

# OptiSystem applications: BER analysis of BPSK with RS encoding



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- This application note demonstrates how to perform the BER testing of a BPSK system with Reed Solomon (RS) encoders and decoders.
- The typical output of a BER analysis is a set of waterfall curves that map a system's BER results against gradually increasing background noise levels, defined as  $E_b/N_0$  (the ratio of energy per bit to noise density). When Reed Solomon encoding is applied, the BER performance can be significantly improved as RS encoding can correct multiple errors per symbol block.
- An OptiSystem project has been built to allow for the automatic creation of BER waterfall curves for different settings of the RS encoder/decoder. The project folder includes three files:
  - The OptiSystem project for the BPSK system analysis (***BER\_Calculation\_RS\_FEC\_BPSK.osd***)
  - The Excel output file where the results are exported and plotted (***BER Analysis BPSK FEC - Export Excel.xlsx***)
  - The data tracking file which provides more detailed information on the simulation results (***BER\_FEC\_Analysis\_Tracking.txt***)
- The BER results for three common RS coding schemes (RS4, RS8, RS16) can be seen in the file ***BER Analysis BPSK FEC - Export Excel.xlsx***. Prior to running a simulation these coding schemes can be set from the OptiSystem global parameters RSN and RSK. For example for RS16,  $RSN = 255$  and  $RSK = 223$

Name	Value	Units	Mode
Simulation window	Set bit rate		Normal
Reference bit rate	<input checked="" type="checkbox"/>		Normal
Bit rate	10e+009	bit/s	Normal
Time window	6.5536e-006	s	Normal
Sample rate	320e+009	Hz	
Sequence length	65536	bit	
Samples per bit	32		
Guard Bits	0		
Symbol rate	10e+009	symbols/s	
Number of samples	2097152		Normal
Cuda GPU	<input type="checkbox"/>		Normal
RSN	255		Normal
RSK	223		Normal

These global parameters are linked to the "RS Index N" and "RS Index K" parameters of the FEC Encoder and FEC Decoder

# How to run a BER simulation (1)

1. Open the OptiSystem project **BER\_Calculation\_RS\_FEC\_BPSK.osd**
2. After determining which RS coding scheme you wish to run (see previous slide for further information), select the tab “Script” (see GREEN box below)
3. Got to the line “Set objWorkbook = objExcel.Workbooks.Open(…)” (see BLUE box below) and set up the file path information such that it matches the location of the Excel export file on your computer. The format should be as follows:  
*"C:\YourFilePath\BER analysis Reed Solomon\BER Analysis BPSK FEC - Export Excel.xlsx ")*

```
'BER Calculations for BPSK with RS FEC
IterSNRPerSym = 20 'Number of sweeps for EbNo
IterBER = 5 'Number of times to repeat BER calculation per EbNo sweep
SNRPerSymStart = 0 'dB - EbNo start value
SNRPerSymStep = 0.5 'dB - EbNo incremental value
StartIndex = 0 'Use this setting to perform BER runs over sub-sets of the EbNo sweep values (Default = 0)
ESym = 1 'PSK
SequenceLength = 65536 '8192 16384 32768 65536 131072 262144 524288 1048576 2097152 4194304 8388608

'Open specified spreadsheet and select the first worksheet.
Set objExcel = CreateObject("Excel.Application")
Set objWorkbook = objExcel.Workbooks.Open("C:\MyFilePath\BER analysis Reed Solomon FEC\BER Analysis BPSK FE
objExcel.Application.DisplayAlerts = False
objExcel.Application.Visible = True

Set objExplorer = CreateObject("InternetExplorer.Application")

objExplorer.Navigate "about:blank"
objExplorer.ToolBar = 0
objExplorer.StatusBar = 0
objExplorer.Width = 400
objExplorer.Height = 200
objExplorer.Visible = 1
objExplorer.Document.Title = "BER Analysis"

'Setup text file for tracking progress of simulation
Set objFileToWrite = CreateObject("SystemObject").OpenTextFile("C:\MyFilePath\BER analysis Re
```

File path for Excel spreadsheet

OptiSystem Script tab

Script

# How to run a BER simulation (2)

- Go to the line “Set objFileToWrite = CreateObject("Scripting.FileSystemObject").OpenTextFile(...)” (see GREEN box below) and set up the file path information such that it matches the location of the data export file on your computer. The format should be as follows:  
*"C:¥YourFilepath¥BER analysis Reed Solomon¥BER\_FEC\_Analysis\_Tracking.txt",2,true)"*
- Go to the code section where the BER calculations are exported to Excel (see RED box below). Make sure to set the second number in the brackets (objExcel.Cells (7+i, 8)) to align with the configuration for your simulation (no FEC, RS4, RS8, RS16 or 6, 7, 8 or 9; respectively).

```
'Open specified spreadsheet and select the first worksheet.
Set objExcel = CreateObject("Excel.Application")
Set objWorkbook = objExcel.Workbooks.Open("C:\MyFilePath\BER analysis Reed Solomon FEC - Export Excel.xls")
objExcel.Application.DisplayAlerts = False
objExcel.Application.Visible = True

Set objExplorer = CreateObject("InternetExplorer.Application")

objExplorer.Navigate "about:blank"
objExplorer.ToolBar = 0
objExplorer.StatusBar = 0
objExplorer.Width = 400
objExplorer.Height = 200
objExplorer.Visible = 1
objExplorer.Document.Title = "BER Analysis"

'Setup text file for tracking progress of simulation
Set objFileToWrite = CreateObject("Scripting.FileSystemObject").OpenTextFile("C:\MyFilePath\BER analysis Reed Solomon FEC_Analysis_Tracking.txt",2,true)

Next
'Calculate average EbNo and EbNo(dB) for all BER iterations
AvrResult1 = SumResult1/IterBER
AvrResult2 = SumResult2/IterBER

'Calculate BER
BER = SumResult3/SumResult4
objFileToWrite.WriteLine("Total bit errors counted: " & SumResult3 & " Total " & SumResult4)

objExcel.Cells(7+i, 3).Value = AvrResult1
objExcel.Cells(7+i, 4).Value = AvrResult2
objExcel.Cells(7+i, 8).Value = BER '6 (no FEC), 7(RS4), 8(RS8), 9(RS16)
```

Run script action button

File path for data file

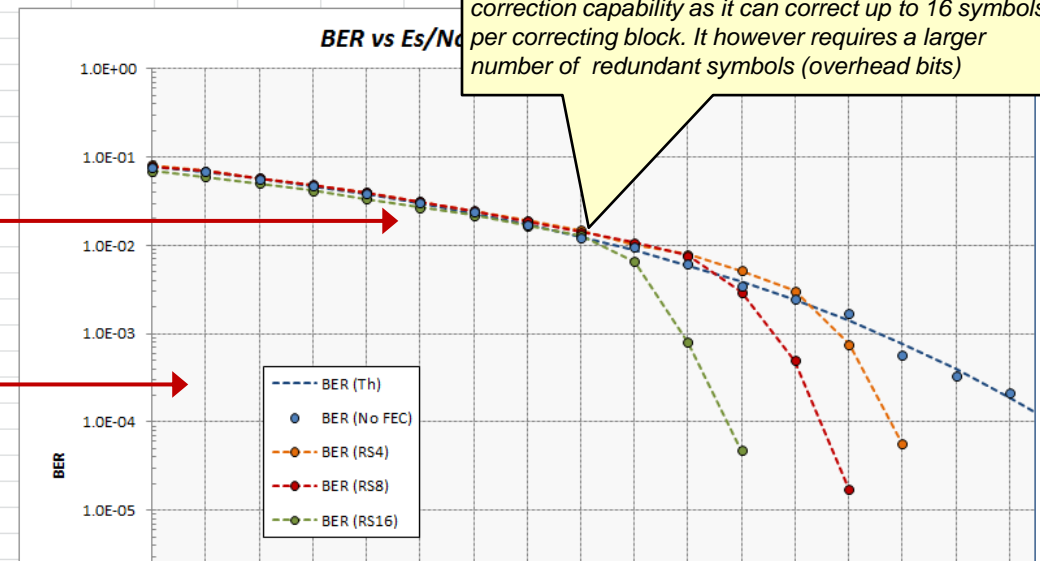
**IMPORTANT: On the third line of objExcel.Cells(...) make sure to set the second value to 6, 7, 8 or 9 depending on the FEC configuration. Otherwise the wrong column will be populated with the BER results**

# How to run a BER simulation (3)

- On the upper right menu bar, left-click select the “Run Script” action button (see GREEN box previous slide). The simulation will start.
- The Excel spreadsheet will automatically open. At the end of each BER iteration, the simulation data for the BPSK system will be exported to the associated data columns in the spreadsheet (including **Eb/No**, **Eb/No (dB)** and one of the BER test configurations: **BER (No FEC)**, **BER(RS4)**, **BER(RS8)**, or **BER(RS16)** (see RED boxes)
- During the simulation a progress box will appear to provide information on the status of the simulation sweeps. Once the message “Simulation complete!” is posted, this dialog box can be closed

The data for each row is updated after a simulation run of the OptiSystem script

BER Analysis Reed Solomon Coding							
C2	C3	C4	C5	C6	C7	C8	C9
Eb/No	Eb/No (dB)	BER (Th)	BER (No FEC)	BER (RS4)	BER (RS8)	BER (RS16)	BER (RS16)
1	1.000205	0.0008886	0.078628313	0.07699585	0.080752461	0.078863755	0.069778442
2	1.121935	0.4996783	0.067072398	0.067962646	0.069296765	0.069180113	0.060112
3	1.2589	0.9999128	0.056283754	0.056732178	0.058073136	0.057971314	0.050460815
4	1.412419	1.4996359	0.046408102	0.046875	0.047925457	0.048438146	0.041984558
5	1.58453	1.9990045	0.03752281	0.038299561	0.039803094	0.0395773	0.033748627
6	1.778759	2.501171	0.029638144	0.030578613	0.03125879	0.031523238	0.02696228
7	1.995393	3.000285	0.022874847	0.024261475	0.024409283	0.024572473	0.021850586
8	2.239771	3.502034	0.017151463	0.01739502	0.019022504	0.01868363	0.016746521
9	2.511759	3.9997793	0.012502658	0.012207031	0.014824191	0.014180803	0.012889862
10	2.817129	4.4980675	0.008806395	0.00970459	0.010246132	0.010746794	0.006585447
11	3.161885	4.999459	0.005956504	0.006195068	0.007890295	0.007654117	0.000795263
12	3.548908	5.5009466	0.003858898	0.003509521	0.005203938	0.002975452	4.72954E-05
13	3.980989	5.9999094	0.002388509	0.002471924	0.003037975	0.000496483	0
14	4.462798	6.496072	0.001406008	0.001678467	0.000752461	1.7239E-05	0
15	5.01161	6.999772	0.000772895	0.000579834	5.62588E-05	0	0
16	5.624698	7.5009915	0.000398245	0.000335693	0	0	0
17	6.304689	7.996635	0.000191908	0.000213623	0	0	0
18	7.075203	8.4973884	8.43804E-05	0.000106812	0	0	0

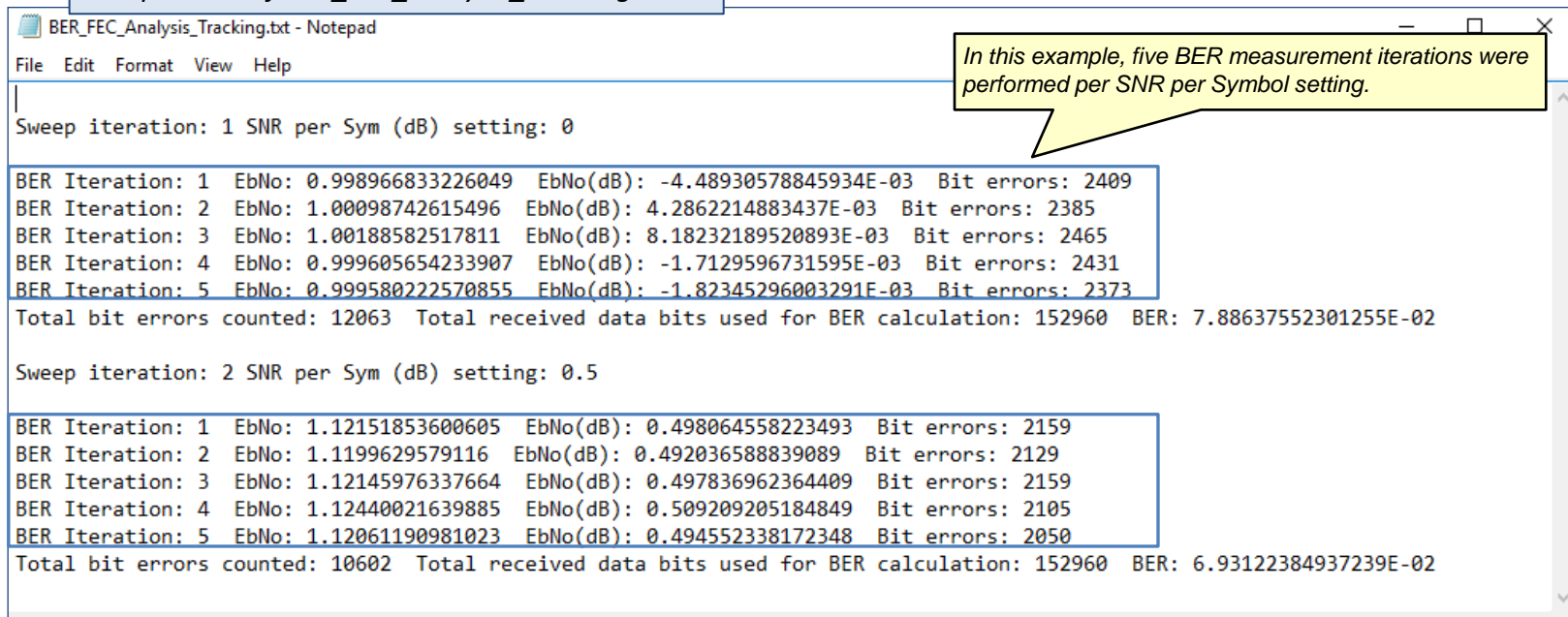


BER vs Eb/No simulation results are automatically plotted for the specified RS format. Also the associated BER theoretical limit is calculated (obtained from column **BER – Th**).

As expected, RS16 provides the most powerful error correction capability as it can correct up to 16 symbols per correcting block. It however requires a larger number of redundant symbols (overhead bits)

- In addition to the Excel spreadsheet analysis tool kit, a data file is also created during the simulation. An example view of the data file content (from *BER\_FEC\_Analysis\_Tracking.txt*) is shown below. The content of this file can be modified as required by using the *objFileToWrite.WriteLine("...")* command in the simulation script

Sample view of *BER\_FEC\_Analysis\_Tracking.txt*



```
BER_FEC_Analysis_Tracking.txt - Notepad
File Edit Format View Help

Sweep iteration: 1 SNR per Sym (dB) setting: 0

BER Iteration: 1 EbNo: 0.998966833226049 EbNo(dB): -4.48930578845934E-03 Bit errors: 2409
BER Iteration: 2 EbNo: 1.00098742615496 EbNo(dB): 4.2862214883437E-03 Bit errors: 2385
BER Iteration: 3 EbNo: 1.00188582517811 EbNo(dB): 8.18232189520893E-03 Bit errors: 2465
BER Iteration: 4 EbNo: 0.999605654233907 EbNo(dB): -1.7129596731595E-03 Bit errors: 2431
BER Iteration: 5 EbNo: 0.999580222570855 EbNo(dB): -1.82345296003291E-03 Bit errors: 2373
Total bit errors counted: 12063 Total received data bits used for BER calculation: 152960 BER: 7.88637552301255E-02

Sweep iteration: 2 SNR per Sym (dB) setting: 0.5

BER Iteration: 1 EbNo: 1.12151853600605 EbNo(dB): 0.498064558223493 Bit errors: 2159
BER Iteration: 2 EbNo: 1.1199629579116 EbNo(dB): 0.492036588839089 Bit errors: 2129
BER Iteration: 3 EbNo: 1.12145976337664 EbNo(dB): 0.497836962364409 Bit errors: 2159
BER Iteration: 4 EbNo: 1.12440021639885 EbNo(dB): 0.509209205184849 Bit errors: 2105
BER Iteration: 5 EbNo: 1.12061190981023 EbNo(dB): 0.494552338172348 Bit errors: 2050
Total bit errors counted: 10602 Total received data bits used for BER calculation: 152960 BER: 6.93122384937239E-02
```

In this example, five BER measurement iterations were performed per SNR per Symbol setting.

- To create a waterfall curve for a specified modulation format, the VBScripting feature of OptiSystem is used to set up the test conditions, create an instance of OptiSystem, run the simulation and retrieve results from the components and visualizers (thus all simulation runs must start from the **Scripts** tab). If you wish to run a standalone simulation, to verify for example the system setup, start the simulation from the **Layout** tab (in this case the script will be ignored)
- For each simulation run, the parameter Eb/No is configured based on settings in the script and in turn applied to a white noise source in the project layout (specifically the *Noise power* setting for the **AWGN I** noise source)
- To set the number of iterations in your simulation, the start value for Eb/No, and the level of change of Eb/No per iteration use the parameters *IterSNRPerSym*, *SNRPerSymStart* and *SNRPerSymStep* (see below)
- Also if you would like to run a reduced number of iterations over a specific sub-set of the sweep indices, use the parameter *StartIndex* to define at which index point you would like to start your iterations.

Set the total number of iterations with *IterSNRPerSym*

When set to a value greater than 1, multiple runs (equal to this value) will be performed for each Eb/No setting and averaged

```
'BER Calculations for BPSK with RS encoding
IterSNRPerSym = 20 'Number of sweeps for EbNo
IterBER = 5 'Number of times to repeat BER calculation
SNRPerSymStart = 0 'dB - EbNo start value
SNRPerSymStep = 0.5 'dB - EbNo incremental value
StartIndex = 0 'Use this setting to perform BER runs over sub-sets of the EbNo sweep values (Default = 0)
ESym = 1 'BPSK
SequenceLength = 65536 '8192 16384 32768 65536 131072 262144 524288 1048576 2097152 4194304 8388608
```

Set the start value of Eb/No with *SNRPerSymStart*  
NOTE: This value is assumed to be in dB!

Set the incremental value of Eb/No with *SNRPerSymStep*  
NOTE: This value is assumed to be in dB!

Use the parameter *StartIndex* to fine tune your iterations by performing runs over a specific set of iteration indices

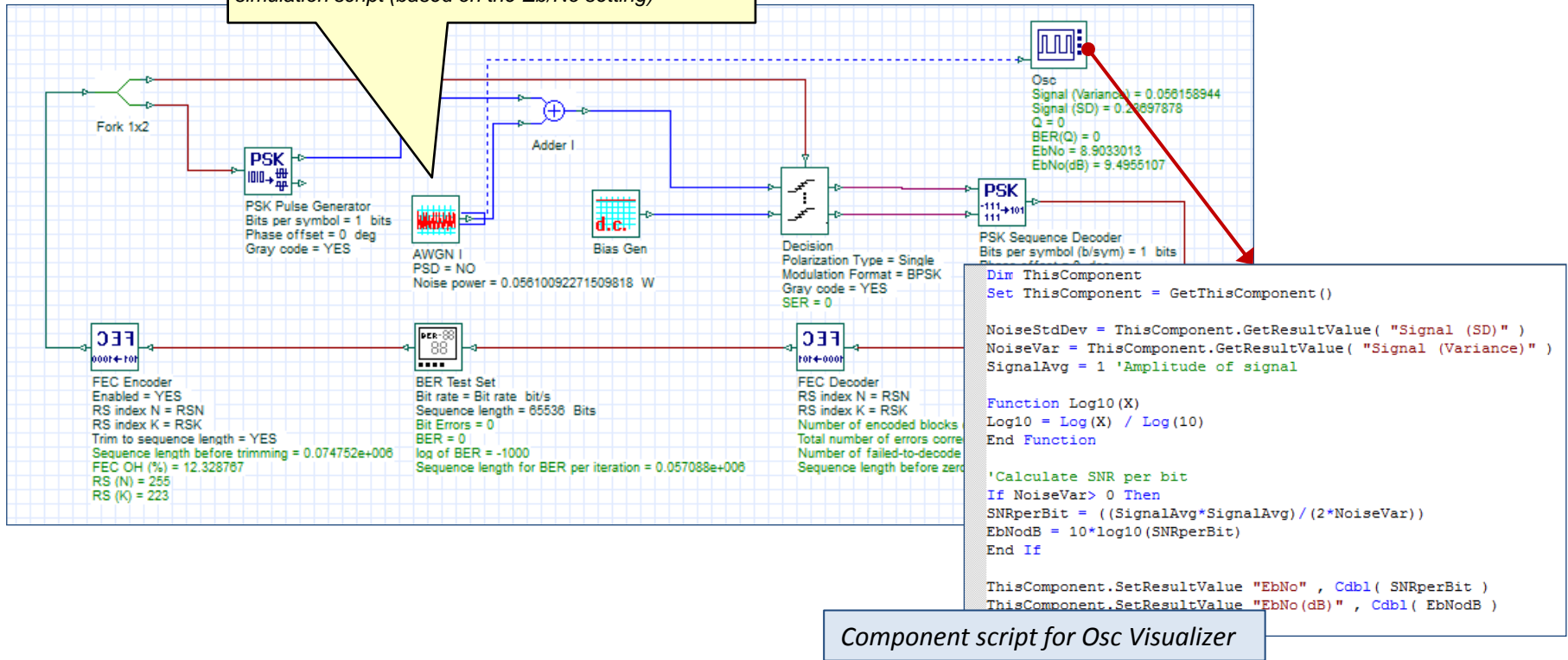
**TIP:** To improve the accuracy of BER results under low noise conditions (where the symbol/bit error counts may be quite low) or when a strong FEC encoding is used, it is recommended to increase the *Sequence length* setting. Also you can increase the parameter *IterBER* to a value greater than 1 (when this is done, the simulation will perform extra runs for each noise level and take the average of the results)

# Notes on BER & FEC analysis (2)

## BER analysis – RS encoding

- To verify that the noise settings are being properly applied to the I channel, the  $E_b/N_0$  parameter is re-calculated in OptiSystem through a Component script procedure written in the Oscilloscope Visualizer (this Visualizer includes a calculation result for **Noise (Variance)** which is applied to the calculation for  $E_b/N_0$ )
- The results  $E_b/N_0$  are in turn exported to the Excel analysis spreadsheet and used for plotting of the BER waterfall curves
- The *Bit Errors* (and the associated *Sequence length for BER per iteration*) are obtained from the BER Test Set

For each iteration, the **Noise power** is updated via the simulation script (based on the  $E_b/N_0$  setting)



Component script for Osc Visualizer



- The FEC Encoder works by adding redundant bits ( $n-k$ ) to information blocks of length  $k$ . The bit sequence at the output of the FEC Encoder will thus be longer than the input. When performing tests on higher order modulation systems, the parameter **Trim to sequence length** should be enabled. This will ensure that the Decision component correctly recovers all information and redundant (error correcting) symbols that cover the length of the original sequence length.
- At the FEC Decoder, the redundant symbols will then be removed and thus the output of the Decoder will have a shorter sequence than the original sequence from the BER Test Set. This is not a problem as the BER Test Set automatically checks for this condition and only applies error counting against the shorter sequence length (this can be confirmed by viewing the result *Sequence length for BER per iteration* which is equal to 57088; equal in value to the output sequence of the FEC Decoder)

