlaying of successive pulses. On the receive side this means that greater effort is required for decoding the data signal when demodulating.

[1] **GMSK**

*Gaussian Minimum Shift Keying* is a special variation of MSK in which bandwidth is saved by using a Gaussian filter to free the bit pulses of their steep edges before modulation.

### 8.3 Signal dispersion




Special demands on sending and receiving technique are made by mobile communications, since the transmission channel changes with the location of the (mobile) receiver. The signal reaches the receiver over multiple paths due to reflection[1] , scattering[2] and diffraction[3] . Depending on the phase position of the overlaid signals, the result is a weakened signal. MSK and GMSK have especially favorable properties in this regard. They are characterized by a relatively low bit error frequency with a low bandwidth requirement.

[1] **Reflection**

Electromagnetic waves are reflected on electrically conductive surfaces (analogous to a mirror).

[2] **Scatter**

Electromagnetic waves are scattered for example in gases.

[3] **Diffraction**

Deflection of the straight-line propagation of an electromagnetic wave at edges, obstacles or along electrical conductors (for example along high-tension wires, along the curved surface of the earth or ocean, etc.)

### 8.4 GSM - Digital mobile communications


GMSK is used especially in digital mobile communications according to the GSM[1] standard. GSM was originated by the **G**roupe **S**pécial **M**obile, which in 1982 began developing a pan-European[2] Standard for digital mobile communication. In the meantime **GSM** stands for **G**lobal **S**ystem for **M**obile Communication. The original operating frequency range of the GSM networks is 900 MHz, and has been used in Germany since 1992 by the D-networks. An 1800 MHz-Standard has also existed for some time.

[1] **GSM**

The Global System of Mobile Communication is a technical standard for digital wireless telephony. In Germany frequency ranges around 900 MHz (D1- and D2-network) and 1800 Mhz (E-Plus-network) are used. For speech transmission, data can also be sent at 9600 bps in these networks.

[2] **Pan-European**

Including all of Europe.

### 8.5 GSM Standards

**Overview of GSM900 and GSM1800**

| | GSM 900 | GSM 1800 |
|---|---|---|
| Frequency (Uplink) | 890-915 MHz | 1710-1785 MHz |
| Frequency (Downlink) | 935-960 MHz | 1805-1880 MHz |
| Duplex separation | 45 MHz | 95 MHz |
| Bandwidth of the frequency channel | 200 kHz | 200 kHz |
| Carrier frequencies | 124 | 372 |
| Data burst duration | $576.9 * 10^{-6}$ s | $576.9 * 10^{-6}$ s |
| Bit number per data burst | 156.25 | 156.25 |
| Bit duration | $3.692 * 10^{-6}$ s | $3.692 * 10^{-6}$ s |
| Bit rate | 270.833 kBit/s | 270.833 kBit/s |
| Modulation procedure | GMSK (BT=0.3) | GMSK (BT=0.3) |
| Cell radius | 2 - 35 km | 0.2 - 8 km |
| Max. mobile station power | 20 Watt | 1 Watt |

The DCS1800-Standard is a further development of GSM, though only technical details were changed. The differences from GSM involve for example the frequency range, the cell radii and the transmitting power of the mobile stations. Since all network-specific parameters are the same, the designations were changed from DCS1800 and GSM1800 and GSM to GSM900. The adjacent table provides an overview of the key parameters of both GSM standards.

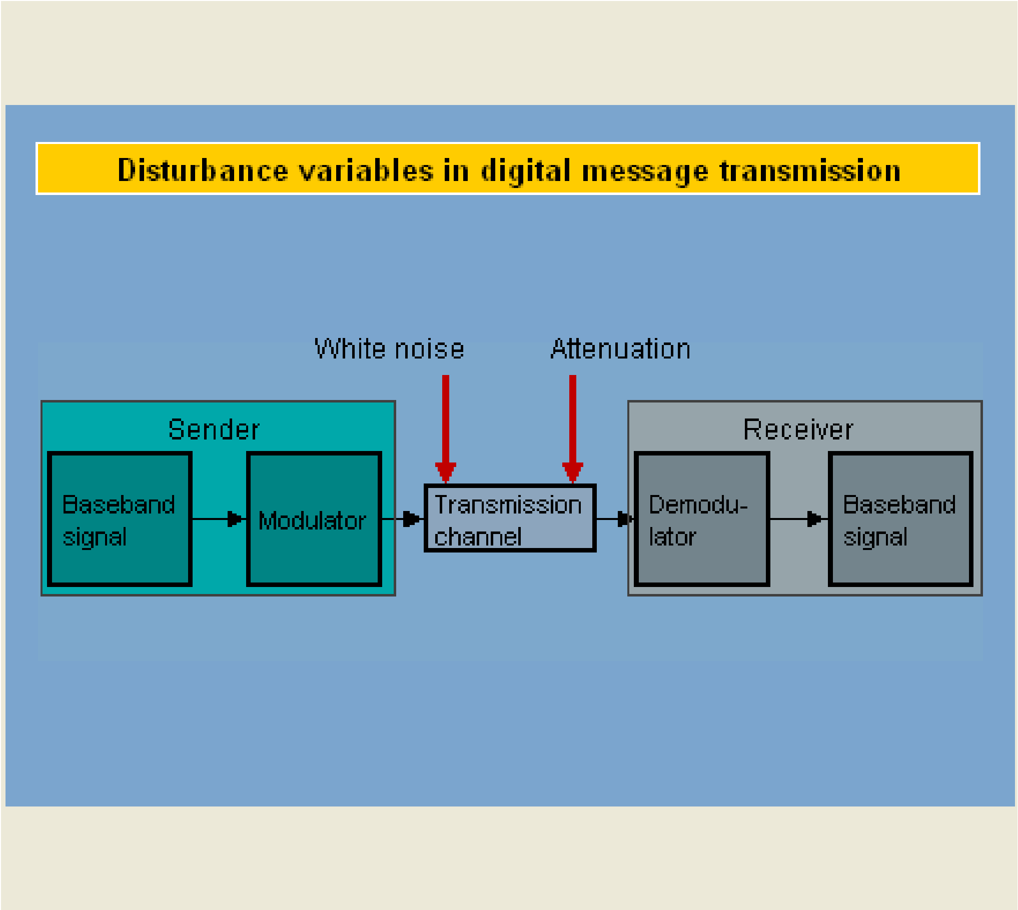
### 8.6 Summary

On the right side you will see a summary of the material covered in this chapter.

**Summary of this chapter**

- Minimum Shift Keying (MSK) is a bandwidth-optimized special form of FSK in which the two characteristic frequencies differ by only half an oscillation within a bit duration.
- In GMSK the bit pulses are also fed through a Gaussian filter for bandwidth saving prior to modulation.
- GMSK is especially noise-immune and is therefore preferred for use in mobile communication (GSM network).

### 9.1 Bit error rate

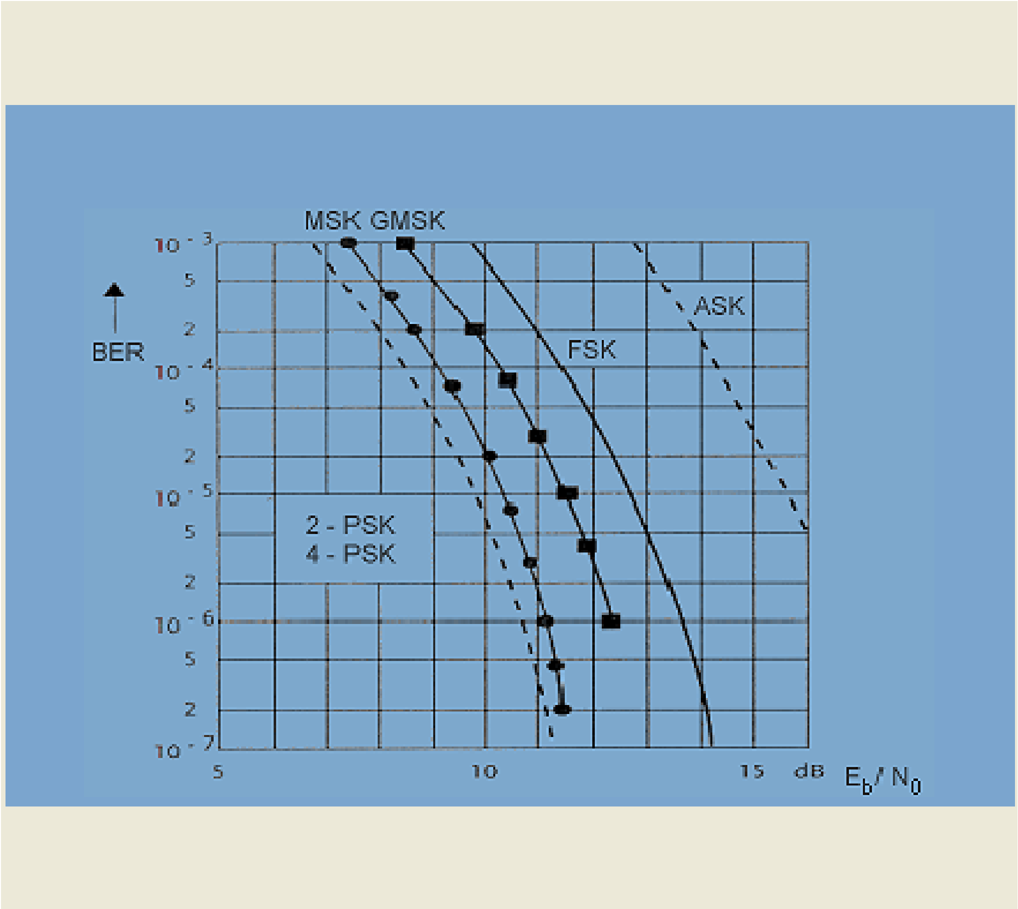



In addition to the energy and bandwidth requirement, freedom from errors in the transmitted information also plays an important role in digital message transmission. This can be expressed quantitatively by the bit error rate (**B**it **E**rror **R**ate BER[1] ). Errorless message transmission is made more difficult on one hand by noise in the signal path, and on the other by signal attenuation by the transmission channel and the resulting deformation of the original bit pulses.

[1] **Bit error rate**

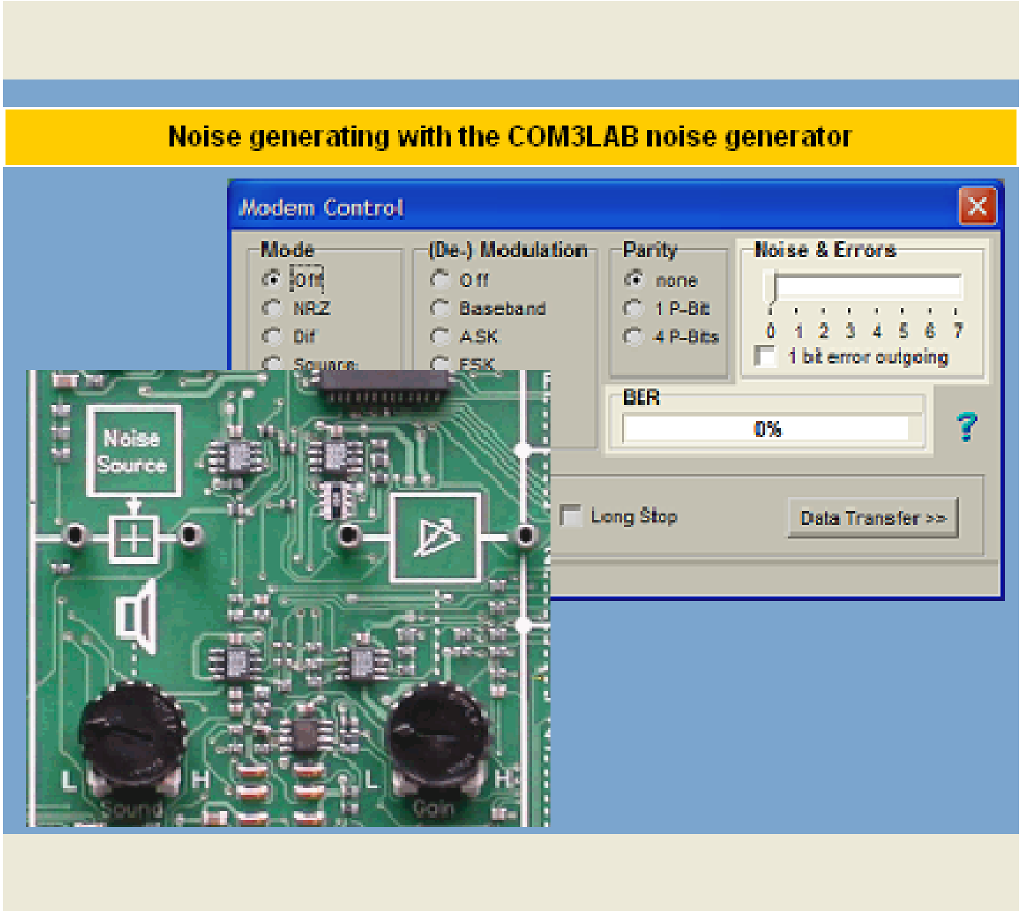
The bit error rate gives the ratio of the number of incorrectly sent bits to the total number of sent bits.

### 9.2 BER with various shift keying procedures



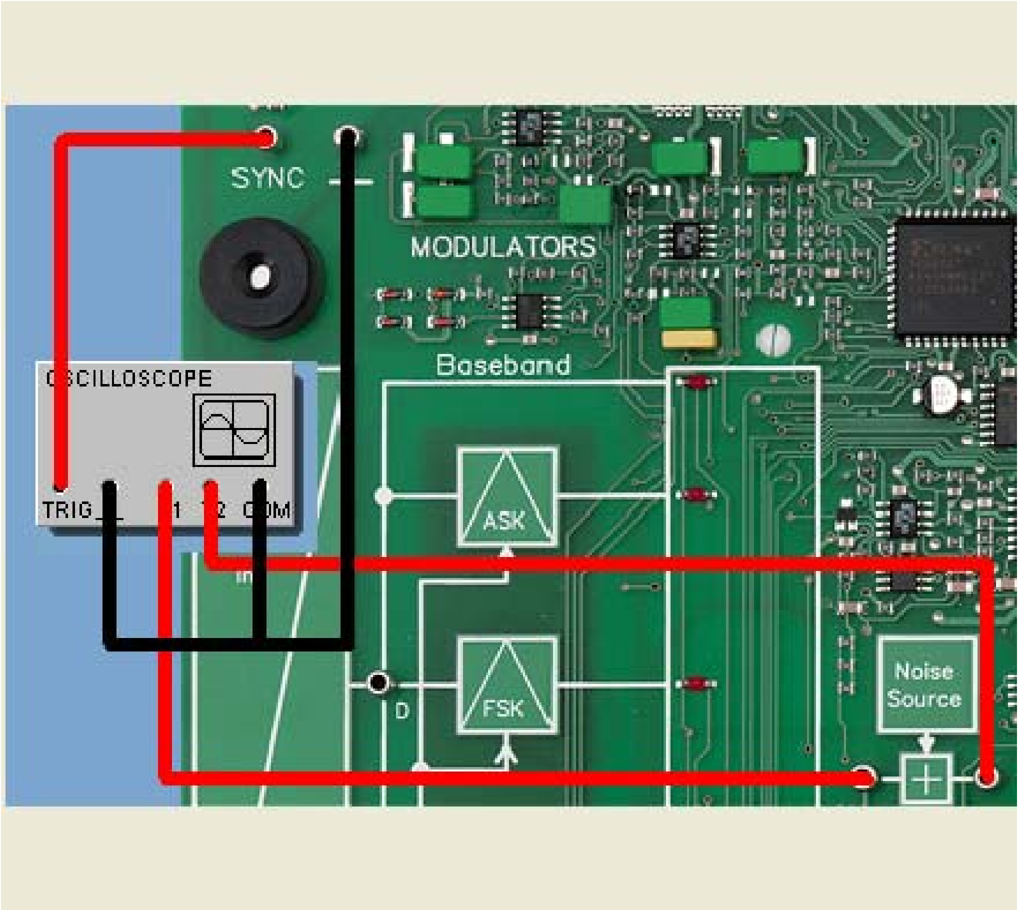

In addition to the formatting of the data in the baseband, the modulation procedure has an especially great effect on the bit error rate, as does the switching technique used in the modulator and demodulator. The adjacent graphic shows the bit error rate for the procedures under discussion as a function of the quotient $E_b/N_0$ as a measure of the signal-to-noise ratio ($E_b$: Energy per bit, $N_0$: Noise power density at the receiver).

### 9.3 The COM3LAB Noise Generator



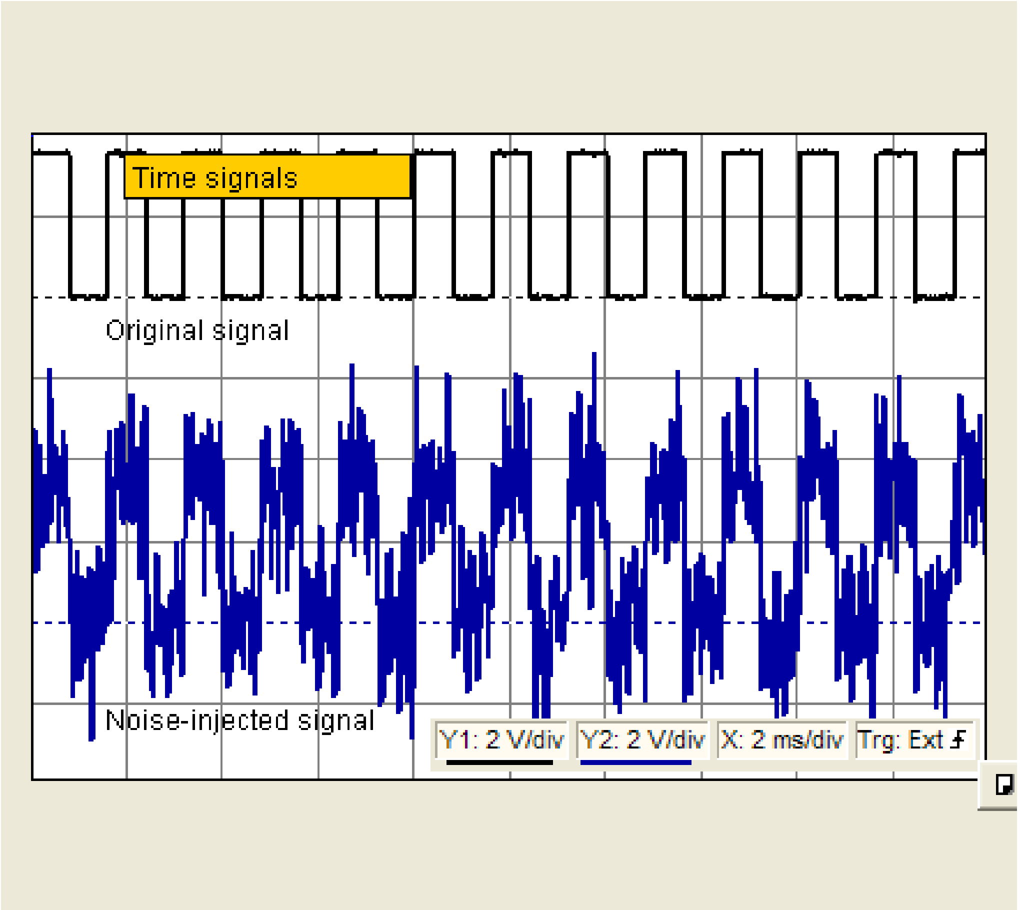

The COM3LAB-Board 700 74 incorporates a noise generator which can be used to generate an additive noise signal on to the send signal for studying the bit error rates for the various shift keying procedures. The noise power of the generator can be varied from the Control Panel. Beneath the slide controller is a bar display which indicates the resulting bit error. A loudspeaker can be used to make the send signal audible.

### 9.4 Experiment



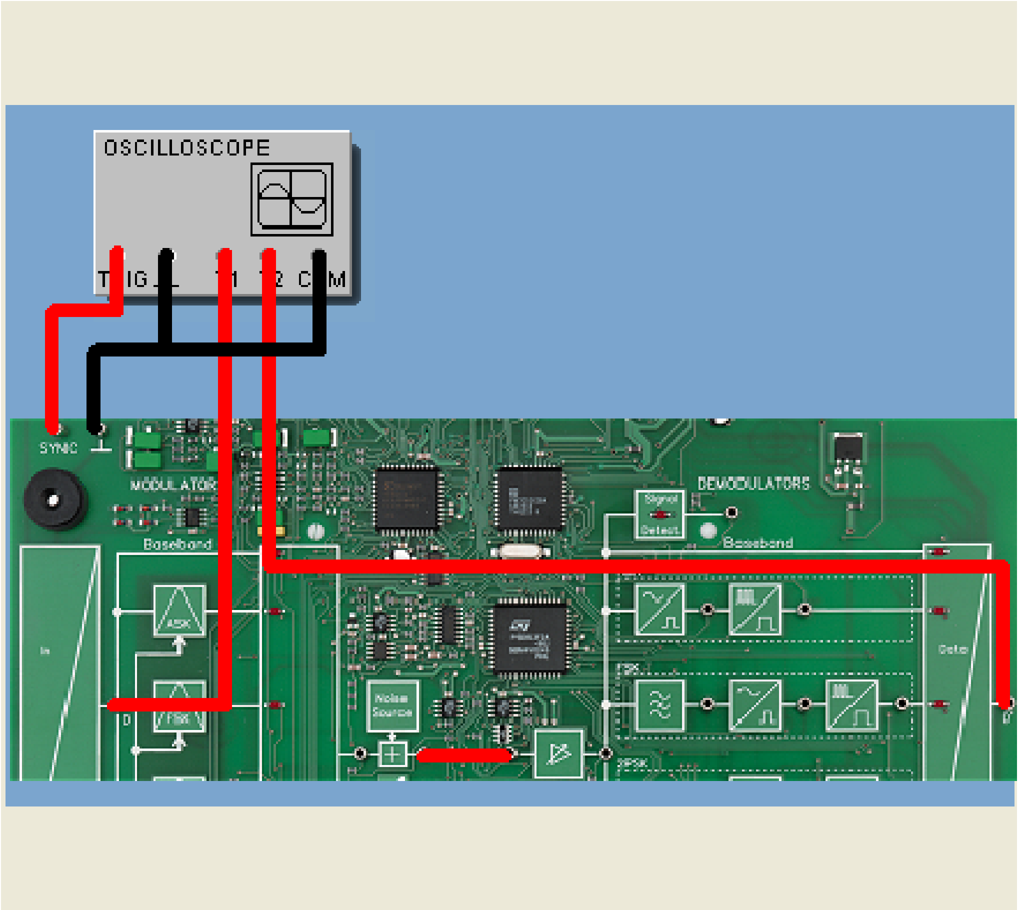

In the following experiment we will analyze the noise signal in the time and frequency ranges. A square-wave signal which is sent in the baseband will be additively overlaid. Note that the COM3LAB noise generator can, for didactic purposes, generate significantly higher error rates than actually occur in commercial systems!

### 9.5 Result



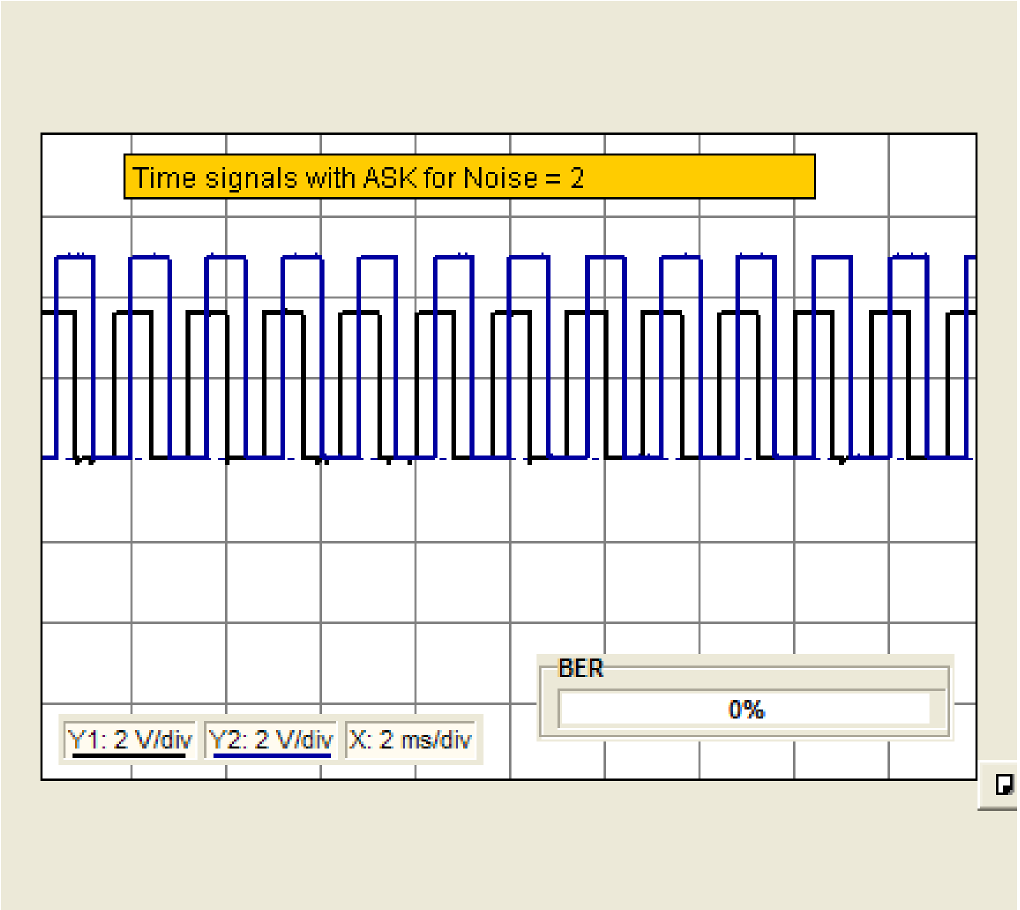

The noise generator approximates white noise, which is noise with a constant spectral power density over the entire frequency range. In the spectrum of the noise-injected signal this noise thus becomes apparent over the entire frequency range. Since statistically in the case of a square-wave modulation signal approximately every second bit is correctly recognized, the BER counter shows a maximum error rate of 50 %.

### 9.6 Experiment



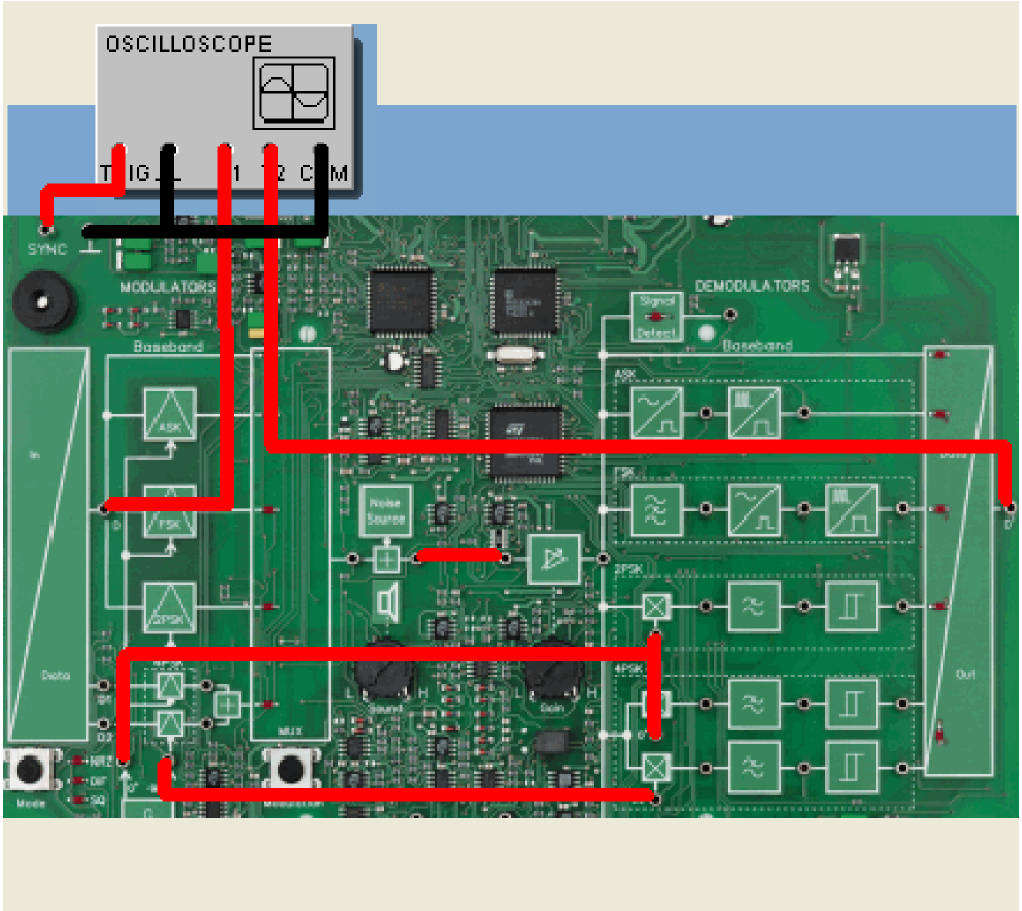
In the following experiment we will first investigate the effect of the noise level on the bit error rate in amplitude shift keying (ASK). A periodic square-wave signal will be used as the data signal. Since the bit error counter averages the occurring bit errors over a certain period of time, you must wait for a short time after the noise level changes before the correct value for the bit error rate can be read. **Note:** Note that the results obtained in this experiment may vary slightly due to sample deviation in the noise generator!

### 9.7 Result




In this example with a noise level of 2 all the sent bits could be decoded without error on the receive side. The first bit errors begin to occur at a noise level of 4. The higher the noise level is, the more bit errors occur. You may get slightly different results do to manufacturing tolerances of the noise generator.

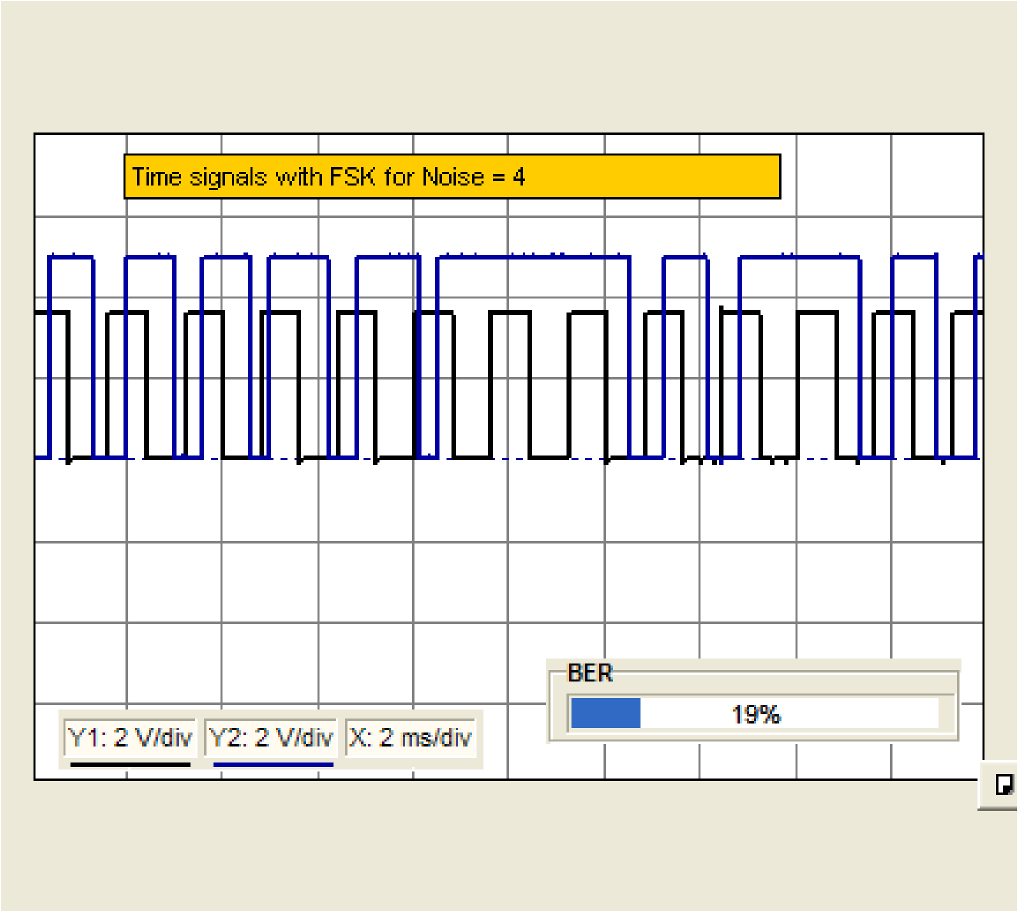
### 9.8 Experiment




In the following experiment we will investigate the effect of the noise level on the bit error rate with Frequency Shift Keying (FSK) and Four-Phase Shift Keying (2PSK and 4PSK[1]) and compare the relationships with Amplitude Shift Keying. To exclude the effect of carrier recovery in 2PSK and 4PSK demodulation, the original carrier signal is used in these cases for demodulation.

[1] Caution: The data signal changes here. Although a symmetrical square-wave is set, the dibit formation means that a periodic signal with changing duty cycle appears on Output D.

**9.9 Result**




For FSK the theory is contradicted by worse results than for ASK, since the FSK demodulator in the COM3-LAB is based on prior ASK demodulation; FSK and ASK would be superior if more complex FSK demodulation were used. For 2PSK and 4PSK there are practically no bit errors at the observed noise level; PSK is the most noise-immune type of modulation. Even when the noise is raised to the maximum value the bit error rate remains practically zero.

### 9.10 Application examples for shift keying types

| Shift keying | Typical application |
|---|---|
| MSK, GMSK | Mobile communications, GSM |
| 2PSK | Space telemetry, cable modems |
| 4PSK | Satellite communications - special code multiplex (CDMA) |
| | Bundle radio (TETRA), mobile communications for EU air traffic (TFTS) |
| | Digital television (DVB-S), cable (special return channel) |
| OQPSK | Satellite communications (CDMA) |
| FSK, GFSK | DECT, beepers, data communications, public mobile communications |
| | Police radio, American mobile phone system (AMP) |
| 8PSK | Satellites, aircraft |
| 16QAM | Microwave digital radio, modems, DVB-C, DVB-T |
| 32QAM | Terrestrial microwave radio, DVB-T |
| 64QAM | DVB-C, modems, Broadband-TV-Set-Top-Boxes |
| 256QAM | Modems, DVB-C (Europe), Digital-Video (USA) |

As the preceding chapters have shown, the various shift keying types all have their special advantages and disadvantages which predestine them for use in particular areas. The adjacent table shows a few application examples for shift keying types covered in this course, as well as additional procedures such as quadrature amplitude modulation (QAM[1] ).

[1] **QAM**

QAM stands for *Quadrature Amplitude Modulation*. In QAM digital signals are represented by a combination of for example four phases and four amplitudes. The data are represented in the resulting matrix. This procedure is used for example in transmitting faxes.

See also: Modulation, V.32

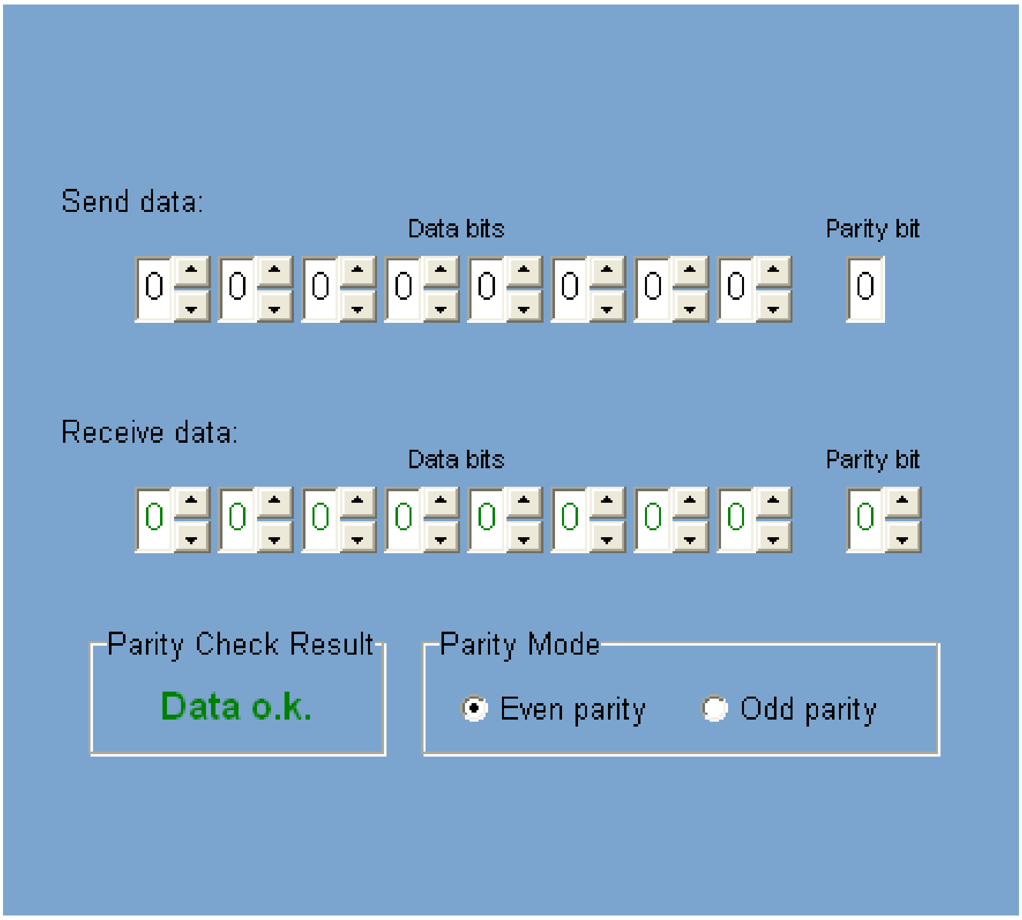
### 9.11 Summary

On the right side you will see a summary of the material covered in this chapter.

**Summary of this chapter**

- The transmission quality in digital communication is affected by attenuation in the transmission channel and by noise.
- The bit error rate (BER) as a number of the incorrect decisions with respect to the total number of bits sent represents a measure of the transmission quality.
- In practice a compromise must be made between low bandwidth requirements on one hand and low bit error rate on the other.
- Phase shift keying has the lowest bit error rate, amplitude shift keying the greatest; FSK, GMSK and MSK lie in between.

### 10.1 Detecting bit errors

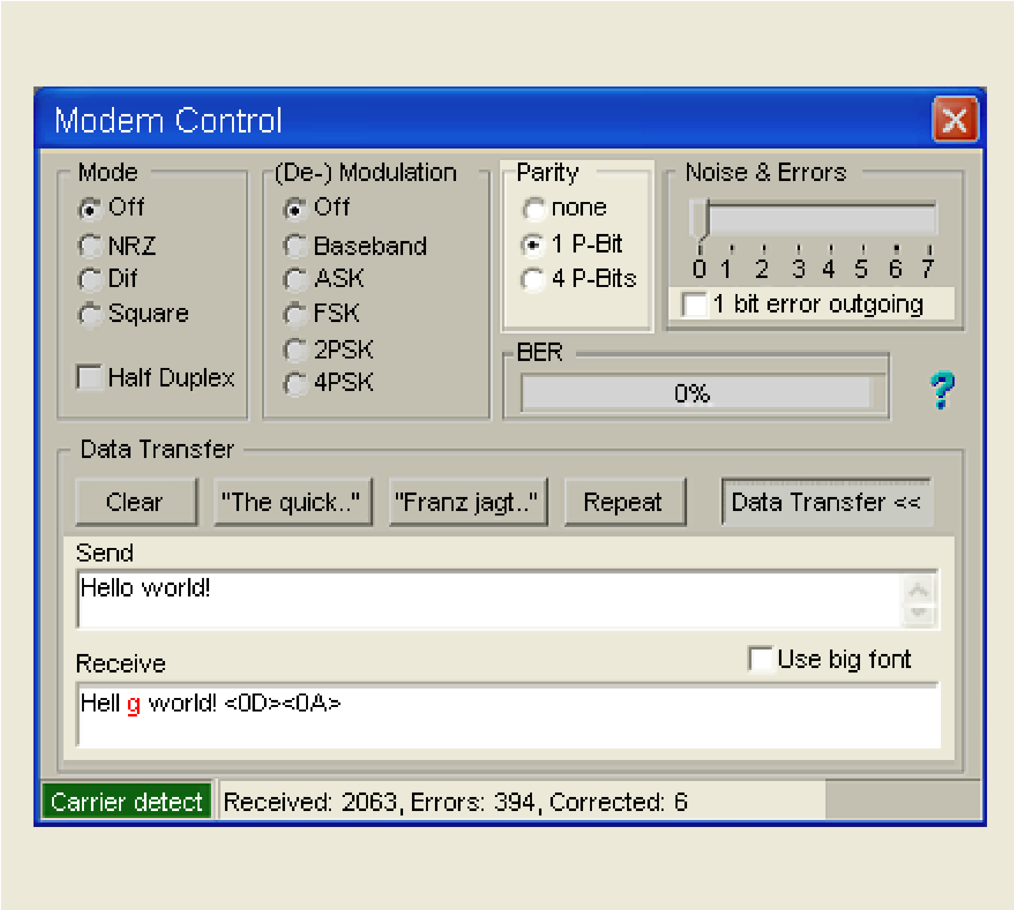



Due to disturbing effects bit errors can arise in transmission, with a distinction made between single and multi-bit errors. Error detection on the receive side is possible only by increasing the redundancy, in other words adding additional bits to the data word. Thus an additional sent parity bit[1] allows detection (but not correction!) of single-bit errors. It brings the total number of "1" bits to an even number (even parity) or uneven number (odd parity).

[1] **Parity**

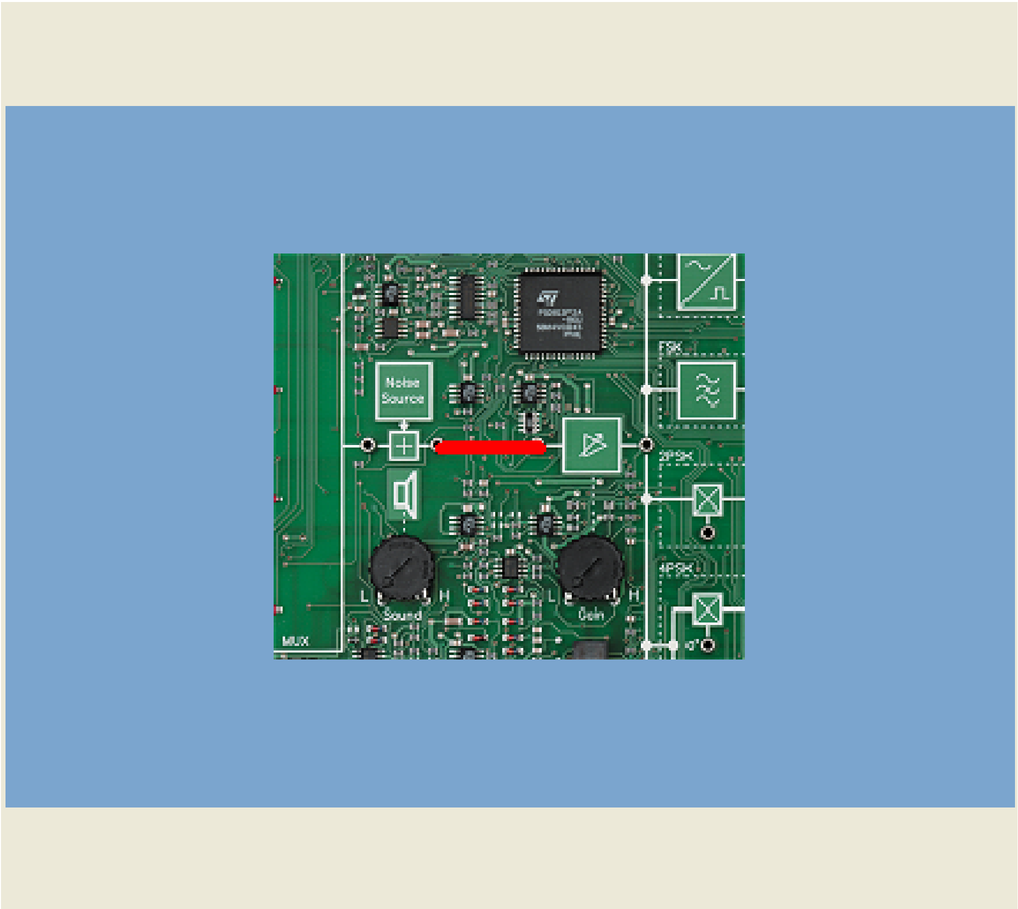
In data transfer, a bit used for error detection. A component of the transmission format. Sometimes omitted (no parity) or always one (mark) or zero (space). In even parity the bit is set when the number of '1' bits in the data is odd. Likewise, in odd parity the bit is set if the number of '1' data bits is even.

### 10.2 Bit error generation




The noise generator of the COM3LAB is not suitable for analyzing error detection and correction procedures, since the noise signal it generates results in relatively uneven bit error rates. For these purposes the COM3-LAB does however include a built-in bit error generator which results in generation of a nearly constant bit error rate. This bit error generator can be activated from the '1 bit error outgoing' option field in the Control Panel. The bit errors are generated on the send side and affect only data bits; the bit error counter (BER display) in the Control Panel does **not** show these bit errors.

### 10.3 Experiment: Detecting single-bit errors




In the following experiment we will investigate detection of single-bit errors when a single parity bit is used. The bit error generator on the COM3LAB is used to generate the bit errors. Since the actual transmission is undisturbed (no noise), data formatting and type of modulation do not matter; in this example NRZ format and ASK are used.

### 10.4 Hamming Distance I

**Hamming-Code for representing decimal numbers**

| Bit-No. | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Value | | $K_0$ | $K_1$ | $2^3$ | $K_2$ | $2^2$ | $2^1$ | $2^0$ |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Decimal- | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 |
| number | 2 | 0 | 1 | 0 | 1 | 0 | 1 | 0 |
| | 3 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| | 4 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| | 5 | 0 | 1 | 0 | 0 | 1 | 0 | 1 |
| | 6 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| | 7 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| | 8 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |

$K_0$ : Check bit for Bit-No. 1, 3, 5 and 7

$K_1$ : Check bit for Bit-No. 2, 3, 6 and 7

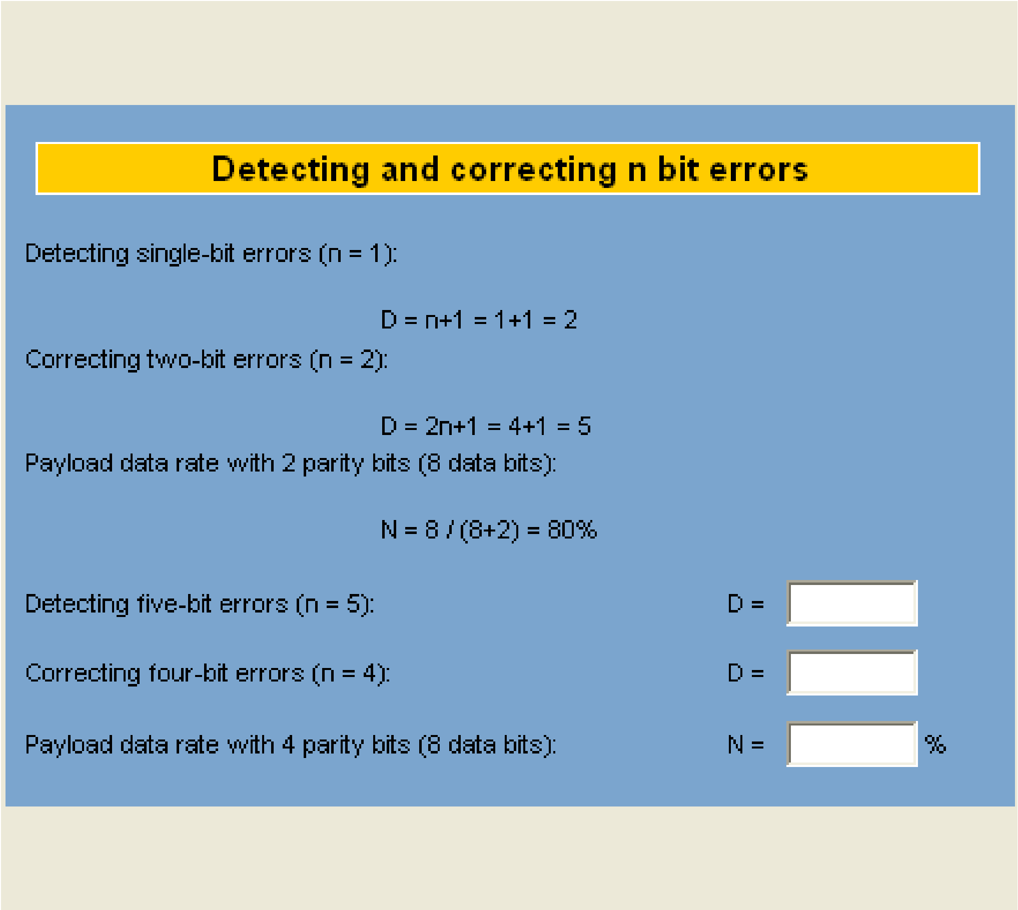
$K_2$ : Check bit for Bit-No. 4, 5, 6 and 7

The effectiveness of an error detection and correction scheme depends on the so-called Hamming distance[1] D, which gives the minimum number of binary places in which any two code words differ. For a fully used code without redundancy D = 1, and a single parity bit results in D = 2. A code expanded by several check bits is called Hamming code.

[1] **Hamming distance**

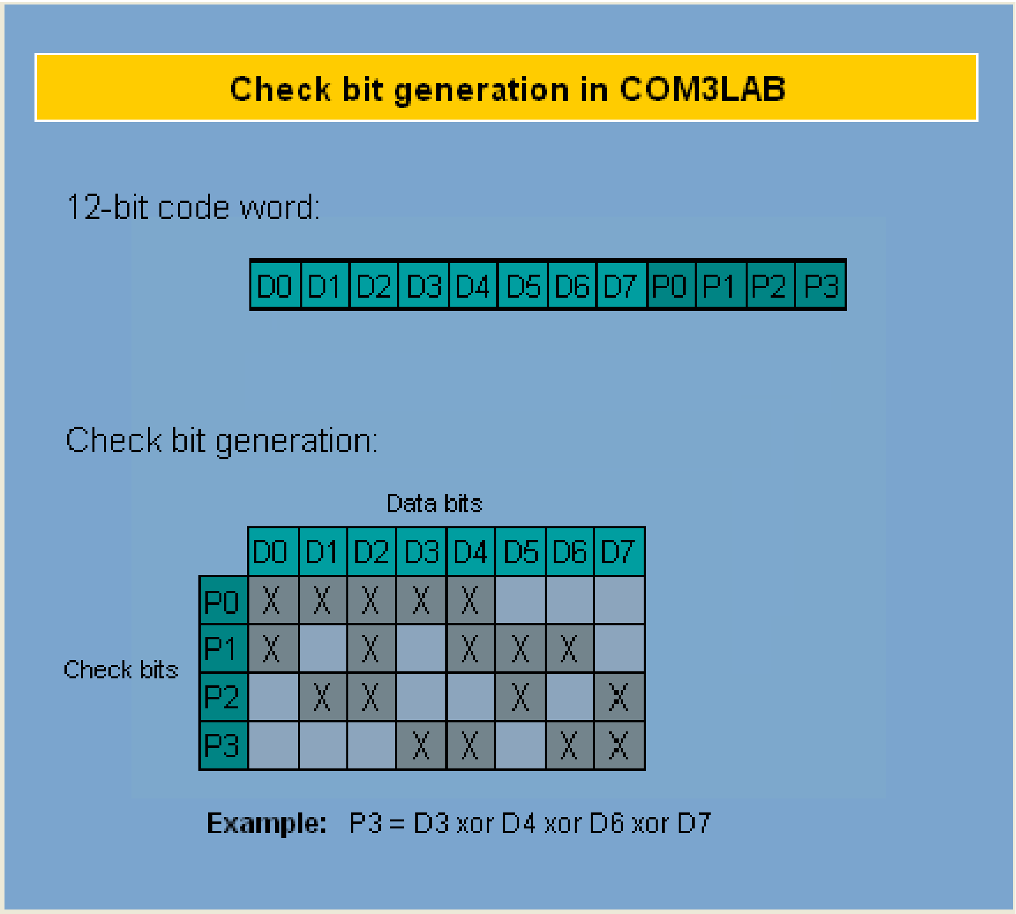
The Hamming distance is the number of positions in two strings of equal length for which the corresponding elements are different. The Hamming distance is used in telecommunication to count the number of flipped bits in a fixed-length binary word, an estimate of error, and so is sometimes called the signal distance.

### 10.5 Hamming Distance II



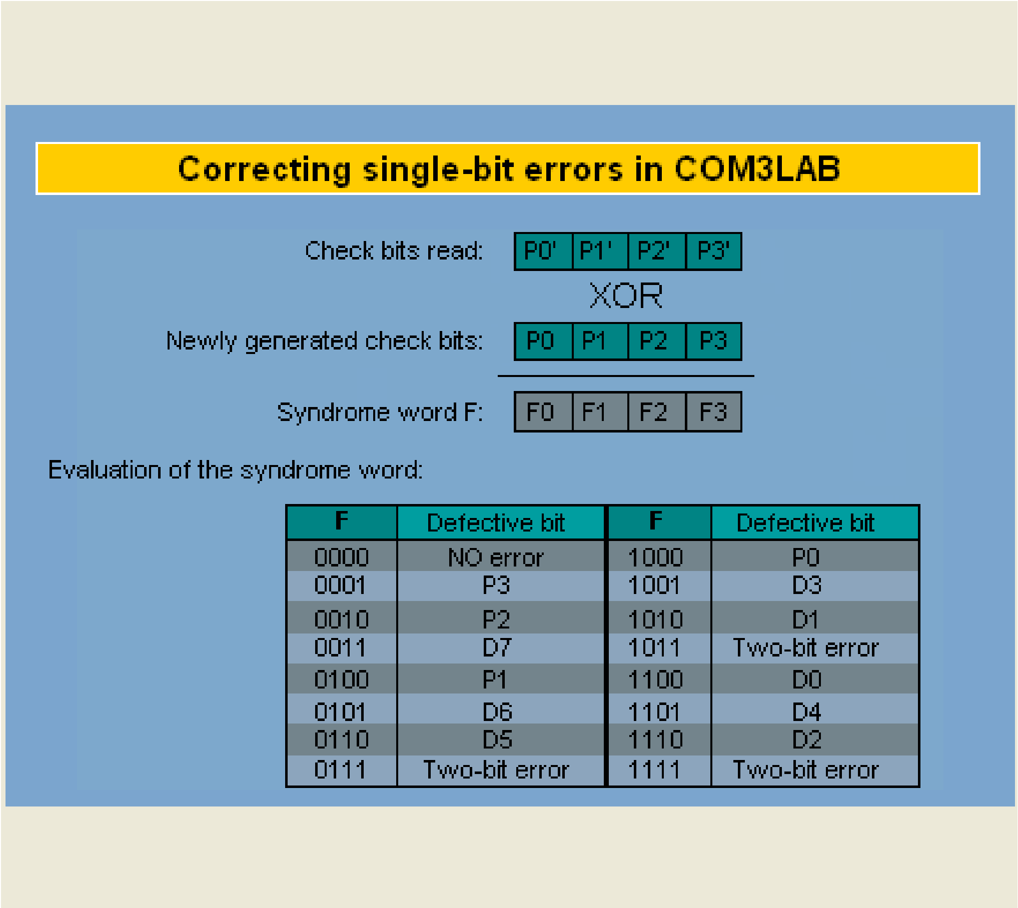

To detect n bit errors the Hamming distance D must be ≥ n+1, and for correcting n bit errors D ≥ 2n+1. By inserting the parity bit, the code does not however get any redundancy, in other words the payload data rate N - the ratio of payload data bits to the total number of bits (payload data bits + parity bits) - drops. The adjacent graphic shows some examples.

### 10.6 COM3LAB check bit generation




The Modem Technology board allows you to add eight data bits D0 ... D7 and four check bits P0 ... P3, so that a 12-bit code word results. This allows you then to detect certain two-bit errors and to correct single-bit errors. The check bits are formed as parity bits over several data bits, whereby a different combination is always selected and each data bit is checked by at least two check bits. When there is a defective data bit, there is a difference in exactly those check bits which are influenced by this bit.

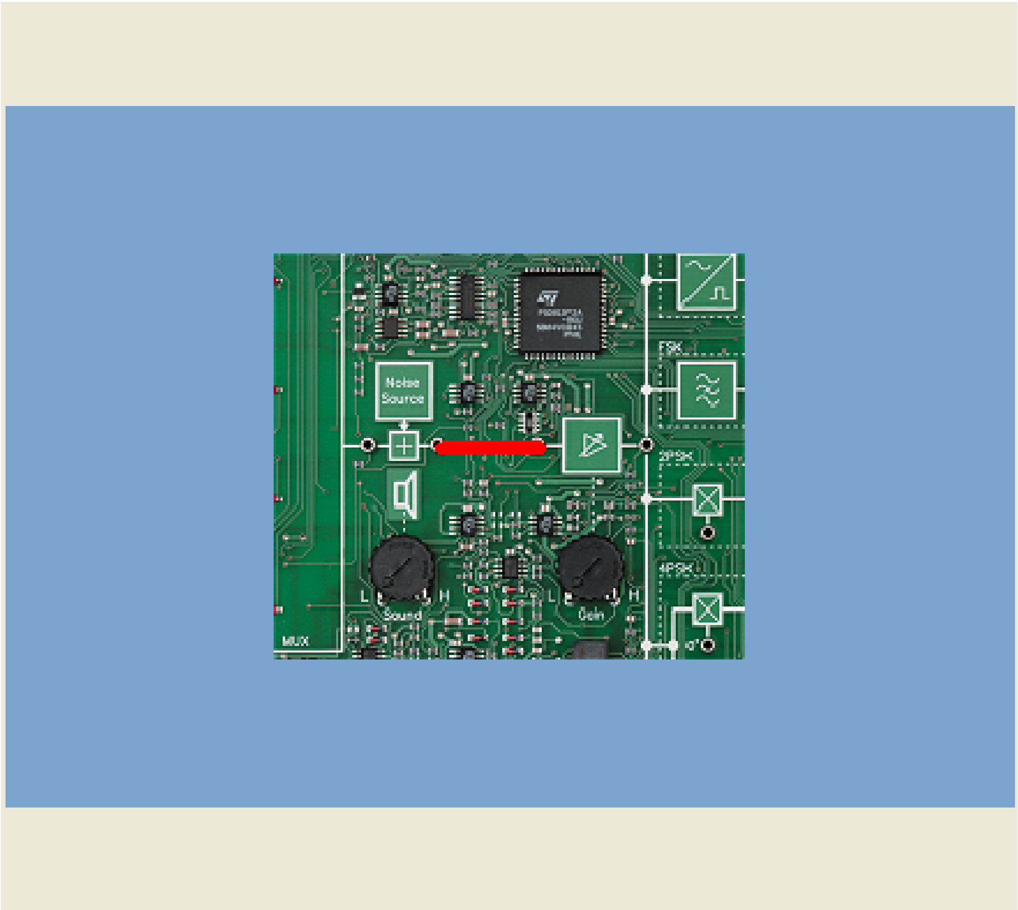
### 10.7 COM3LAB error correction




| F | Defective bit | F | Defective bit |
|---|---|---|---|
| 0000 | NO error | 1000 | P0 |
| 0001 | P3 | 1001 | D3 |
| 0010 | P2 | 1010 | D1 |
| 0011 | D7 | 1011 | Two-bit error |
| 0100 | P1 | 1100 | D0 |
| 0101 | D6 | 1101 | D4 |
| 0110 | D5 | 1110 | D2 |
| 0111 | Two-bit error | 1111 | Two-bit error |

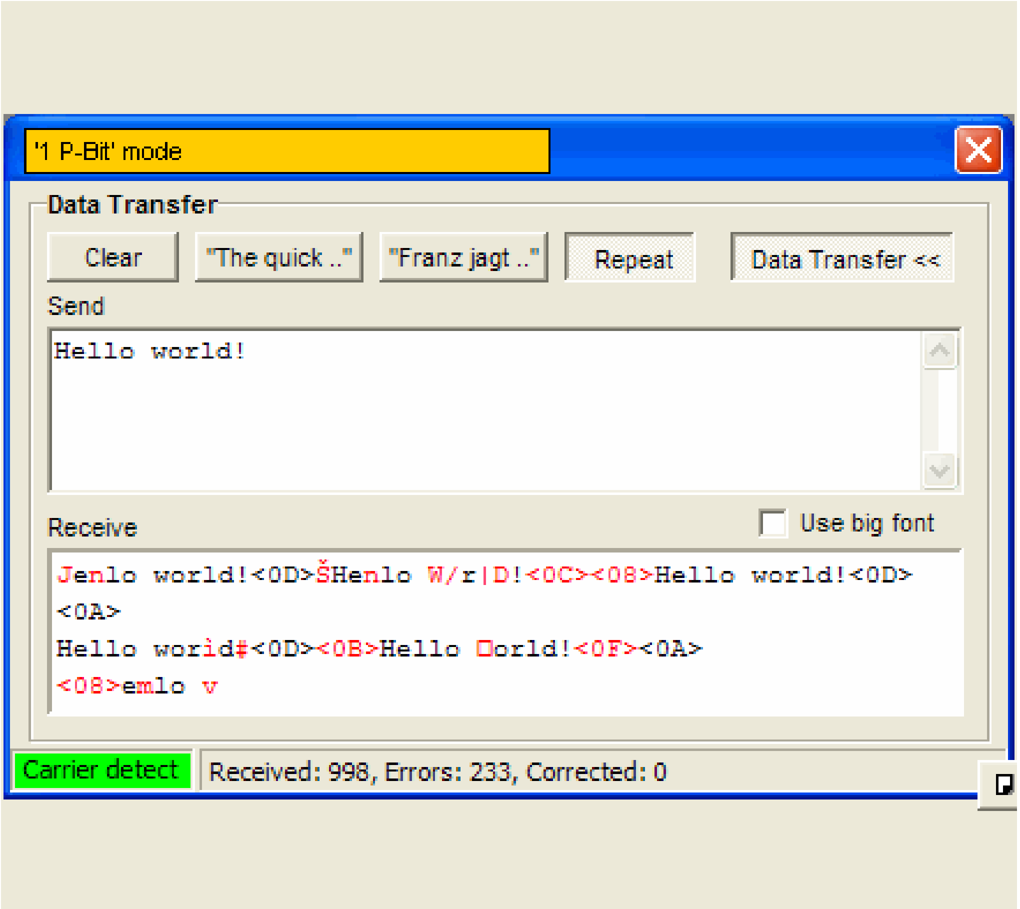
For error correction the read check bits P0' ... P3' with the newly generated check bits P0 ... P3 newly generated from the read data bits on the receive side are XORed to produce a so-called syndrome word F0 ... F3. The defective bit results from this syndrome word for single-bit errors. Correction is performed by inverting the affected bit. Three combinations of the syndrome word indicate two-bit errors; this does **not** however mean that all two-bit errors are detected.

### 10.8 Experiment: Error correction in the COM3LAB




In the following experiment we will investigate the correction of single-bit errors using a 12-bit code word with four check bits. Since the actual transmission is undisturbed (no noise), data formatting and type of modulation do not matter; in this example NRZ format and ASK are used. Any desired texts are sent. Corrected single-bit errors are shown in pink in the receive field of the Control Panel and multi-bit errors are shown in red.

### 10.9 Result




Whereas single-bit errors are detected when using a single parity bit (‚1 P-Bit') but cannot be corrected (red characters in the receive field), coding with four parity bits (‚4 P-Bits') is able to correct these single-bit errors as well (pink characters in the receive field). The total number of generated (and corrected) single-bit errors here is around 20-25 %.

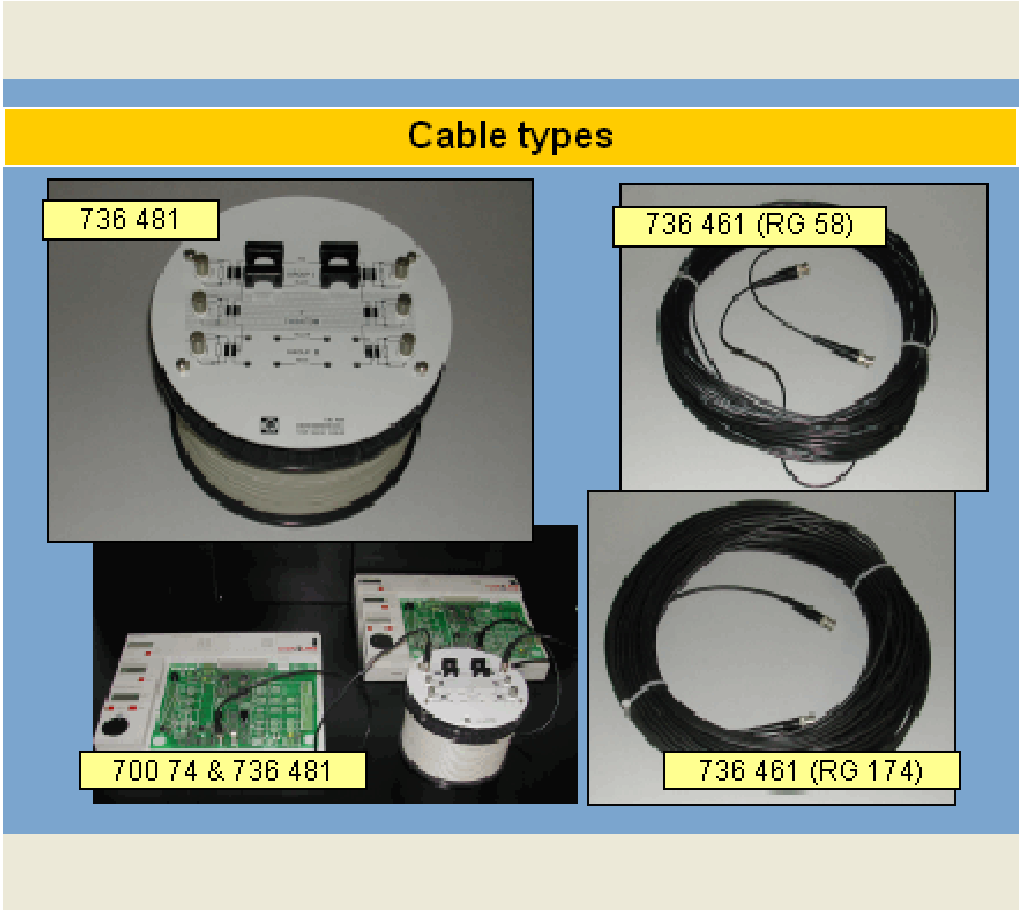
### 10.10 Summary

On the right side you will see a summary of the material covered in this chapter.

**Summary of this chapter**

- For error detection and correction redundancy must be added to the data word in the form of additional check bits.
- The Hamming distance D of a code indicates by how many binary places any two code words differ at least.
- To detect n bit errors, a Hamming distance of n+1 is required, or 2n+1 for error correction.
- A code consisting of eight data and four check bits allows correction of single-bit errors as well as detection of certain (but not all) two-bit errors.

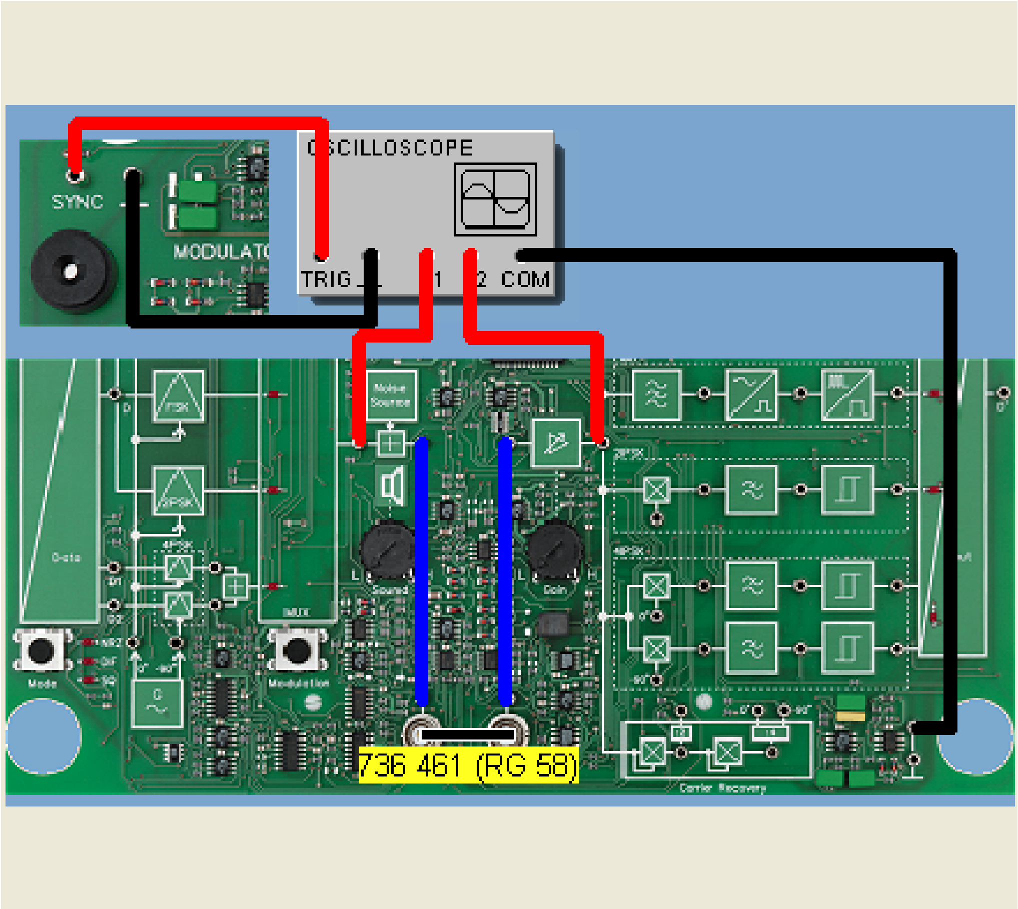
### 11.1 Cable types




The communication channel - for land-line transmission this means the type of connection cable - has a significant influence on the quality of the data transfer. An improvement in transmission can for example be realized by refreshing the signal after a certain length of cable. In the following we will investigate various types of cables.

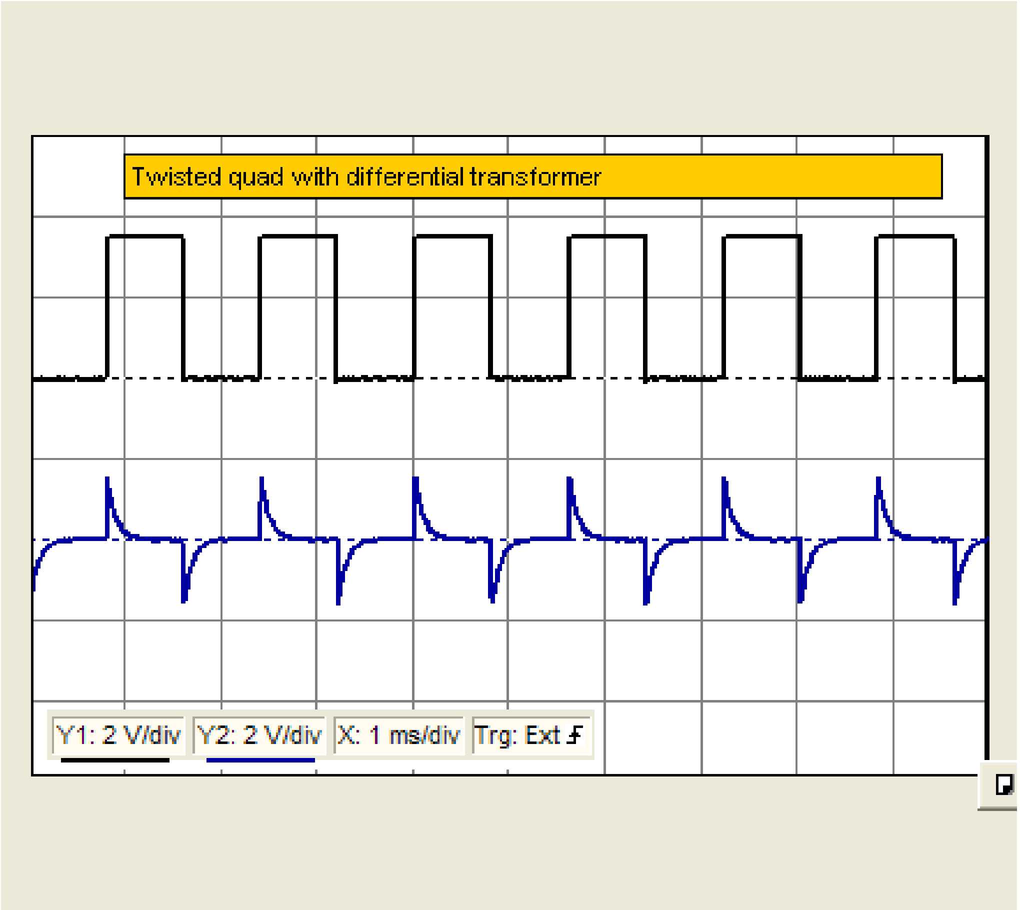
**Note:** Various additional equipment is needed for the following experiments.

### 11.2 Experiment: Influence of the transmission line in the baseband



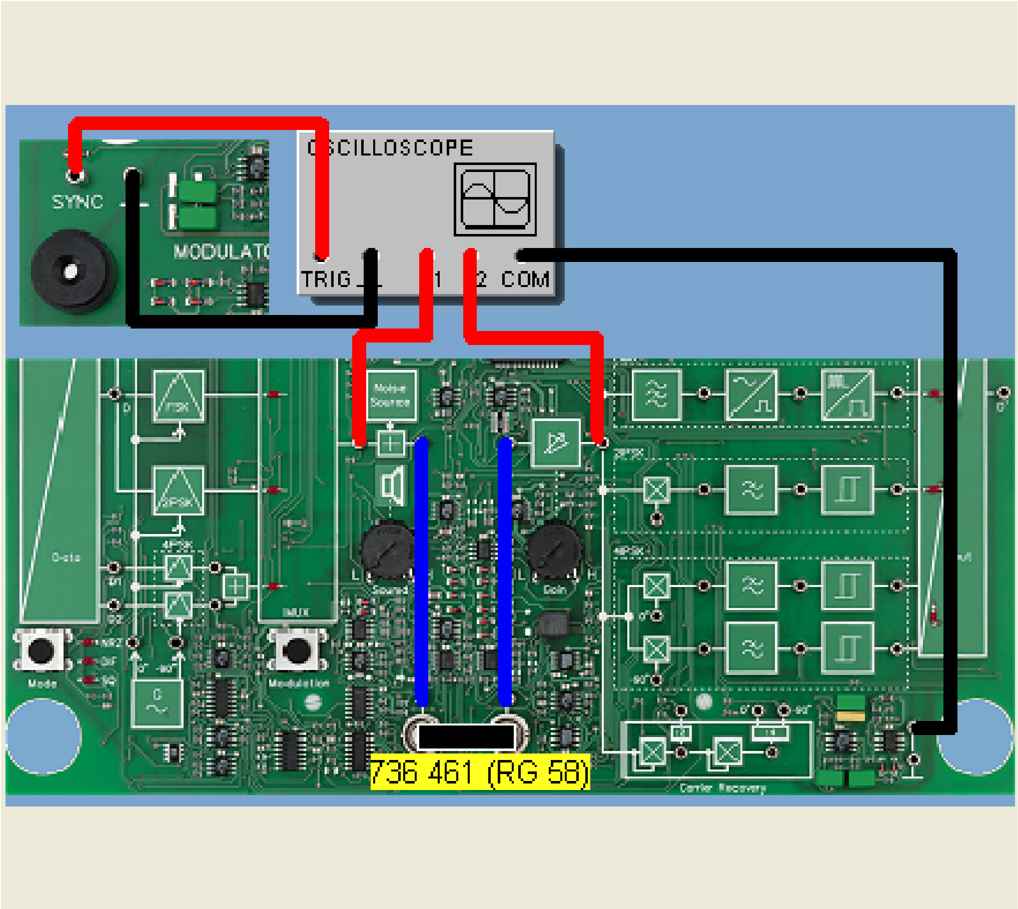

In the following experiment we will first investigate the influence of the transmission line when transmitting in the baseband. A square-wave data signal will be sent (SQ format) and the course of the signal recorded on the send and receive end. Two different coaxial cables as well as a twisted quad with differential transformer will be used.

### 11.3 Result



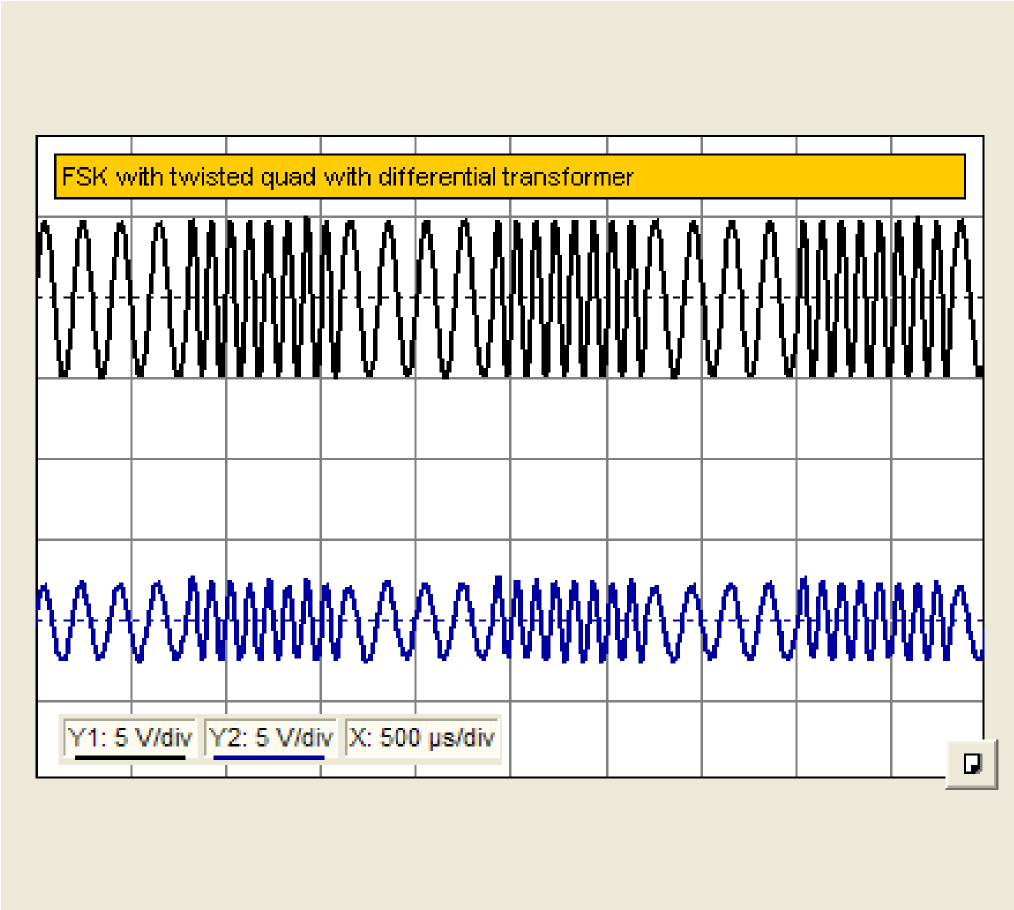

With the 50 m long coaxial cable types RG 58 and RG 174 the bit pulses are only somewhat 'clipped' by the transmission characteristic of the cable but retain their basic shape, so that the send data on the receive side can be reconstructed with no problem. The twisted quad cable with differential transformer on the other hand filters out the DC component of the send signal, so that instead of the bit pulses only narrow pulses appear at the original pulse edges and data reconstruction is not possible.

### 11.4 Experiment: Influence of transmission cable in ASK/FSK




In the following experiment we will now investigate the influence of the transmission cable in Amplitude Shift Keying (ASK) and Frequency Shift Keying (FSK). A square-wave data signal will again be sent (SQ format) and the course of the signal recorded on the send and receive end. Two different coaxial cables as well as a twisted quad with differential transformer will be used.

### 11.5 Result




With ASK and FSK the baseband signal is shifted by the modulation to a frequency range around the carrier frequency $f_0$. In this frequency range all three studied cable types show only slight attenuation, so that except for the lower amplitude (which can be compensated by the receive-side amplifier) the receive signal is identical with the send signal.

### 11.6 Summary

On the right side you will see a summary of the material covered in this chapter.

**Summary of this chapter**

- The characteristics of the transmission medium have a significant effect on the transmission quality.
- Baseband transmission only makes sense for a transmission channel with low-pass behavior.
- The signal attenuation caused by the cable must be compensated on the receive end by appropriate amplifiers.

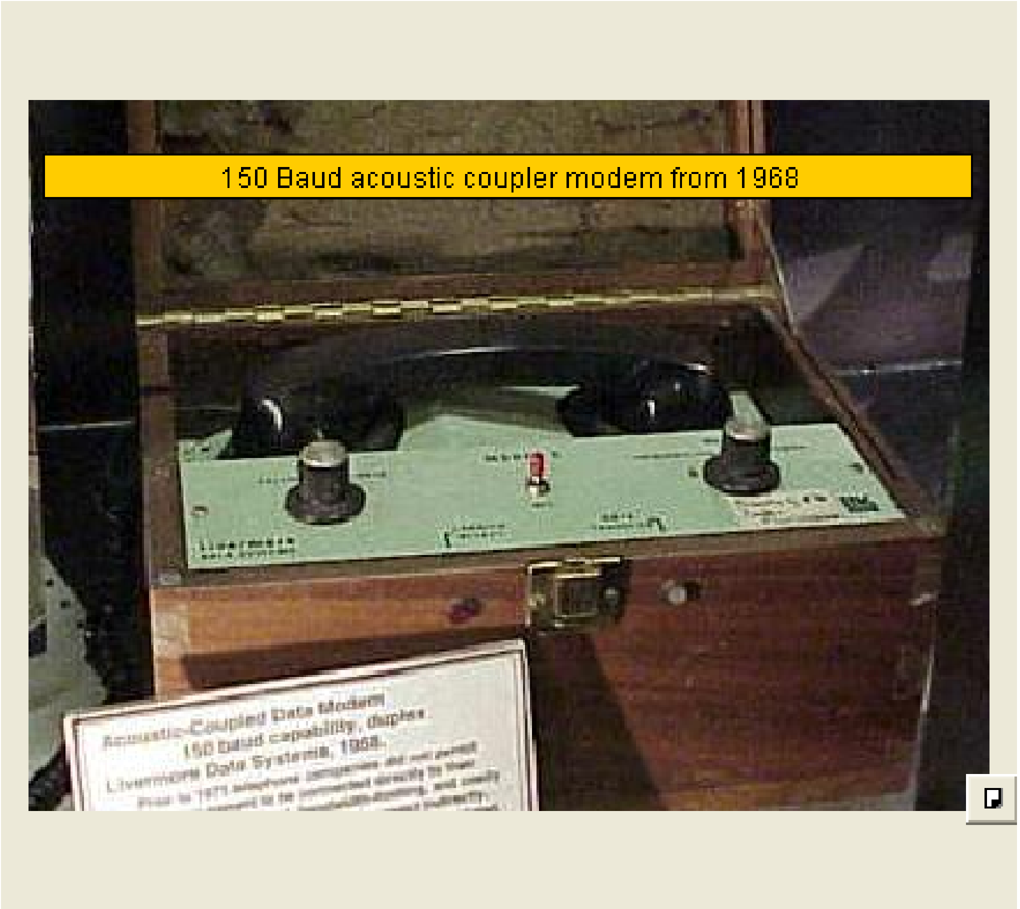
### 12.1 What is a modem?


A modem[1] (abbreviation for **Mod**ulator/**Dem**odulator) Is a device which converts analog acoustic signals in the frequency range between 300 Hz and 3400 Hz into digital signals for the computer interface or vice-versa. Modems have taken on great significance for use in the public telephone network, since they can link data processing systems quickly and cost-effectively.

[1] **Modem**

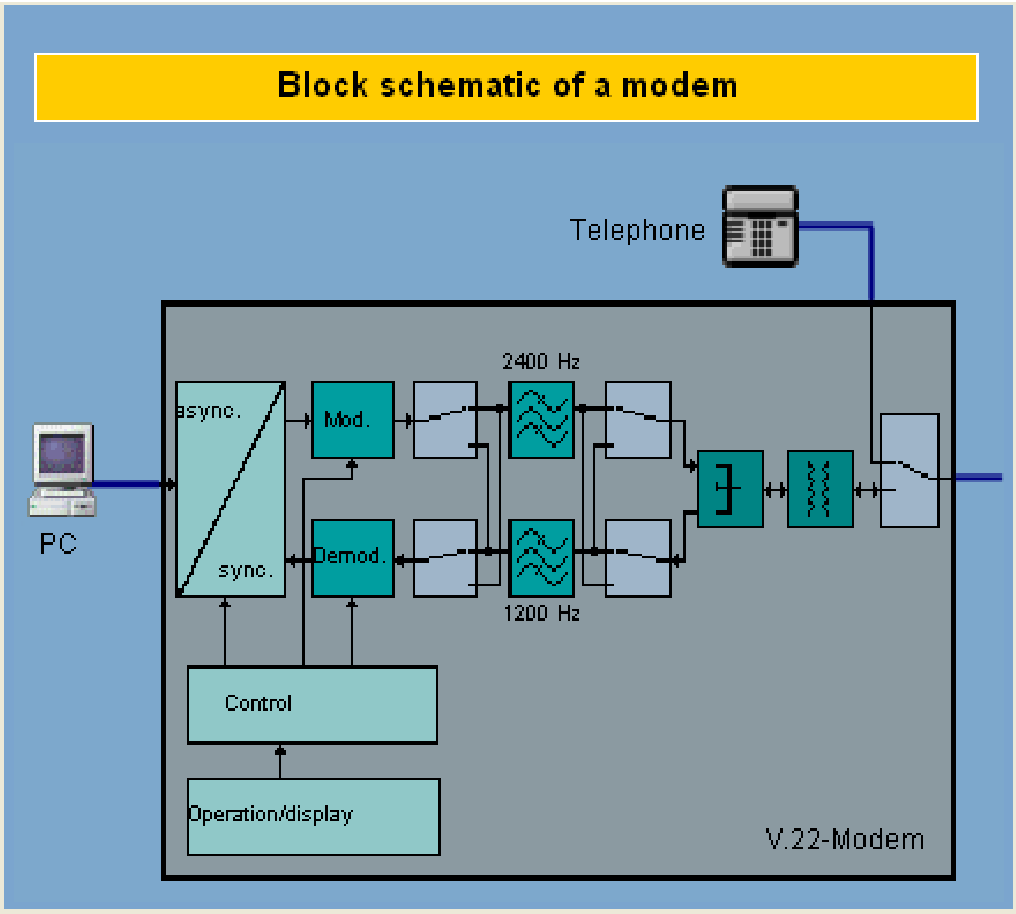
Abbreviation for MOdulator/DEModulator. A modem converts the bit stream of the computer into analog signals, which can then be sent over the telephone network (modulation). The partner modem then reverses the conversion (demodulation). This means the acoustic coupler is also a modem, even though it is not usually referred to as such. The term is usually used only for devices that are directly connected to the line, as opposed to the telephone itself. In the simplest terms a modem converts outgoing data into tones and converts tones coming back over the telephone line back into data.

### 12.2 Modem types




With the first modem types, the so-called acoustic couplers, the telephone receiver had to be placed in a special device in order to send the signal. In the meantime modems in a wide range of designs are available. Among the most important are external and internal models for use on a PC, which are connected to the serial port or plugged into a free ISA, PCI or PCMCIA slot in the computer.

### 12.3 Block schematic of a modem




The modulator and demodulator form the core components of a modem. In addition, a modern modem has a variety of additional components which are responsible mainly for control of the modem and switching between the send and receive channel. The adjacent graphic shows a detailed block schematic of a modem.

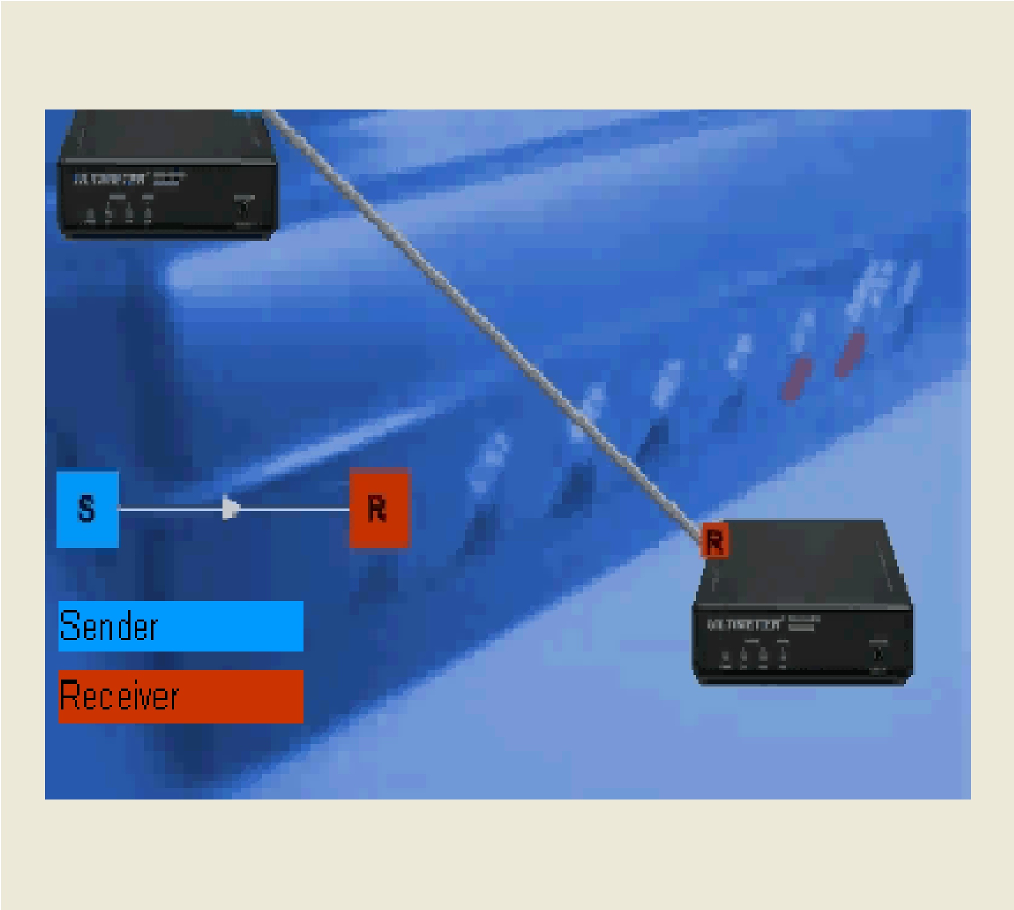
### 12.4 Experiments

| Quantity | Catalog-No. | Description | Illustration |
|---|---|---|---|
| 1 | 700 00 | Second COM3LAB Master Unit | |
| 1 | 700 74 | Second Exp.-Board "Modem Techn." | |
| 1 | 736 481 | Twisted quad | |
| 1 | 736 461 | Coaxial cable set | |
| 2 | 575 24 | Test cable BNC / 4 mm plug | |
| 2 | 501 02 | HF cable, 1 m long | |
| 1 | 501 511 | 10 connectors, black | |

Accessories for the experiment series "Modem Operating Modes"

For the experiments described in the following involving different operating modes of modems you will need additional components which go beyond what is included in the course. At right you will see an overview of those components that are required for completing all the experiments.

### 12.5 Simplex mode

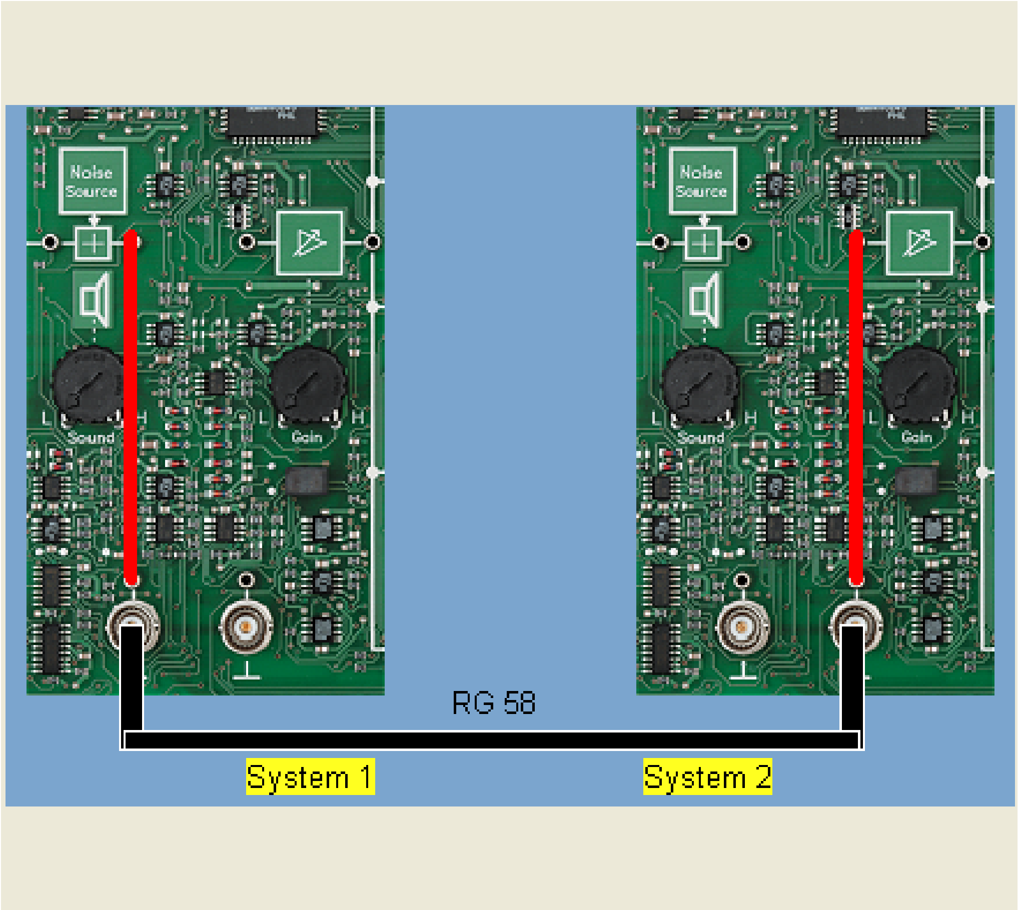



Depending on the transmission systems and the desired applications, there are various transmission types (direction modes) for the physical arrangement of data connections and the logical information flow over these connections. In simplex mode[1] data can be sent in only one direction from the data source (Sender S) to the data sink (Receiver R). Examples of simplex mode are radio and TV transmissions.

1 **Simplex**

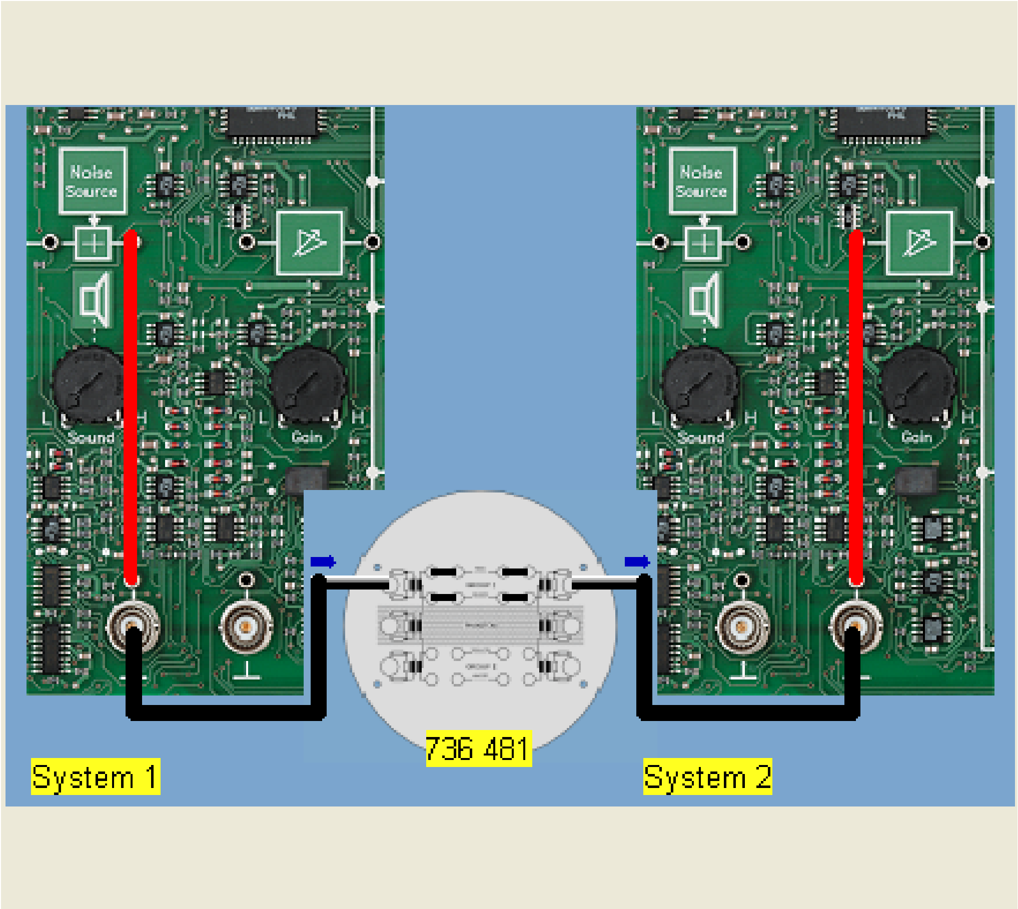
Data transfer in just one direction.

### 12.6 Experiment: Simplex mode



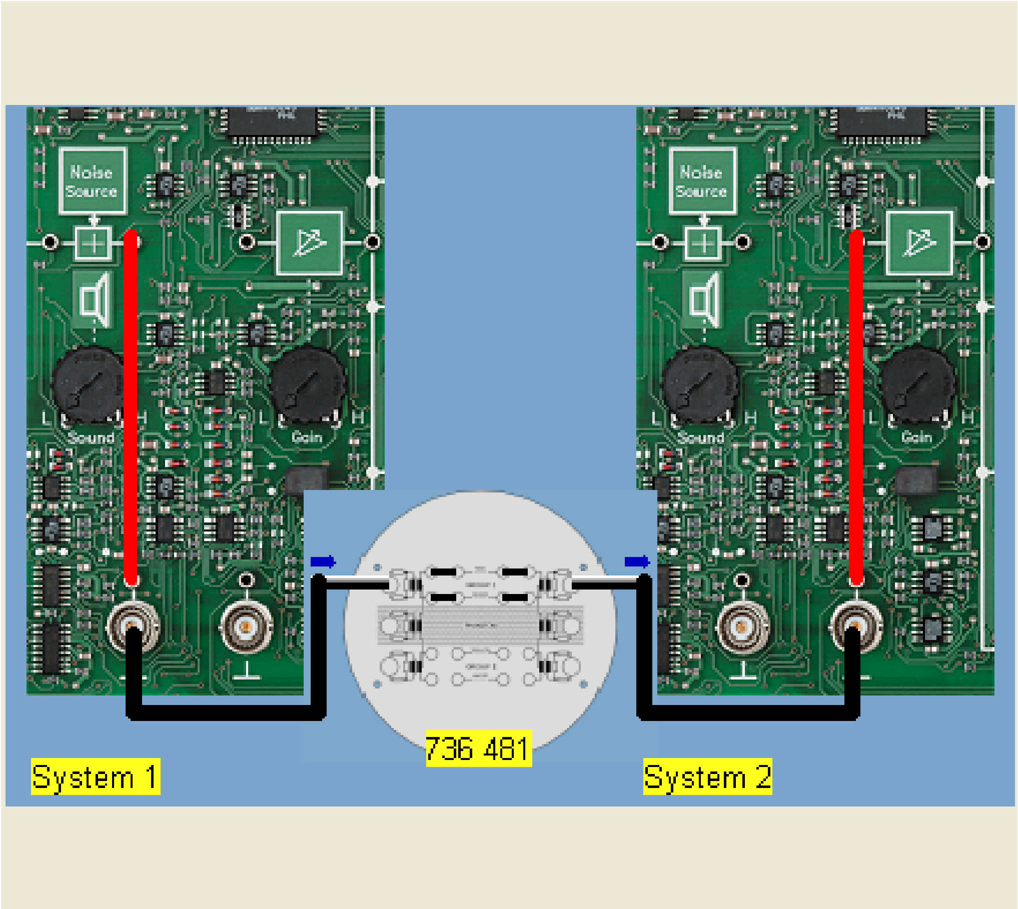

In the following experiment we will investigate simplex mode with two COM3LAB Master Units with the 700 74 Modem Technology experiment board. Both boards are connected here by way of example via a coaxial cable of type RG 58. Any desired texts are sent; transmission takes place without error checking and correction ('Parity' - none).

### 12.7 Experiment: Simplex mode via twisted quad (Baseband)



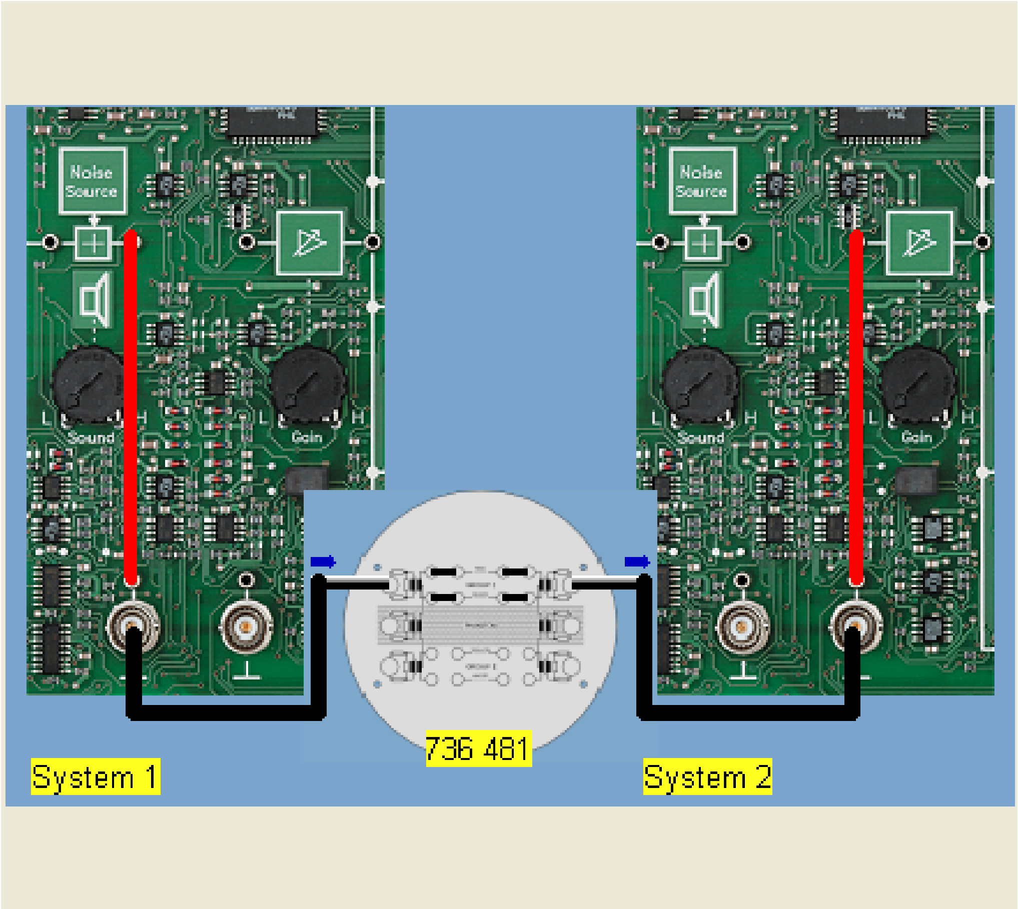

In the following experiment we will investigate simplex operation of two COM3LAB Master Units with the 700 74 Modem Technology experimenting board for sending over a transformer coupled twisted quad in baseband. Any desired texts are sent; transmission takes place without error checking and correction ('Parity' - none).

**12.8 Experiment: Simplex mode using twisted quad (ASK)**



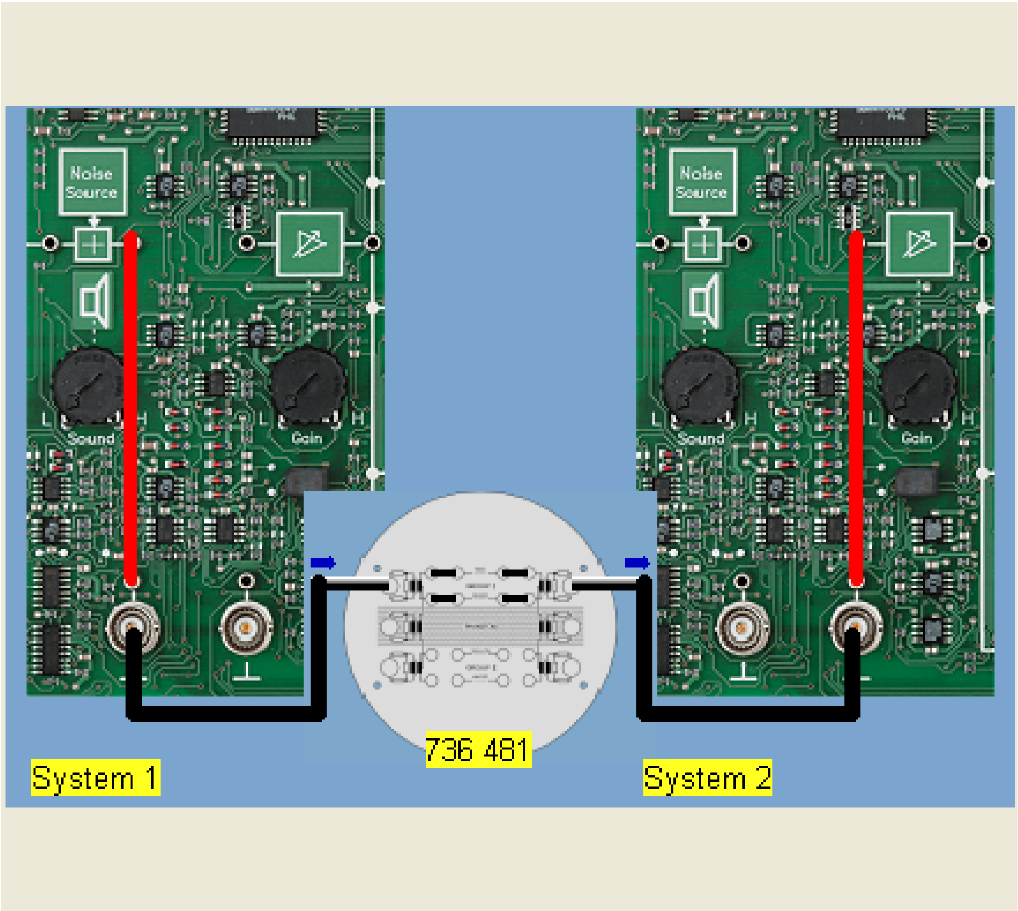

In the following experiment we will investigate simplex operation of two COM3LAB Master Units with the 700 74 Modem Technology experimenting board for sending over a transformer coupled twisted quad with amplitude shift keying in baseband. Any desired texts are sent; transmission takes place without error checking and correction ('Parity' - none).

### 12.9 Experiment: Simplex mode using twisted quad (FSK)



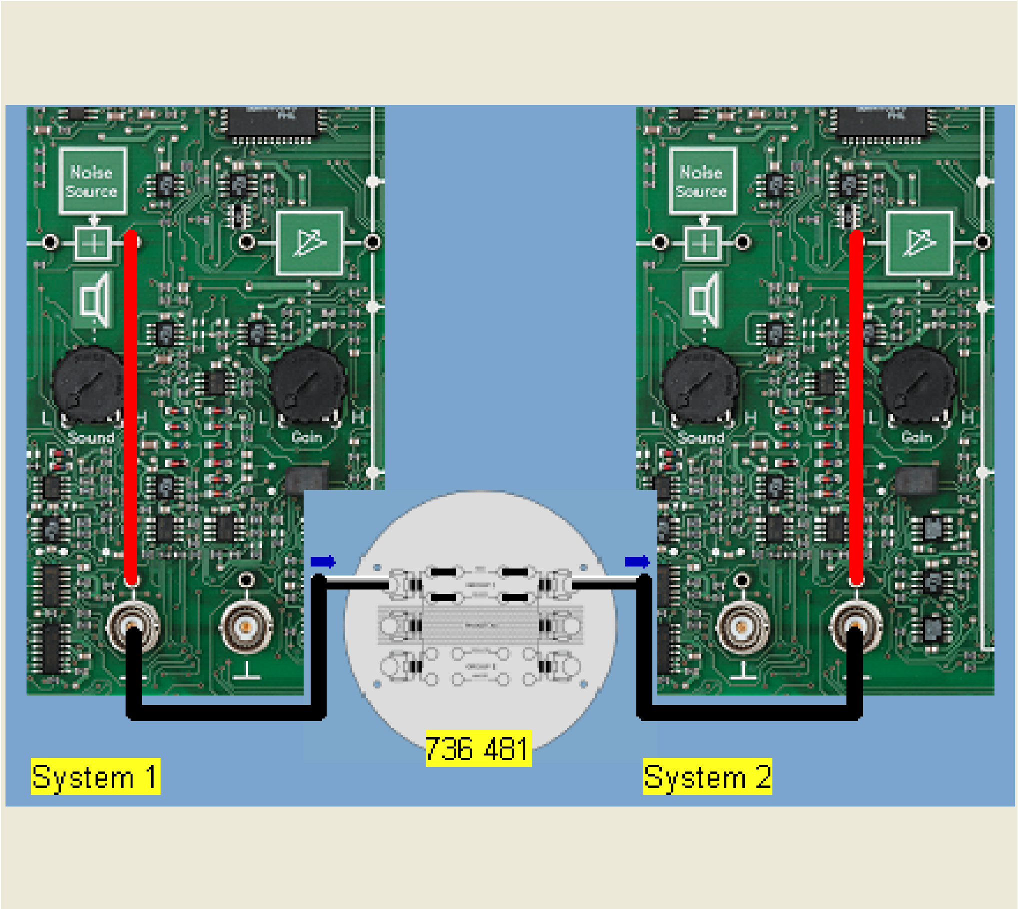

In the following experiment we will investigate simplex operation of two COM3LAB Master Units with the 700 74 Modem Technology experimenting board for sending over a transformer coupled twisted quad with frequency shift keying in baseband. Any desired texts are sent; transmission takes place without error checking and correction ('Parity' - none).

### 12.10 Experiment: Simplex mode using twisted quad (2PSK)



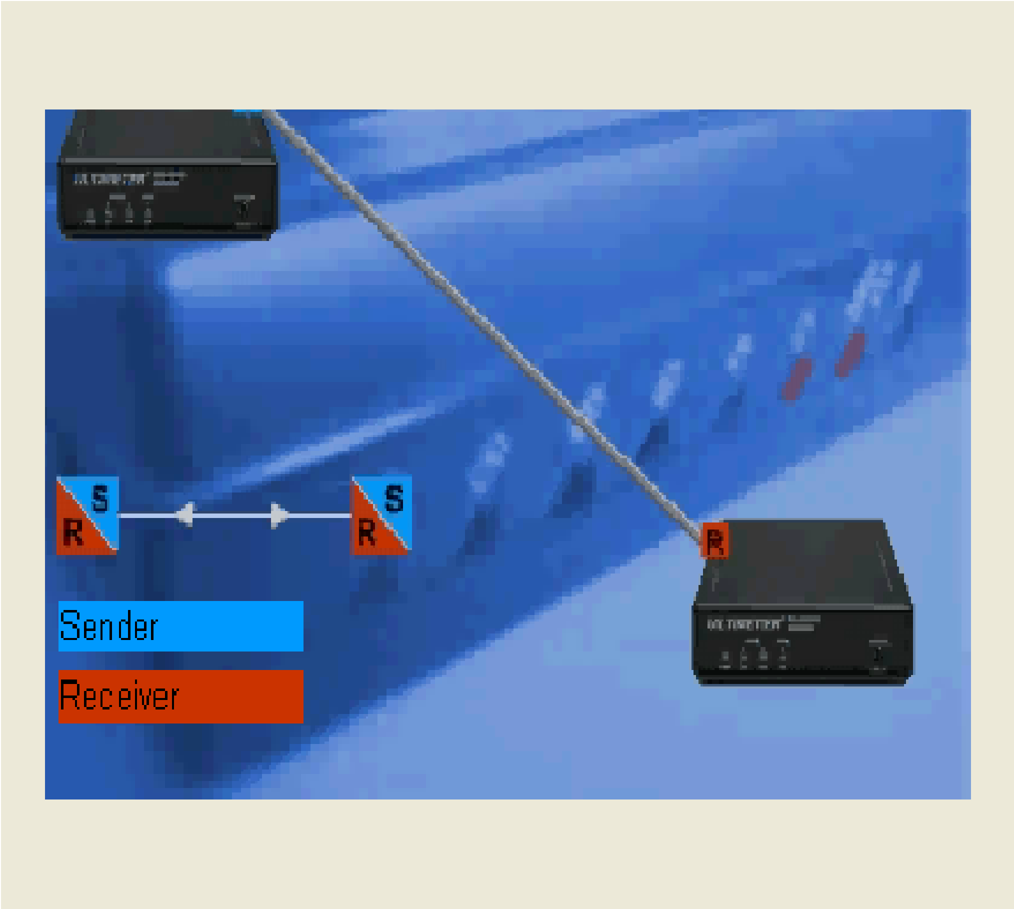

In the following experiment we will investigate simplex operation of two COM3LAB Master Units with the 700 74 Modem Technology experimenting board for sending over a transformer coupled twisted quad with two-phase shift keying in baseband. Any desired texts are sent; transmission takes place without error checking and correction ('Parity' - none).
Note: For demodulation use the original carrier ( **not** shown in the experiment setup shown here).

### 12.11 Experiment: Simplex mode using twisted quad (4PSK)




In the following experiment we will investigate simplex operation of two COM3LAB Master Units with the 700 74 Modem Technology experimenting board for sending over a transformer coupled twisted quad with four-phase shift keying in baseband. Any desired texts are sent; transmission takes place without error checking and correction.
Note: For demodulation use the original carriers ( **not** shown in the experiment setup shown here).

### 12.12 Half-duplex mode

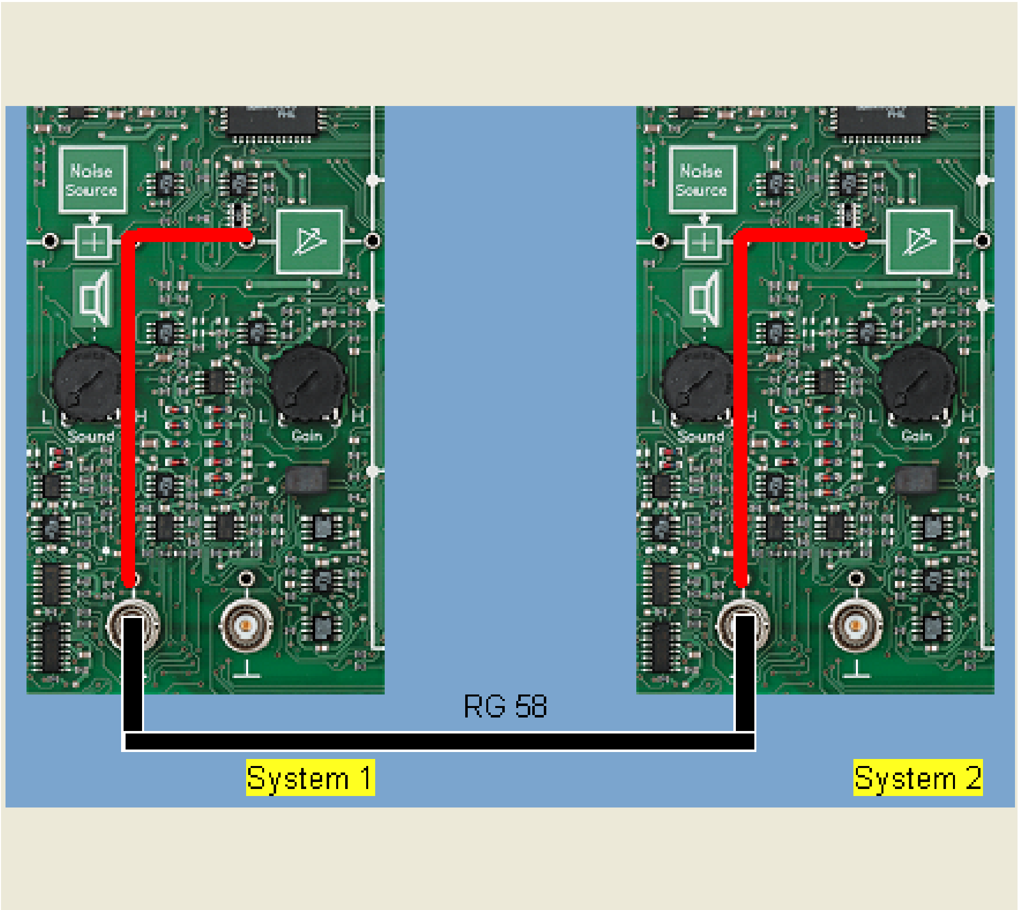



In half-duplex mode[1] the data are sent alternately in both directions over a common data line. At any given time this means that information only runs in one of the two directions, whereby the devices involved function alternately as a sender or receiver. Examples for half-duplex mode are short-wave (CB radio), walkie-talkies and intercom systems.

[1] **Half-duplex**

Data transfer in only one direction (alternating). To send in both directions (pseudo-full duplex), you must continuously switch back and forth.

### 12.13 Experiment: Half-duplex mode




In the following experiment we will investigate half-duplex operation of two COM3LAB Master Units with the 700 74 Modem Technology experimenting board. Both boards will be connected here using a type RG 58 coaxial cable. Any desired texts are sent; transmission takes place without error checking and correction ('Parity' = none).

### 12.14 Channel access control

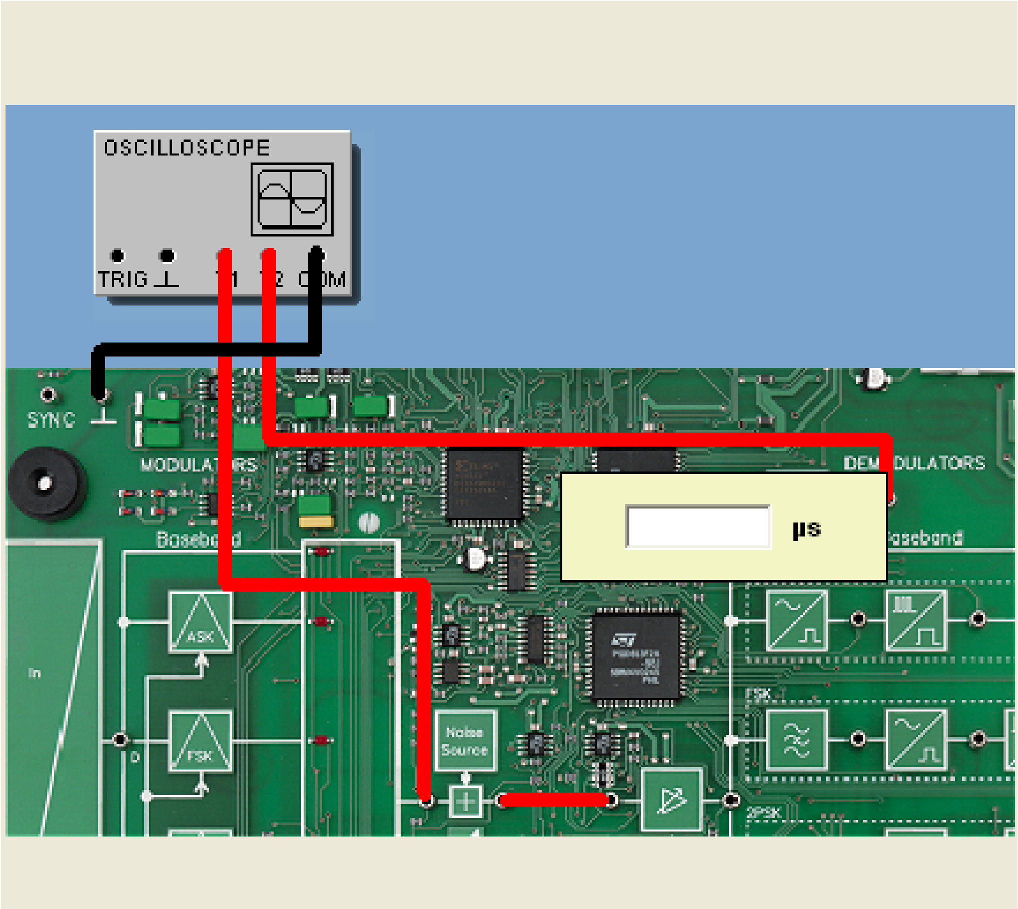
| Half-duplex | | | |
|---|---|---|---|
| | NRZ | DIF | Remark |
| ASK | ✓ | ✗ | With DIF, errors in transmission detection are possible |
| FSK | ✓ | ✗ | With DIF, errors in transmission detection are possible |
| 2PSK | ✗ | ✗ | Carrier error |
| 4PSK | ✗ | ✗ | Carrier recovery error |

✓ Access control o.k.

✗ Access control problematic or defective

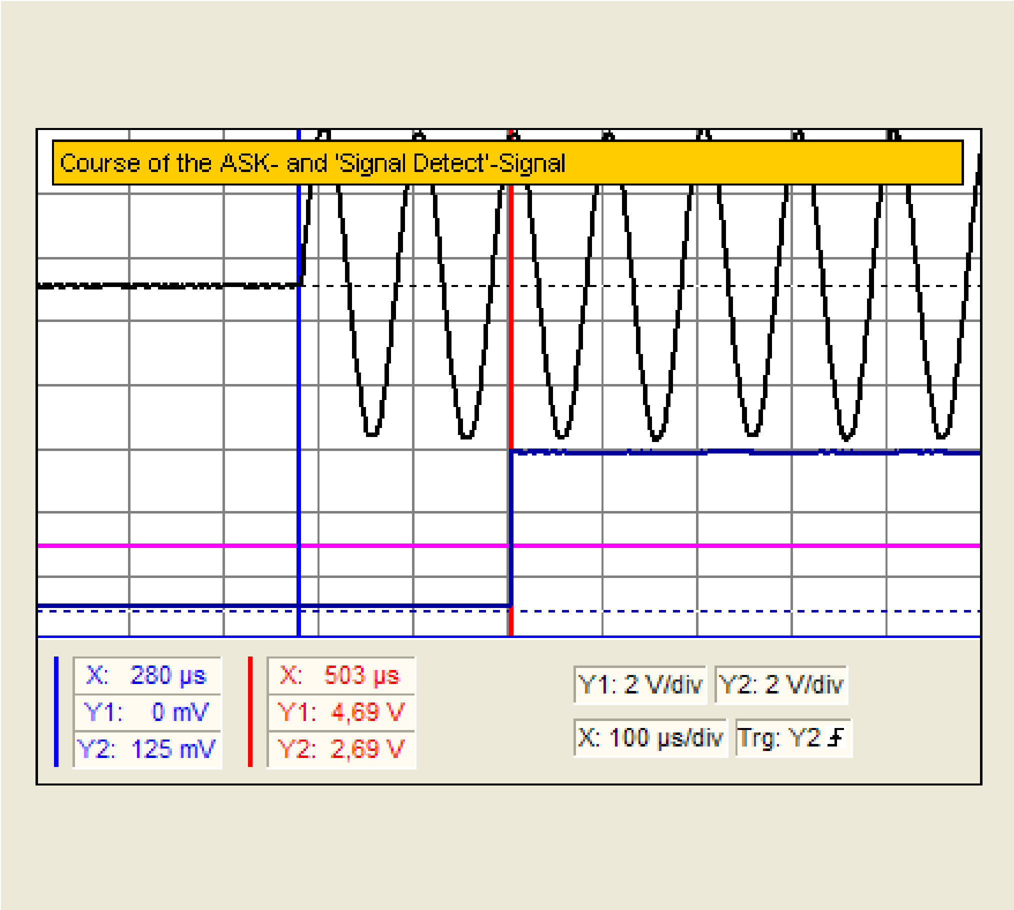
The channel access control implemented here in half-duplex detects the presence or absence of a carrier on the cable. Each station enables the channel after data transfer by turning off its carrier. The partner connected on the same cable detects the available carrier in the network and for its part activates its own sender. But as a result of unavoidable signal propagation times in the 'Signal Detect' stage, errors occur for individual modulation types (see table at right).

### 12.15 Experiment: Channel access control in half-duplex



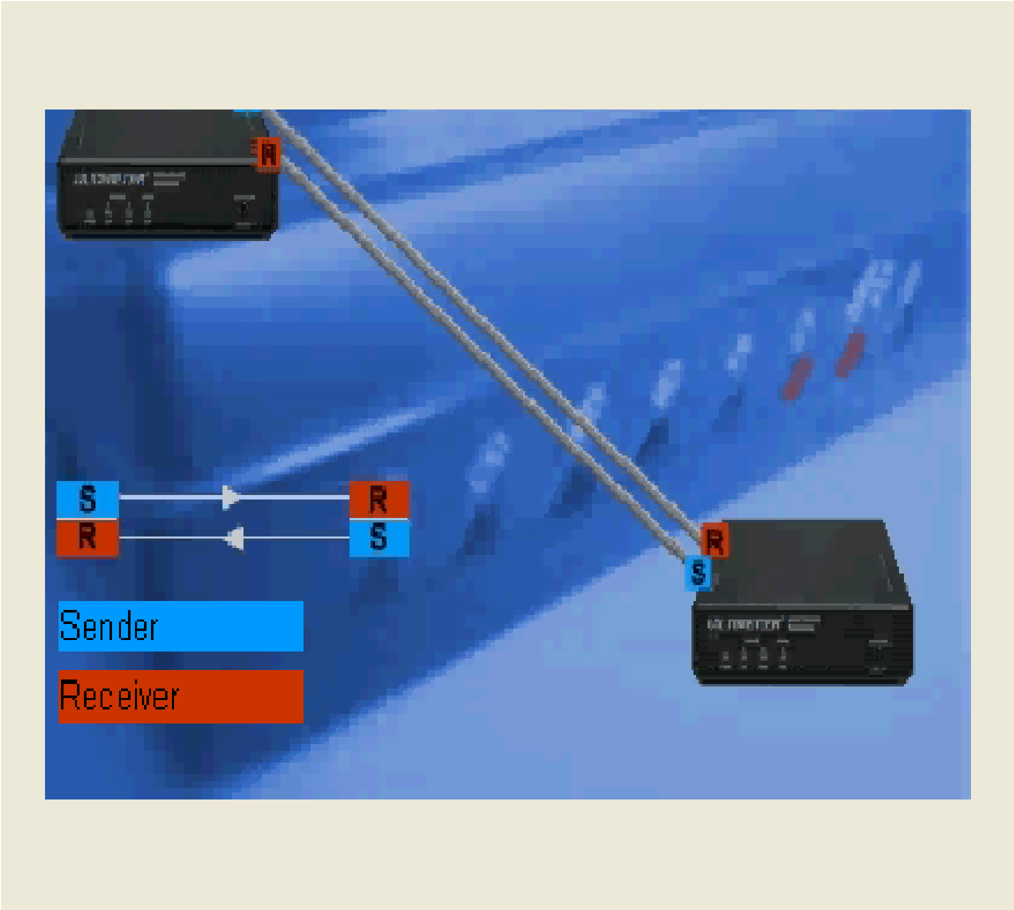

In the following experiment the access procedure to the common transmission channel in half-duplex mode will be investigated. The oscilloscope will be used to simultaneously measure and compare the modulated signal (her using ASK and NRZ format) and the output signal from the 'Signal Detect' stage.

### 12.16 Result




The output signal of the ‚Signal Detect' stage is a square wave jump and appears after the ASK-modulated signal after a delay of about 220 µs. This time delay is a critical phase in the half-duplex method of channel access control, since both partners detect the channel as available during this time.

### 12.17 Duplex mode

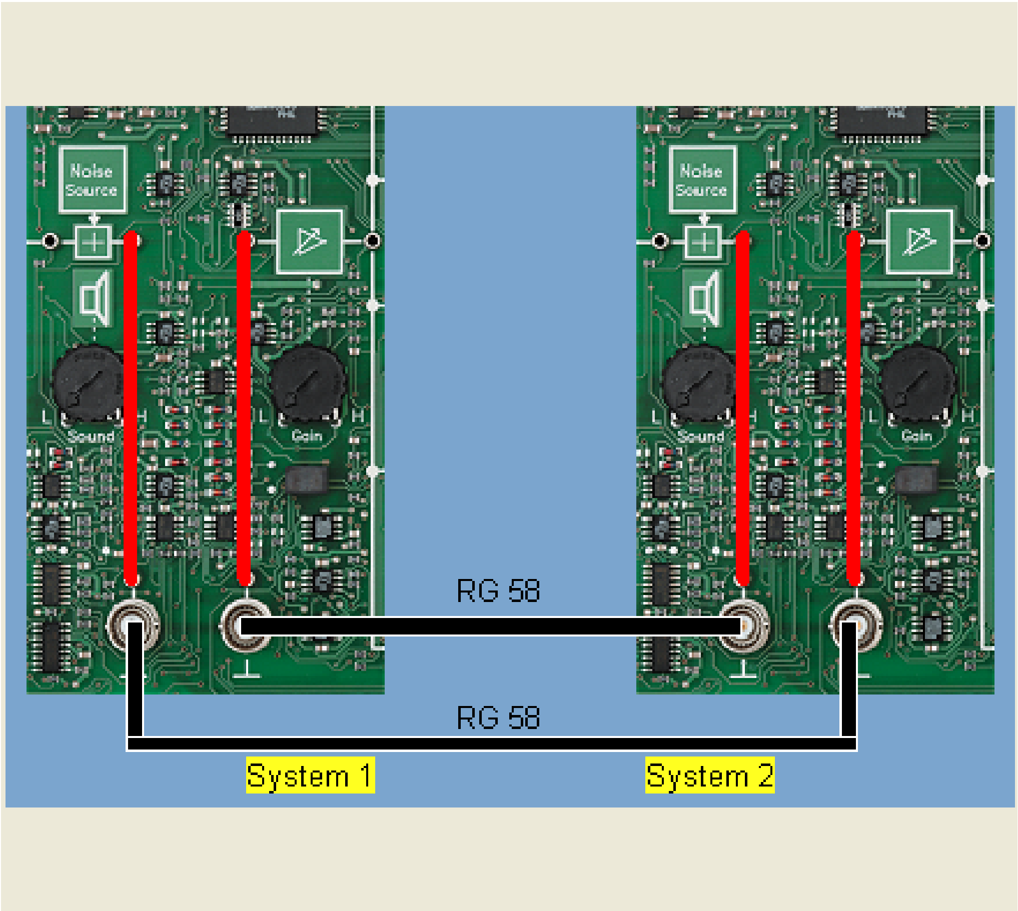



In full-duplex mode, or simply duplex[1] for short data can be sent simultaneously in both directions, in other words the respective devices function as both sender and receiver at the same time. Telephones and most modems use full-duplex connections. To use duplex mode over a single line, corresponding measures are required such as direction separation using a hybrid terminating circuit as used in telephones or a time or frequency multiplexing procedure.

[1] **Full duplex**

In full duplex, often called simply duplex, data are exchanged simultaneously in both directions.

### 12.18 Experiment: Duplex mode




In the following experiment we will investigate full-duplex operation of two COM3LAB Master Units with the 700 74 Modem Technology experimenting board. Both boards will be connected here using a type RG 58 coaxial cable. Any desired texts are sent; transmission takes place without error checking and correction ('Parity' = none).

### 12.19 AT commands

**Overview of the most important AT commands**

| Command | Short description |
|---|---|
| ATH0 | Hang up |
| ATH1 | Go off-hook |
| ATDP... | Dial next number in pulse dialing |
| ATDT... | Dial next number in tone dialing |
| ATDW | Wait for second dial tone |
| ATD! | Hang up briefly and then pick up again |
| ATI0 | Return product code |
| ATL... | Set volume |
| ATM0 | Turn off loudspeaker |
| ATS... | Set S-Register |
| ATQ... | Quiet-Mode |
| ATZ | Reset |

Modems are controlled according to the de-facto standard of the American company Hayes using the so-called AT commands[1] (AT stands for "Attention"). These commands always begin with the two letters "AT", followed by the command codes for certain functions. After a command has been sent to a modem, it responds with a reply value such as CONNECT ("Connection opened"), ERROR, or OK.

[1] **AT command set**

Command language for modem control. 'AT' stands for 'Attention'.

### 12.20 Modulation standards

**Overview of the main modulation standards**

| Standard | Max. bit rate/bps | Modulation procedure |
|---|---|---|
| V.21 | 300 | 2-FSK |
| V.22 | 1200 | 4-PSK |
| V.22bis | 2400 | 16-QAM |
| V.27ter | 4800 | 8-PSK |
| V.29 | 9600 | 16-QAM |
| V.32 | 9600 | 32-QAM |
| V.32bis | 14400 | 128-QAM |
| V.34 | 33600 | 960-QAM |
| V.90 | 56000 | -- |

Of all the modem standards, those which describe modulation techniques are the most important. In order to be able to communicate with each other at all, modems must use the same modulation technique. In modern modems a kind of 'negotiation phase' between the modems is used at the beginning of the connection opening to determine the most capable procedure used by both modems. The modulation standards are specified by the CCITT[1] .

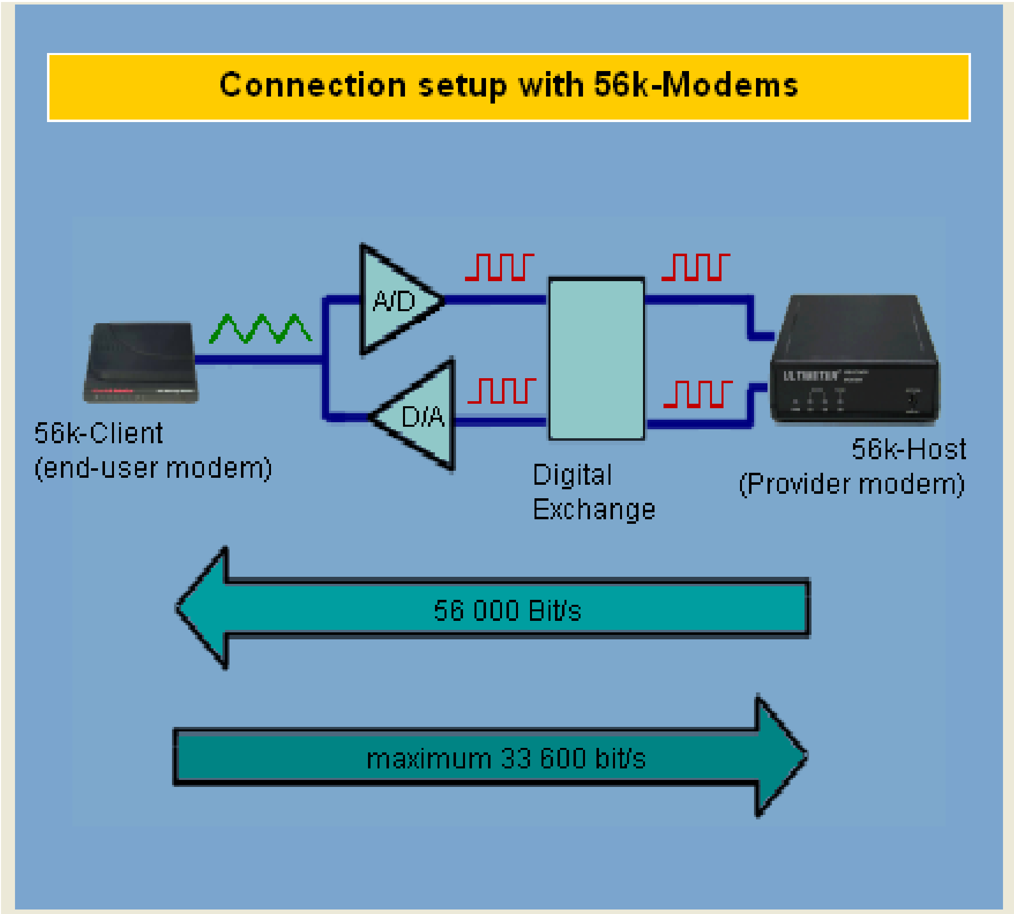
[1] **CCITT**

Comite Consultatif International Telephonique et Telegraphique, an international standards organization for telephone and telegraphy made up of representatives of the post office, industry and science from 159 countries. The standards for data transfer are:

- Telephone = V-Standards
- Data networks = X-Standards
- ISDN = I-Standards

Today this committee is called ITU-T.

### 12.21 "Breaking the Shannon Barrier"




Modern 56k modems allow - even if only in the host-to-client direction - transmission rates to be achieved which are theoretically not possible for pure analog technology according to the Shannon Theorem[1] and the bandwidth of the telephone network, which is limited to around 3.1 kHz. This is accomplished by configuring one end of the transmission channel digital and in the analog part sending analog signals directly instead of a digitally modulated signal.

[1] **Shannon Theorem**

The information scientist Shannon used a theoretical approach to represent the relationship between the upper limit frequency $f_G$ of a signal and the sampling rate necessary for error-free transmission of the signal. According to the theorem, a signal must be sampled with at least double the limit frequency, i. e. $2\ f_G$, for it to be correctly reconstructed on the receive end. Likewise, the highest transmittable frequency for a signal being sampled at equidistant tine intervals is exactly half of the sampling rate.

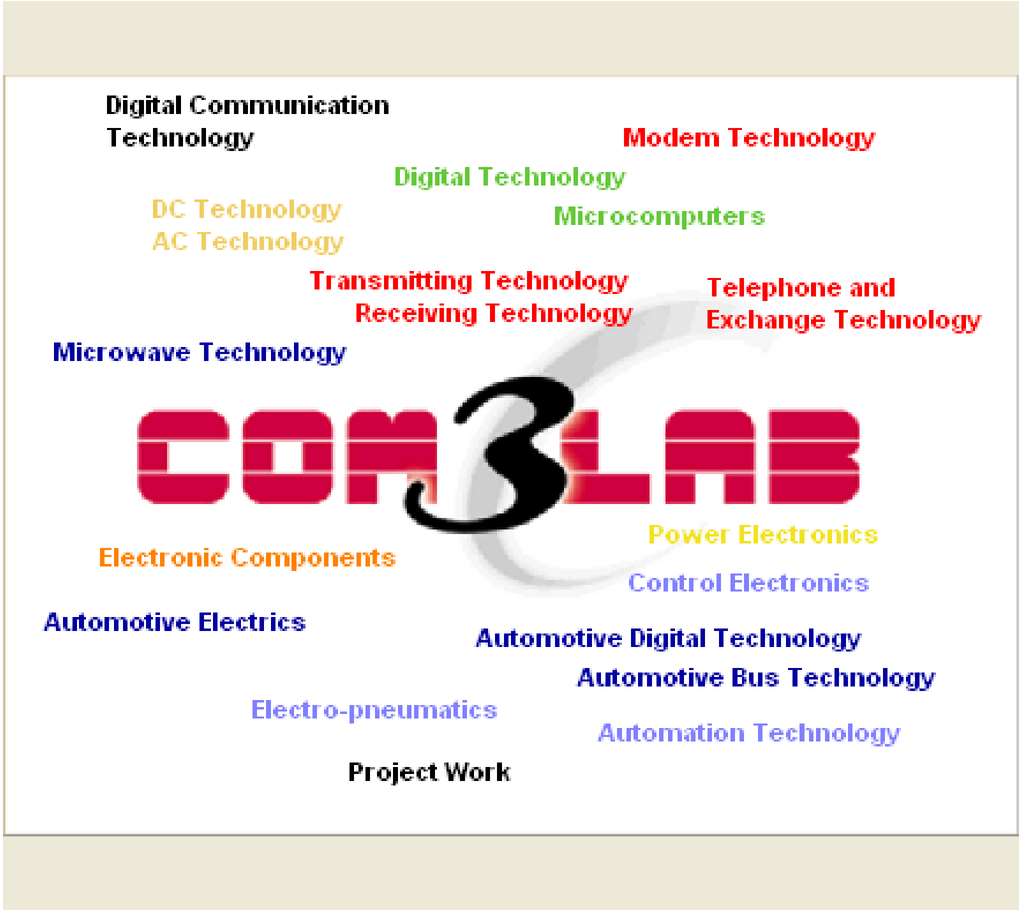
### 12.22 Summary

On the right side you will see a summary of the material covered in this chapter.

**Summary of this chapter**

- Data terminal devices can be operated in simplex, half-duplex or full-duplex (duplex) mode.
- Modems generally work in duplex mode.
- Modems are controlled using so-called AT commands.
- There is a variety of different modulation standards for modems.
- When the connection is first set up the modems first agree on a standard which is accepted by both.
- Modern modems allow bit rates of up to 56 kbps.

### 12.23 The end




That was the COM3LAB Course! We hope you enjoyed working out this CBT. We would be glad to hear your remarks, ideas and praise just as we welcome your suggestions for improvement, any mistakes you may have found, or other criticism! The fastest way is to send an e-mail to COM3LAB@ld-didactic.de[1]. Your LD Didactic Team is signing off now and we wish you much continued success in your future studies!

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