Description of techniques to analyse unknown waveforms with 160 pictures and 31 tables
Acknowledgement:

Thanks for those persons who have supported me in the preparation of this book:

Aikaterini Daskalaki-Proesch

Disclaimer:

The information in this book have been collected over years. The main problem is that there are not many open sources to get information about this sensitive field. Although I tried to verify these information from different sources it may be that there are mistakes. Please do not hesitate to contact me if you discover any wrong description.
Content

1 LIST OF PICTURES 13

2 LIST OF TABLES 17

3 GENERAL 19

4 INTRODUCTION 21

4.1 Tools 21
   Audio Tools 21
      Adobe Audition 1.5 21
      Sound Card Oscilloscope 23
   Decoding Tools 25
      Code 300-32 25
      PROCEED 30

4.2 Recordings and Playback 34
   Wave File Format 34

5 DESCRIPTION OF WAVEFORMS AND ANALYSIS 39

5.1 Analogue Modulation 39
   Amplitude Modulation (AM) 39
      Double Sideband Reduced Carrier (DSB-RC) 40
      Double Sideband Suppressed Carrier (DSB-SC) 41
      Single Sideband Full Carrier 41
      Single Sideband Reduced Carrier (SSB-RC) 42
      Single Sideband Suppressed Carrier (SSB-SC) 43
      Single Sideband Modulation (SSB) 43
      Independent Sideband Modulation (ISB) 44
      Vestigial Sideband Modulation (VSB) 45
      Frequency Modulation (FM) 46
      Wide Frequency Modulation (WFM) 47
      Pre-emphasis and De-emphasis 48

5.2 Digital Waveforms 51
   Amplitude Shift Keying (ASK) 51
   Analysis of an ASK 54
Determination of Baud rate of an ASK 54
Oscilloscope Display 54
Spectrum Measurement 55
Eye Diagram Measurement 57
Frequency Shift Keying (FSK) 60
Analysis of a FSK 61
Automatic Detection of Center Frequency 61
Manual Detection of Center Frequency 62
Frequency Resolution of FFT 62
Frequency Measurements 63
Single Cursor 63
Two Cursors 64
Three or Harmonic Cursor 64
Determination of Baud rate 65
Baud rate by Sonogram 65
Baud rate by Spectrum via the Envelope Method 67
Baud Rate by Time Length of a Demodulated Bit Stream 68
Continuous Phase Frequency Shift Keying (CPFSK) 70
Double Frequency Shift Keying (DFSK) 71
Analysis of a TWINPLEX Signal 71
Constant Envelope 4-Level Frequency Modulation (C4FM) 77
Minimum Shift Keying (MSK) 78
Tamed Frequency modulation (TFM) 79
Gaussian Minimum Shift Keying (GMSK) 79
Multi Frequency Shift Keying (MFSK) 80
Analysis of MFSK signals 81
Phase Shift Keying (PSK) 85
Binary Phase Shift Keying (BPSK) 85
Quadrature Phase Shift Keying (QPSK) 87
Offset Quadrature Phase Shift Keying (OQPSK) 89
Staggered Quadrature Phase Shift Keying (SQPSK) 90
Compatible Differential Offset Quadrature Phase Shift Keying (CQPSK) 90
Coherent Phase Shift Keying (CPSK) 91
Differential Coherent Phase Shift Keying (DCPSK) 91
8PSK Modulation 91
Differential Phase Shift Keying (DPSK) 92
Differential Binary Phase Shift Keying (DBPSK) 93
Differential Quadrature Phase Shift Keying (DQPSK) 93
Differential 8 Phase Shift Keying (D8PSK) 93
Quadrature Amplitude Modulation (QAM) 93
Analysis of a PSK 95
Measurement of Baud rate and Center Frequency 95
Baud rate Measurement with AM-Method 95
Phase Tools CODE 300-32 98
Synchronous Data Transmission 156
Simplex 156
Duplex 157
Half Duplex 157
Semi Duplex 157
Baud Rate, Bit Rate, Symbol Rate 158
Bit Rate 158
Symbol Rate 158
Baud rate 158
Data Formats 159
NRZ (Non Return to Zero) 161
NRZ (S) (Non Return to Zero - Space) 161
NRZ (M) (Non Return to Zero - Mark) 161
Bi-ϕ-L (Biphase Level) 161
Bi-ϕ-S (Biphase Space) 162
Bi-ϕ- M (Biphase Mark) 162
Coding 163
Code 163
Codes in Communication used for Brevity 163
An example: the ASCII code 164
Interleaving in Error-Correction Coding 164
Interleaving Examples 165
Codes to Detect or Correct Errors 166
Error-Correcting Code (ECC) 166
Forward Error Correction (FEC) 167
Convolutional Code 168
Viterbi Algorithm 169
Reed-Solomon Error Correction 170
Overview of the Method 170
Properties of Reed-Solomon Codes 170
Use of Reed-Solomon Codes in Optical and Magnetic Storage 171
Timeline of Reed-Solomon Development 172
Satellite Technique: Reed-Solomon + Viterbi coding 172
Turbo Code 172
Shannon-Hartley Theorem 173
Theorem 173
Examples 175
Used code tables 176
ITA2, ITA2P and ITA3(CCIR342-2) 176
Russian MTK2 177
CCIR476-4, HNG-FEC, PICCOLO MK VI 178
ITA 2 P 179
ITA 3 179
CCIR 476 180
1. List of Pictures

Picture 1: Main view Adobe Audition 1.5 ................................................................. 22
Picture 2: View of a waveform in Adobe Audition 1.5 ........................................... 22
Picture 3: Time measurement of an OTHR .......................................................... 23
Picture 4: Main view of the Soundcard Oszilloscope ........................................... 24
Picture 5: Main view Code300-32 ....................................................................... 25
Picture 6: Phase constellation with and without noise ........................................... 28
Picture 7: CODE300 Symbol rate measurement of a 8PSK .......................... 28
Picture 8: CODE300 FSK oscilloscope ............................................................... 28
Picture 9: CODE300 Speed bit measurement ....................................................... 29
Picture 10: CODE300 spectrogram ..................................................................... 29
Picture 11: PROCEED main screen ........................................................................ 30
Picture 12: PROCEED signal identification .......................................................... 31
Picture 13: PROCEED production .......................................................................... 31
Picture 14: PROCEED measurement with harmonic cursors .............................. 32
Picture 15: PROCEED analysis display ................................................................. 33
Picture 16: PROCEED phase constellation ............................................................ 33
Picture 17: Different AM waveforms ..................................................................... 39
Picture 18: Spectrum and sonagram of an amplitude modulation ..................... 40
Picture 19: Spectrum of a double sideband suppressed carrier signal .............. 41
Picture 20: Spectrum and sonagram of a single sideband modulation with full carrier .......................................................... 42
Picture 21: Spectrum and sonagram of a single sideband modulation with reduced carrier .................................................. 43
Picture 22: Spectrum of a single sideband modulation ......................................... 44
Picture 23: Spectrum of an independent modulated signal .................................. 45
Picture 24: Frequency Modulation ....................................................................... 46
Picture 25: Spectrum and sonagram of a frequency modulation ....................... 46
Picture 26: Spectrum of a wide FM broadcast transmitter .................................. 47
Picture 27: Spectrum of FM stereo signal with sub-channels ............................. 48
Picture 28: Amplitude Shift Keying (ASK) ............................................................. 51
Picture 29: Spectrum of an ASK with 100 Bd ....................................................... 52
Picture 30: Oscilloscope display of an ASK .......................................................... 53
Picture 31: Measurement of ASK baudrate .......................................................... 54
Picture 32: Different method of baudrate measurement of an ASK ................... 55
Picture 33: Spectrum measurement of an ASK with 200 Bd ............................... 56
Picture 34: Spectrum measurement of an ASK with 2000 Bd ............................. 56
Picture 35: Different measurement of the baudrate of an ASK ......................... 57
Picture 36: Measurement with eye diagram .......................................................... 58
Picture 37: Eye diagram with moderate noise ....................................................... 59
Picture 38: Eye diagram with more noise .............................................................. 59
Picture 39: Frequency Shift Keying (FSK) ............................................................. 60
Picture 40: Spectrum of an FSK ........................................................................ 60
Picture 41: Automatic measurements ................................................................. 61
Picture 42: Automatic baud rate and shift measurement ..................................... 62
Picture 43: Spectrogram display with low FFT resolution ............................................................. 62
Picture 44: Spectrogram display with high FFT resolution ............................................................ 63
Picture 45: Mark and space frequency measurement ................................................................. 64
Picture 46: Frequency measurement with three or harmonic cursor .......................................... 65
Picture 47: Baud rate measurement with sonagram .................................................................. 66
Picture 48: Baud rate measurement with sonagram and harmonic cursor ................................... 66
Picture 49: Spectrum envelope method display ......................................................................... 67
Picture 50: Frequency measurement of Baud rate .................................................................. 68
Picture 51: Demodulated FSK signal ......................................................................................... 68
Picture 52: Bit length measurement with two cursors ................................................................. 69
Picture 53: Bit length measurement with harmonic cursor ......................................................... 69
Picture 54: Spectrum of a CPFSK with 100 Bd ........................................................................ 70
Picture 55: Spectrum of a DFSK ............................................................................................. 71
Picture 56: Spectrum of a typical TWINPLEX signal ................................................................. 73
Picture 57: Measurement of TWINPLEX tone distance ............................................................. 73
Picture 58: Baudrate measurement of a TWINPLEX signal ....................................................... 74
Picture 59: Sonogram of a TWINPLEX signal ........................................................................... 75
Picture 60: Example of a Voice Frequency Telegraphy (VFT) .................................................... 75
Picture 61: IQ Plot of C4FM ...................................................................................................... 77
Picture 62: Sonogram and spectrum of C4FM in idle mode ....................................................... 78
Picture 63: Minimum Shift Keying ............................................................................................ 79
Picture 64: Spectrum of a Tamed Frequency Modulation (TFM 3) with 100 Bd ....................... 79
Picture 65: Spectrum of a MFSK with 12 tones ........................................................................ 80
Picture 66: MFSK in the spectrogram view ................................................................................... 81
Picture 67: Number of tones of a MFSK .................................................................................... 82
Picture 68: MFSK with 36 tones .................................................................................................. 82
Picture 69: Spectrum of a MFSK with 36 tones ........................................................................ 82
Picture 70: Measurement of tone duration of a MFSK ............................................................... 83
Picture 71: MFSK measurement with harmonic cursor .............................................................. 83
Picture 72: Tone duration measurement with MFSK oscilloscope ............................................. 84
Picture 73: Determination of numbers of tones of a MFSK ...................................................... 84
Picture 74: Phase shift Keying .................................................................................................... 85
Picture 75: BPSK-A .................................................................................................................... 85
Picture 76: Phase plane of a BPSK .............................................................................................. 86
Picture 77: Spectrum of a BPSK with 600 Bd ............................................................................ 86
Picture 78: BPSK-B .................................................................................................................... 87
Picture 79: QPSK-A .................................................................................................................... 88
Picture 80: QPSK-B .................................................................................................................... 88
Picture 81: Spectrum of a QPSK with 600 Bd ............................................................................ 88
Picture 82: Phase plane of a QPSK .............................................................................................. 89
Picture 83: Phase plane of an OQPSK (right) compared to QPSK (left) ....................................... 90
Picture 84: Phase Plane of an 8PSK ........................................................................................... 92
Picture 85: Spectrum of an 8PSK with 600 Bd ......................................................................... 92
Picture 86: Example of an 8QAM and 16QAM in the Phase Plane ............................................. 94
Picture 87: Spectrum of a QAM8 with 600 Bd ................................................................. 94
Picture 88: Spectrum of a QAM16 with 600 Bd .............................................................. 95
Picture 89: Amplitude behaviour of an absolute PSK ...................................................... 96
Picture 90: Amplitude behaviour of a differential PSK .................................................... 97
Picture 91: Amplitude method of symbol rate measurement .......................................... 97
Picture 92: Spectrum of a PSK ........................................................................................ 98
Picture 93: Estimation of center frequency ....................................................................... 99
Picture 94: Symbol rate measurement of a PSK .............................................................. 99
Picture 95: Baudrate of a PSK signal ................................................................................ 99
Picture 96: Spectrum of a BPSK ...................................................................................... 101
Picture 97: 8PSK after single squaring .............................................................................. 102
Picture 98: 8PSK after double squaring ............................................................................ 102
Picture 99: 8PSK after triple squaring ............................................................................... 103
Picture 100. Phase constellation of 8PSK ....................................................................... 103
Picture 101: Double squaring of a QPSK-A .................................................................... 108
Picture 102: Double squaring of a QPSK-B .................................................................... 109
Picture 103: Comparison of FDM and OFDM ................................................................. 119
Picture 104: Spectrum of OFDM with 45 channels .......................................................... 120
Picture 105: OFDM with 45 carriers .................................................................................. 120
Picture 106: Spectrum of a BR6028 signal ...................................................................... 122
Picture 107: Shift measurement of a BR6028 signal ......................................................... 122
Picture 108: Measurement with the FSK oscilloscope ..................................................... 123
Picture 109: CIS12/MS5 spectrum with reference tone .................................................... 123
Picture 110: CIS 12/MS5 spectrum in idle mode .............................................................. 124
Picture 111: CIS12 in the phase spectrum ........................................................................ 124
Picture 112: Selection of one channel of a CIS12 .............................................................. 124
Picture 113: Symbol rate measurement on a CIS12 signal .............................................. 125
Picture 114: Single squaring of one channel of a CIS12 signal ....................................... 125
Picture 115: Double squaring of one channel of a CIS12 signal ..................................... 126
Picture 116: CIS OFDM with 45 channels ........................................................................ 126
Picture 117: Measurement of the total bandwidth of a CIS OFDM with 45 channels ...... 127
Picture 118: Channel spacing of a CIS OFDM with 45 channels ..................................... 128
Picture 119: Display of one channel of a CIS OFDM with 45 channels ......................... 128
Picture 120: Single squaring of one channel of a CIS OFDM 45 channels .................... 129
Picture 121: Phase constellation of one channel of a CIS OFDM 45 channels ............... 129
Picture 122: Spectrum and sonogram of a CODAN signal ............................................. 130
Picture 123: Tone distance measurement with harmonic cursor ..................................... 131
Picture 124: Function of DSSS ....................................................................................... 132
Picture 125: Function of FHSS ....................................................................................... 133
Picture 126: Frequency hopper with a hopping bandwidth of 5 MHz ............................ 134
Picture 127: Selection of one hop of a frequency hopper .................................................. 135
Picture 128: Spectrogram view of a repeated hop ............................................................ 135
Picture 129: Analysis display of a repeated hop ............................................................... 136
Picture 130: Measurement of the duration of one frequency hop ................................... 137
Picture 131: Expanded display of one hop ................................................................. 138
Picture 132: Shift measurement of one hop .............................................................. 138
Picture 133: Baudrate measurement of one hop ........................................................... 139
Picture 134: Different types of amplitude modulation .................................................. 141
Picture 135: Quantization in a PCM ............................................................................. 142
Picture 136: Delta Modulation ........................................................................................ 143
Picture 137: Pause measurement of a SITOR A signal .................................................. 145
Picture 138: Transmission measurement of a SITOR A signal ...................................... 146
Picture 139: Analysis display of a burst signal .............................................................. 146
Picture 140: Analysis display of a burst signal .............................................................. 147
Picture 141: Shift measurement of a burst signal .......................................................... 147
Picture 142: Baudrate measurement of a burst signal .................................................... 148
Picture 143: Parameter of a Radar signal ...................................................................... 149
Picture 144: Measurement of PRT of OTHR .............................................................. 150
Picture 145: Measurement of PW of an OTHR ............................................................ 150
Picture 146: Transmitter AGC ramp down ................................................................. 151
Picture 147: Transmitter AGC ramp up ........................................................................ 151
Picture 148: Pre-carrier of a 75 bd/850 Hz signal with seven pre-carrier bits ............... 152
Picture 149: Demodulation of the 75 Bd/850 Hz pre-carrier with seven pre-carrier bits ... 152
Picture 150: Pre-carrier of a 75 bd/850 Hz signal with one pre-carrier bit ...................... 153
Picture 151: Demodulation of a 75 Bd/850 Hz signal with one pre-carrier bit ............... 153
Picture 152: Example of a 50 Bd/200 Hz signal ............................................................ 153
Picture 153: Tone display of a 4FSK ............................................................................. 154
Picture 154: Demodulation of a 4FSK with peaks ......................................................... 154
Picture 155: Common data formats .............................................................................. 160
Picture 156: Principle of FDMA ................................................................................... 189
Picture 157: Principle of TDMA ................................................................................... 190
Picture 158: Principle of OFDMA ................................................................................ 191
Picture 159: The OSI reference model ........................................................................... 193
Picture 160: STANAG 5066 layers .............................................................................. 201
2. List of Tables

Table 1: Chunks in the wave format ................................................................................................ 35
Table 2: Wave format description ................................................................................................ 37
Table 3: Example of wave file .................................................................................................... 38
Table 4: TWINPLEX modes ....................................................................................................... 72
Table 5: TWINPLEX shift modes .............................................................................................. 72
Table 6: Result of tone frequency measurement ......................................................................... 74
Table 7: C4FM symbol table ..................................................................................................... 77
Table 8: Bit value for QPSK ....................................................................................................... 87
Table 9: Phase shifts for CQPSK .............................................................................................. 90
Table 10: Bit values for QAM .................................................................................................... 94
Table 11: Squaring of PSK signals .......................................................................................... 100
Table 12: Influence of noise to PSK signals ............................................................................ 107
Table 13: Types of PSK and their phase shifts ....................................................................... 107
Table 14: Characteristics of a PSK2-A .................................................................................... 110
Table 15: Characteristics of a PSK2-B .................................................................................... 111
Table 16: Characteristics of a PSK4-A .................................................................................... 113
Table 17: Characteristics of a PSK4-B .................................................................................... 115
Table 18: Characteristics of a PSK8-APSK8-B ....................................................................... 116
Table 19: Characteristics of a PSK8-B .................................................................................... 118
Table 20: BR6028 channel frequencies .................................................................................. 121
Table 21: Different description for data levels ....................................................................... 155
Table 22: Code table for ITA2, ITA2P and ITA3 ..................................................................... 176
Table 23: Code table for CCIR476-4, HNG-FEC and PICCOLO MK VI alphabetsITA 2 ........ 178
Table 24: ASCII table ............................................................................................................. 184
Table 25: CCIR 493 alphabet .................................................................................................. 187
Table 26: X.25 Packet frame ................................................................................................... 203
Table 27: Common used transmission modes ......................................................................... 220
Table 28: Terms and their description .................................................................................... 221
Table 29: Determination of necessary bandwidths for emissions .......................................... 229
Table 30: Table of waveforms and possible user sorted by Baud rate ................................... 245
Table 31: Abbreviations ......................................................................................................... 255
3. General

For years shortwave radio has been used for communication beyond the line of sight. With the introduction of worldwide satellite services in the geostationary or low earth orbits HF radio communication lost more and more in interest.

But with the introduction of new, sophisticated modems and digital broadcast services in high quality HF communication has seen a renewal during the last years.

Shortwave radio, however, has some qualities that will ensure its attractiveness for some time. The most important one for commercial users is that there is no charge for using the ionosphere. In the military context this translates to low cost, potentially global communication that has the important attributes of national ownership and military control. And in comparison to satellite services shortwave communication is harder to disrupt.

The good old radio for shortwave has been perfected during the last years in several ways. Information data rates of a few tens of bits per second were increased to more than 19200 bit/s by sophisticated modem techniques and error correction. Algorithms were created to adapt transmission parameters to channel quality or initiate a change to a better channel. Passive and active channel analysis, i.e. sending and measuring test signals on assigned pool frequencies have been developed to solve problems of channel distortions.

There are new signals “on air” nearly every month. That makes it very difficult to keep track of them. And they often sound the same way.

This book shall give an introduction how to work with signals on shortwave and get that information which is necessary to identify the different waveforms. It will show some techniques for measurement the main parameter of digital signals.

It will also show some tools which I have used over the years to come to a result in a relative short time frame.

You are not bound to those tools described in this book. There are many others with a similar functionality which will do the job.

And please keep in mind:

    Signal analysis is not an easy task!
If you are doing it only occasionally it will be difficult to come to satisfactory results. Signal analysis needs a constant practise.

And sometimes it may be a good idea not to choose an obvious way to do signal analysis.

Most signal analysis tasks are performed on recorded signals. For a successful work you will need good recordings. Information that is lost i.e. by noise can never be reconstructed.
The eye diagram can also be used to measure and calculate the baud rate of a signal. In this example the signal is a 2ASK with 600 Bd. The upper and lower lines are representing the binary 1 and binary 0. The transition between both is the change from 0 to 1 or 1 to 0. These transitions are related to the baud rate. The time distance of two cross points between two transition paths are a value for the bit width $T_B$ in ms. 1000 ms divided by 1.66 ms is equal to the baud rate of the signal, in this case 600 Bd.

The thickness of the eye lines are an indicator for the jitter of a signal. The wider the lines are the more jitter between each bit is on the signal. Jitter is an indicator of timing errors during the transmission or reception.

The eye width or eye opening shows the additive noise on the signal. This is shown in the following two pictures:
Picture 38: Eye diagram with moderate noise

The eye can still be recognized.

Picture 39: Eye diagram with more noise

In this case with a high amount of noise the eye width is very small.
Frequency Shift Keying (FSK)

In frequency shift keying, the carrier frequency changes between discrete values. If only two frequencies are used then this will be called BFSK, for binary frequency shift keying. In the following picture the same data is represented, 0101.

![Picture 40: Frequency Shift Keying (FSK)](image)

Normally FSK is generated by Audio Frequency Shift Keying (AFSK) switching between two tones which then can be used in single sideband (SSB) technique to modulate the transmitter. In relation to the incoming data for a 0 tone 1 is transmitted and for a 1 tone 2.

The following picture shows the typical spectrum of an FSK with discrete frequencies at 1500 Hz and 2350 Hz which gives a shift of 850 Hz:

![Picture 41: Spectrum of an FSK](image)
Analysis of a FSK

For a description of the waveform of a FSK signal the following parameter needs to be determined:

- Center frequency
- Mark frequency
- Space frequency
- Frequency shift
- Baud rate

**Automatic Detection of Center Frequency**

In a first step it is important to determine the correct frequency of a FSK signal, especially when the reception is done with a receiver using a SSB demodulator. A decoder like C300 or C3P will do this automatically as shown in the next picture.

![Picture 42: Automatic measurements](image)

The software measures the two peaks in the spectrum, calculates the peak frequency and the center frequency. These values are also used for an automatic determination of the baud rate.
Manual Detection of Center Frequency

Frequency Resolution of FFT

For the manual measurement the signal needs to be displayed correctly in a spectrum and/or a sonogram view. It is important to use a very high FFT resolution. With a low resolution the frequency distance between each FFT point is very high and results in a spectrum display with less information. The peaks are very wide. The following picture shows a FFT resolution of 256 points.
Analysis of MFSK signals

In this part we will determine the main parameter of a MFSK signal. These are:

- Number of tones
- Tone duration
- Tone distance
- Baud rate

The following picture shows a typical MFSK signal in the spectrogram view.

**Picture 67: MFSK in the spectrogram view**

In the first step we will determine the number of tones. The best tool for this is a spectrum analyser with a peak hold function. Each tone will be held in his highest amplitude. The measurement of number of tone is very easy: just count the number of them. In this example we can see the 12 tones of a PICCOLO signal. The procedure will be more difficult with a MFSK with a high number of tones.
The procedure will be more difficult with a MFSK with a high number of tones like in the following picture.

But with the peak hold function this should also be possible as shown in the above example of a CIS 36 signal.

The next task is the measurement of the tone duration. This can be done in the sonogram with a very low FFT resolution. But as shown in the following picture this method is not very accurate and only practical for low baudrates. Due to the low frequency resolution it is very difficult to find the correct transition between tones.
The smallest pulse corresponds to the time length of one bit. This time $T_B$ is measured with a time cursor. The baud rate $B$ is calculated by dividing one second or better 1000 ms through the time for one bit.

$$1000 \text{ (ms)} / T_B \text{ (ms)} = B.$$  

In this example it is 1000 ms/50 ms = 20 Bd.

If a harmonic cursor is available the correct setup can be proven by the exact match of the cursors to the changes between the different tones.
Another possibility to measure the duration of each tone is the usage of a MFSK demodulator or MFSK oscilloscope. Each tone is demodulated and shown as in the following picture. The duration can be measured with a time cursor. In this example the duration of one tone is 50 ms which corresponds to 20 Bd.

![Picture 73: Tone duration measurement with MFSK oscilloscope](image1)

By placing a cursor of a harmonic cursor on each tone we can also determine the number of tones. It also will give us the distance of the tones which is 20 Hz in this example.

![Picture 74: Determination of numbers of tones of a MFSK](image2)
From the above table can be seen that a PSK-2B has the same shifts as PSK-4A. Thus it may be difficult to recognize if in a PSK transmission it is a BPSK or a QPSK because the phase constellation looks the same way. But fortunately there is another possibility to recognize the correct type.

Recognition of Absolute (PSK-A) and Differential PSK (PSK-B)

The main difference between a PSK-A and a PSK-B can be seen when using the squaring method for measurement of the exact center frequency. The following picture shows a QPSK-A with a 2 times squaring:

![Double squaring of a QPSK-A](image)

**Picture 104: Double squaring of a QPSK-A**

As we can see from the squaring result a QPSK-A is showing 3 peaks. The center peak is related to the center frequency. On the left and right side there are peaks related to the symbolrate of the signal. With the CODE300-32 phase tools the symbolrate is shown. In this example it is 600 Bd.

The following picture shows the spectrum of a QPSK-B after 2 times squaring.
As we can see that there is no center peak but two peak in a distance of 300 Hz to the center. The distance between both peaks correlates with the symbol rate.

**Note:** This is true for the CODE300-32. There are other spectrum analyzers with the possibility of squaring. If the display is not corrected according the function of squaring you will need to multiply the frequency distance with the squaring number. For BPSK is it x2, for QPSK x4 and for 8PSK x8. So the symbol rate is calculated:

\[
\text{Measured frequency distance} \times \text{squaring number} = \text{symbolrate}.
\]
**Table 14: Characteristics of a PSK2-A**

<table>
<thead>
<tr>
<th>PSK2-A</th>
<th>Spectrum</th>
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<table>
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<tr>
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<table>
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<table>
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### Table 15: Characteristics of a PSK2-B

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<table>
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<th>PSK2-B</th>
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<table>
<thead>
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<th>PSK2-B</th>
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<table>
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<th>Phase Constellation</th>
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<td><img src="image" alt="Phase Constellation" /></td>
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</table>
The magnitude window shows the signal each time it is repeated by the replay software. In the frequency window the signal contents can be recognized. In one step the duration of one hop can be determined by measuring the length of the hop with two cursors. This is shown in the following picture.

**Picture 133: Measurement of the duration of one frequency hop**

In this case a hop duration of 8 ms which gives a hopping rate of 125 hops per second. In the next step one hop is displayed and shows the data contest. The frequency display shows a FSK from which a shift of 13500 Hz can be determined.
In a last step the baud rate of the FSK will be measured. This procedure was described in the FSK section before.
The duration of one bit is 0.05 ms which can be calculated to \( \frac{1000 \text{ ms}}{0.05 \text{ ms}} = 20000 \text{ Bd} \).
Incremental Frequency Keying (IFK)

In an incremental frequency keying the data is not represented by the frequency of each tone, but by the frequency difference between one tone and the next. IFK consequently provides complete independence of tuning and tolerance of drift. IFK also makes the management of tone sets possible in order to reduce inter-symbol interference, and reduces the effect of systematic errors, such as those produced by in-band carriers.
Channel access methods

*Frequency-Division Multiple Access (FDMA)*

FDMA, or frequency-division multiple access, is the oldest and most important of the three main ways for multiple radio transmitters to share the radio spectrum. The other two methods are Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA).

In FDMA, each transmitter is assigned a distinct frequency channel so that receivers can discriminate among them by tuning to the desired channel.

TDMA and CDMA are always used in combination with FDMA, i.e., a given frequency channel may be used for either TDMA or CDMA independently of signals on other frequency channels.

![Principle of FDMA](image)

*Picture 159: Principle of FDMA*

*Time Division Multiple Access (TDMA)*

Time Division Multiple Access (TDMA) is a technology for shared medium (usually radio) networks. It allows several users to share the same frequency by dividing it into different time slots.

The users transmit in rapid succession, one after the other, each using their own timeslot. This allows multiple users to share the same transmission medium (e.g. radio frequency) whilst using only the part of its bandwidth they require. TDMA is used extensively in satellite systems, local area networks, physical security systems, and combat-net radio systems.
Code Division Multiple Access (CDMA)

Generically (as a multiplexing scheme), code division multiple access (CDMA) is any use of any form of spread spectrum by multiple transmitters to send to the same receiver on the same frequency channel at the same time without harmful interference. One important application of CDMA is the Global Positioning System, GPS.

CDMA's main advantage over TDMA and FDMA is that the number of available CDMA codes is essentially infinite. This makes CDMA ideally suited to large numbers of transmitters each generating a relatively small amount of traffic at irregular intervals, as it avoids the overhead of continually allocating and de-allocating a limited number of orthogonal time slots or frequency channels to individual transmitters. CDMA transmitters simply send when they have something to say, and go off the air when nothing is to transmit.

Orthogonal Frequency Multiple Access (OFDMA)

Orthogonal Frequency Division Multiple Access (OFDMA) is a multi-user version of the OFDM digital modulation scheme. Multiple access is achieved in OFDMA by assigning subsets of subcarriers to individual users as shown in the picture below. This allows simultaneous low data rate transmission from several users. OFDMA can also be described as a combination of frequency domain and time domain multiple access, where the resources are partitioned in the time-frequency space, and slots are assigned along the OFDM symbol index as well as OFDM sub-carrier index.
Picture 161: Principle of OFDMA