Workshop
PSpice & Minitab

Example: a Power Factor Corrector

Overview

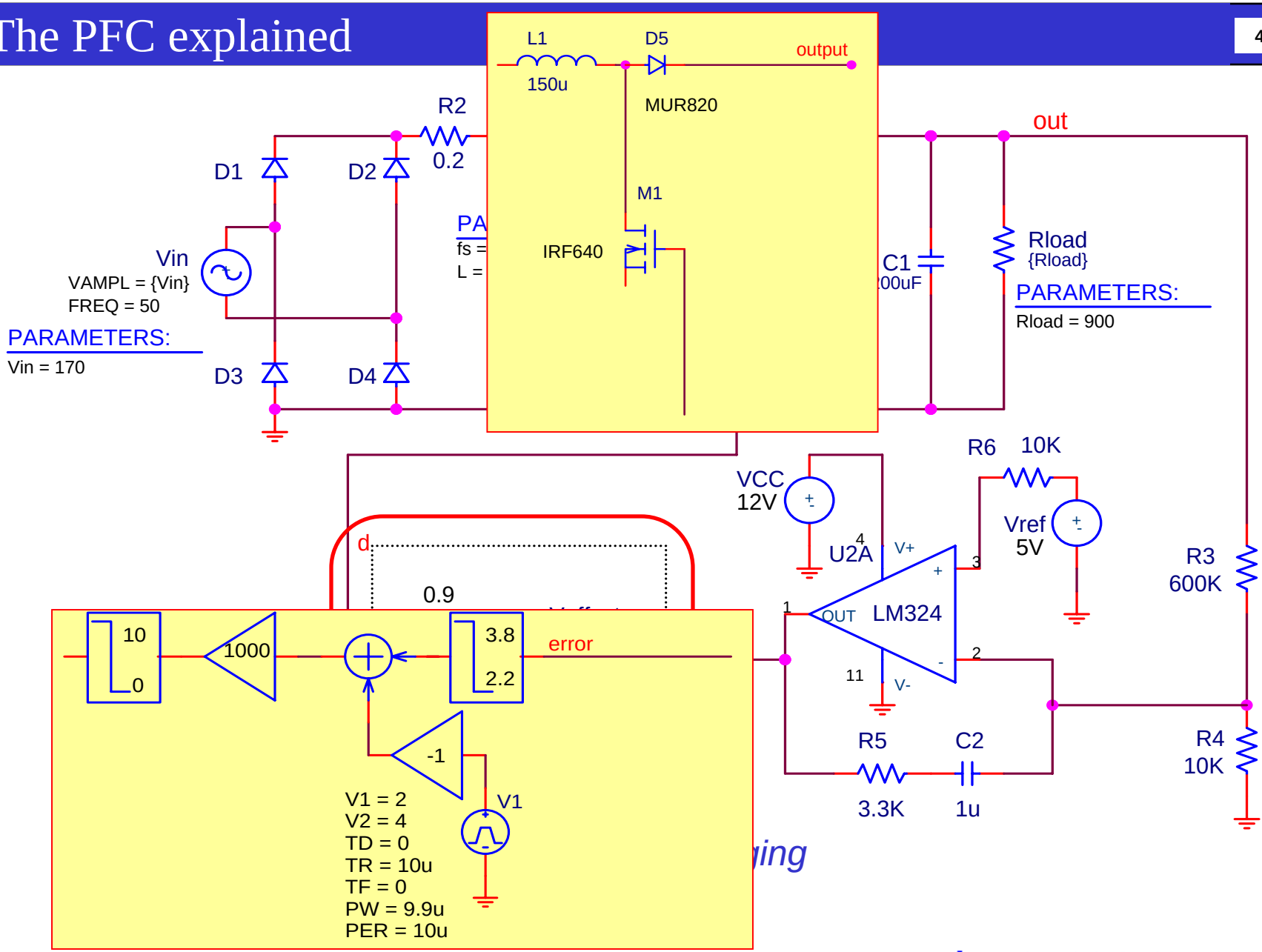
- ***The PFC explained***
- ***What is Critical to Quality***
- ***Exercise step 1: determine the CtQ(=Y) values from simulation***
- ***The influencing factors (X)***
- ***Exercise step 2: determine the influencing factors X***
- ***Exercise step 3: perform the DoE for the PFC***
- ***Exercise step 4: define the transfer functions Y(X)***
- ***Exercise step 5: optimize the component spread for the CtQs***

The PFC explained

In general, the function of a Power Factor Corrector (PFC) is to

1. ***provide a stable DC output bus voltage for e.g. an HF-TL or UHP electronic lamp driver,***
2. ***connect the load to the mains voltage in such a way that the mains current is nearly sinusoidal (low THD) and in phase with the mains voltage (cos φ ~ 1)***

The PFC explained



What is Critical to Quality

1. *The DC output voltage should be stable*
2. *The circuit should be able to withstand overshoots caused by changing dynamic conditions (e.g.: turn on the mains, sudden change in load)*
3. *The harmonic distortion of the mains current should fulfill the regulations specifications*

Note: these requirements should be fullfilled for the allowed variation in mains voltage and in load

What is Critical to Quality

Specifications

requirement	*symbol*	*spec*	*ppm-level*
output voltage	*Vo*	*305V +/-5%*	*500*
output ripple	*Vr*	*< 10V_{pp}*	*500*
harm. distortion	*THDin*	*< 25%*	*500*
overshoot	*Vs*	*< 20V*	*100*

when subjected to

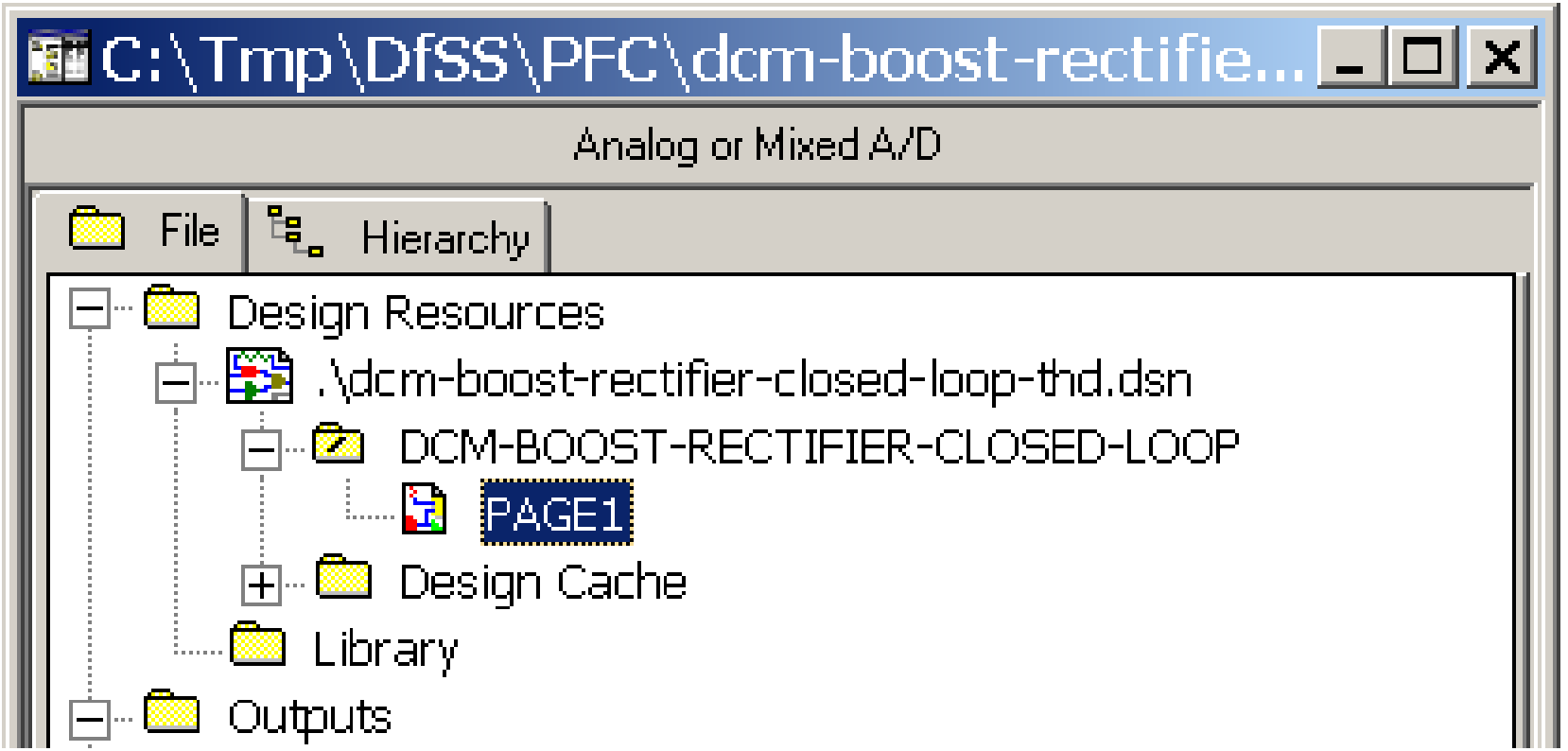
input voltage	*Vin*	*170 V_p, -10% … +20%*
load	*Rload*	*700 – 1600 Ω*

Step 1: simulate output voltage Vo, ripple Vr, and THDin

1. ***perform a transient simulation***
2. ***determine Vo and Vr by hand***
3. ***automate the measurement of Vo and Vr***
4. ***determine THDin***
5. ***determine Vo, Vr and THDin for the specified Rload range***
6. ***determine Vo, Vr and THDin for the specified Vin range***

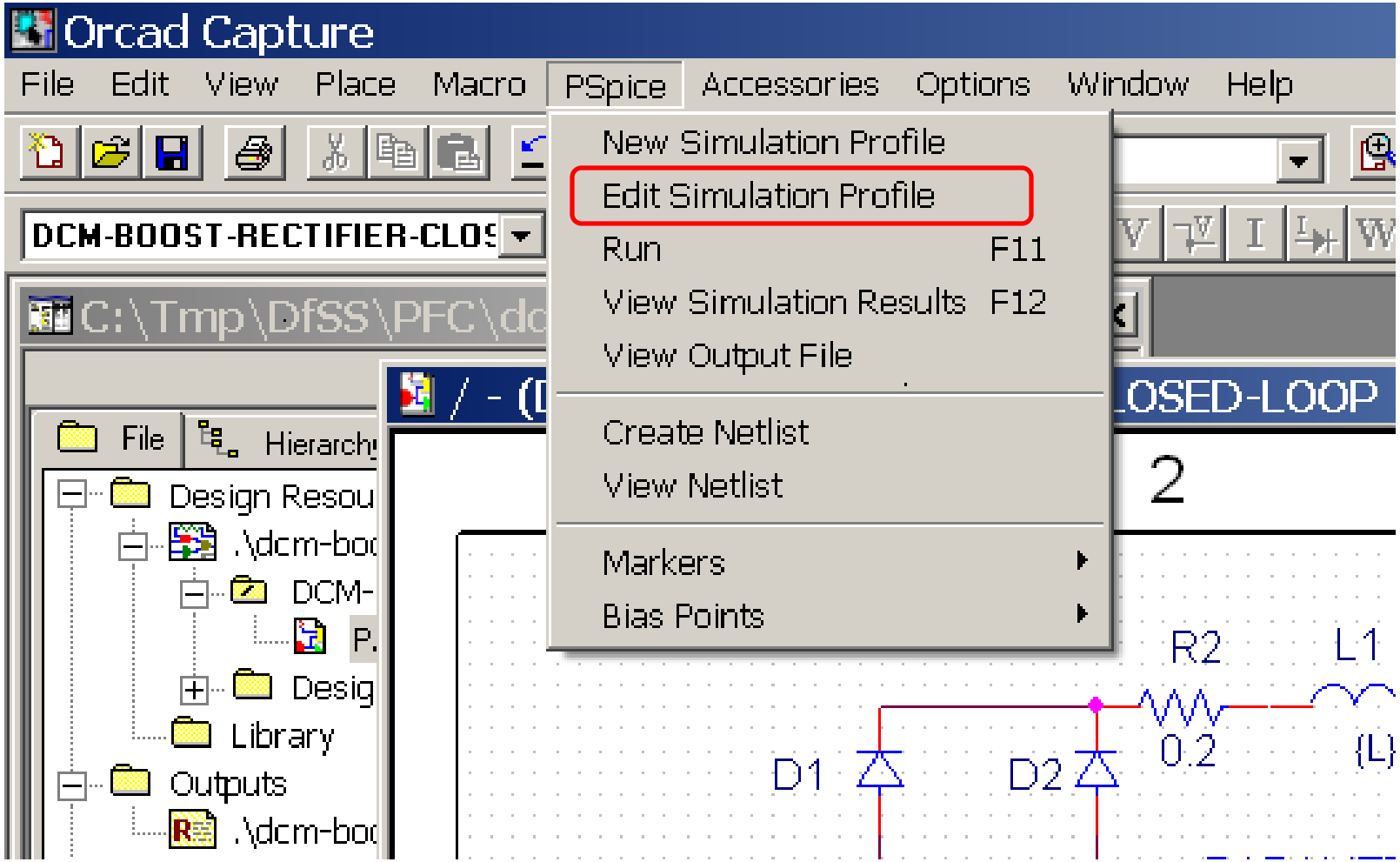
Step 1: simulate output voltage Vo, ripple Vr, and THDin

- ***go to D:\PFC_example***
- ***open dcm-boost-rectifier-closed-loop-thd.opj (double-click)***
- ***go to the schematics page***



Step 1: simulate output voltage Vo, ripple Vr, and THDin

- ***edit the PSpice simulation profile***

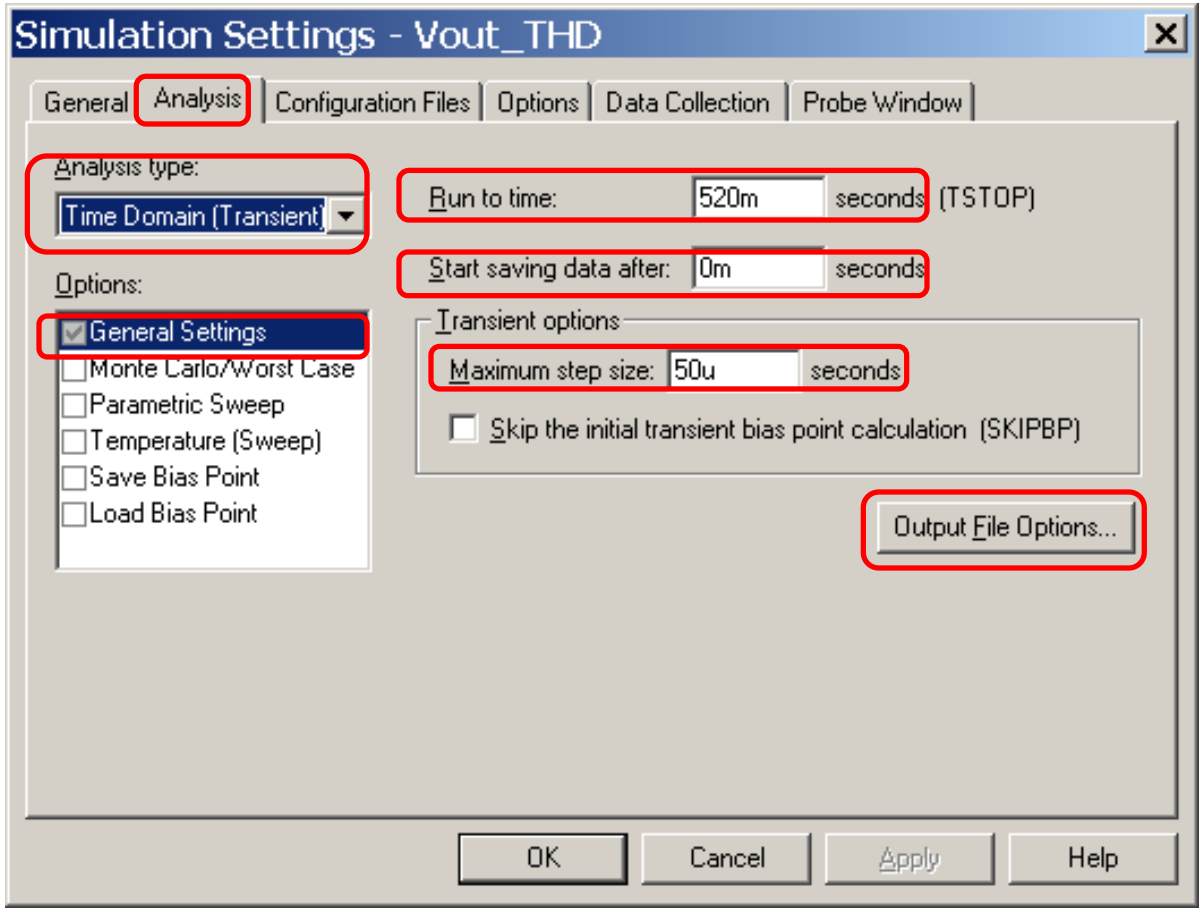


Step 1: simulate output voltage Vo, ripple Vr, and THDin

- ***select tab Analysis***
- ***set analysis type 'Time Domain'***
- ***select General Settings***

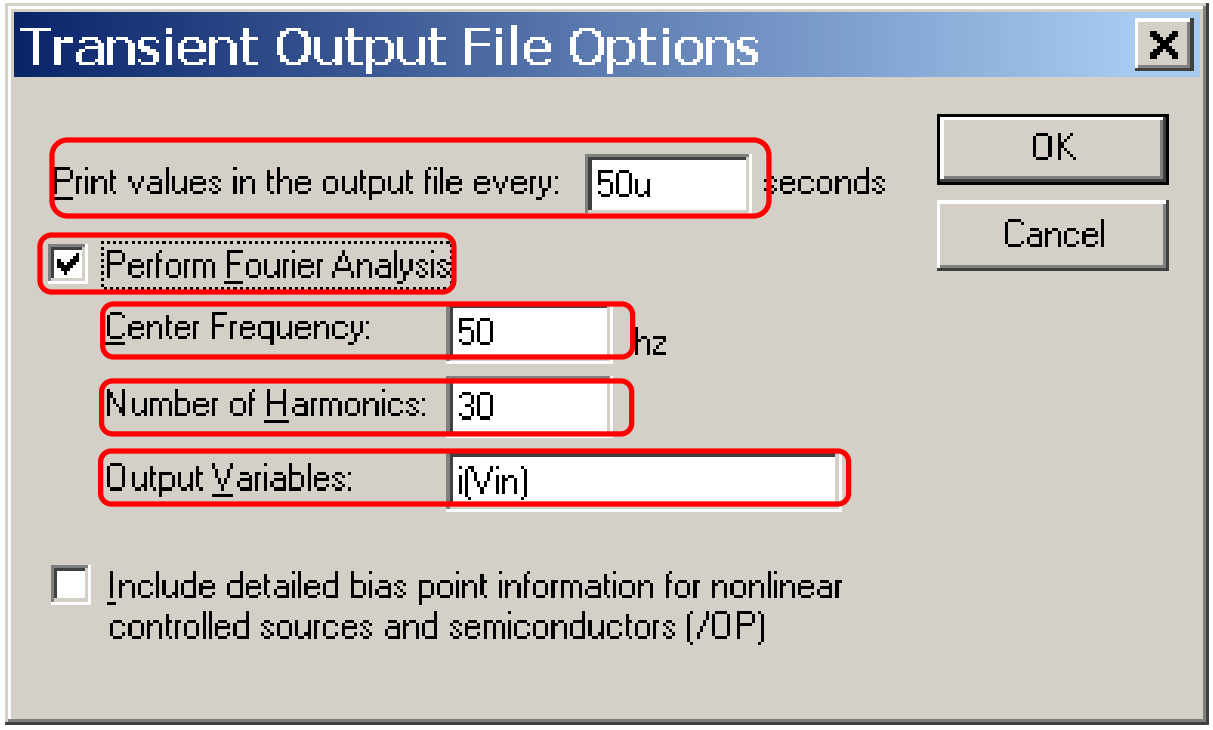
- ***set 'Run to time' to 520m***
- ***set 'Start saving data after' to 0m***
- ***set 'Maximum step size' to 50u***

- ***go to 'Output File Options'***



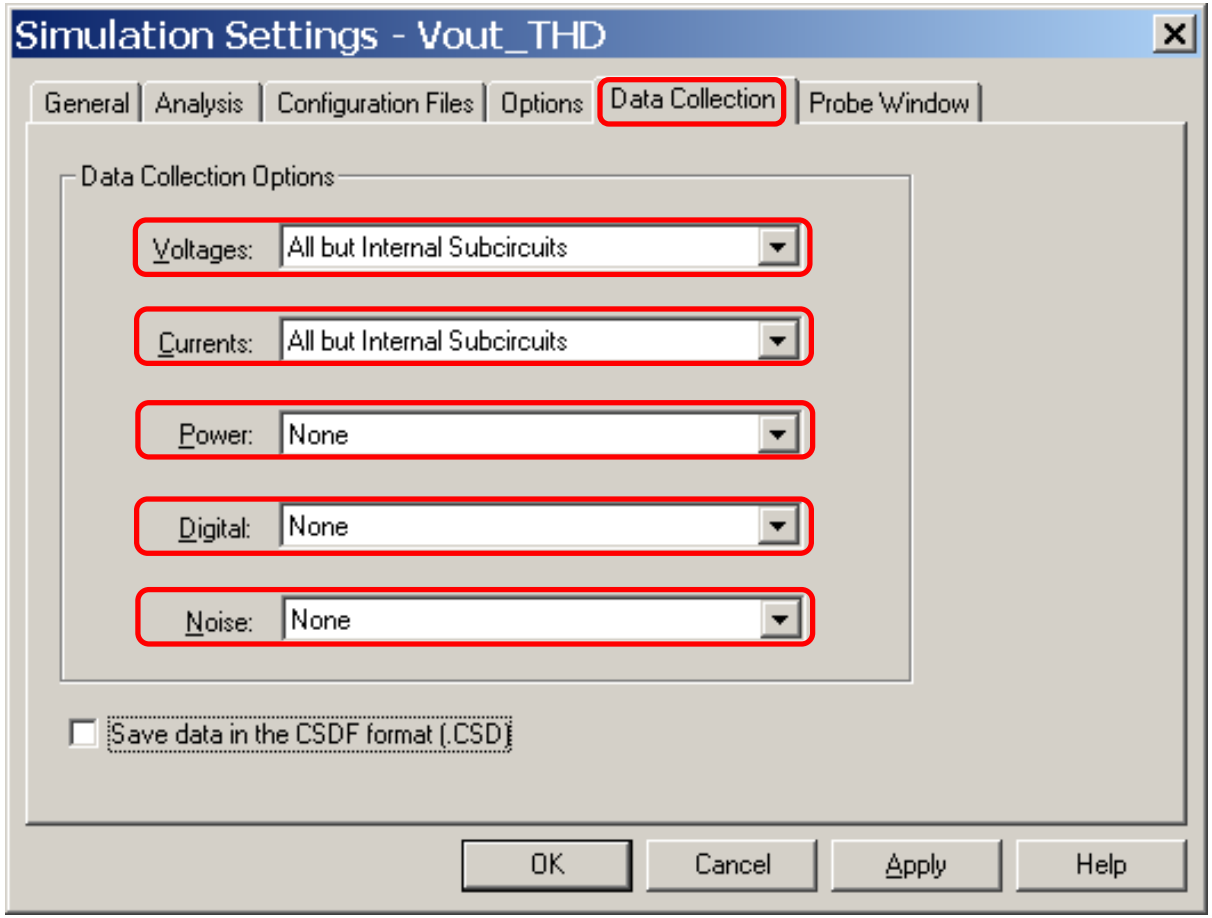
Step 1: simulate output voltage Vo, ripple Vr, and THDin

- ***set 'Print values … every:' to 50u***
- ***check 'Perform Fourier Analysis' and set***
  - *Center Frequency: 50*
  - *Number of Harmonics: 30*
  - *Output Variables: i(Vin)*
- ***… and press OK***



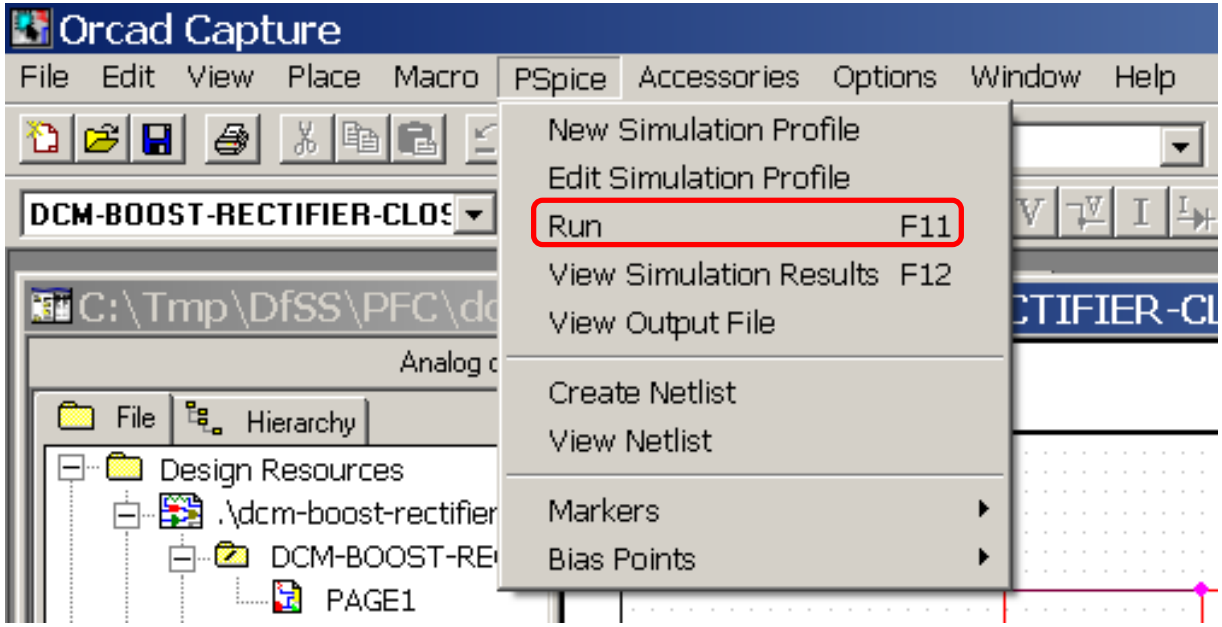
Step 1: simulate output voltage Vo, ripple Vr, and THDin

- ***select tab Data Collection***
- ***for Voltages and Currents select All but Internal Subcircuits***
- ***for Power, Digital and Noise select None***
- ***… and press OK***

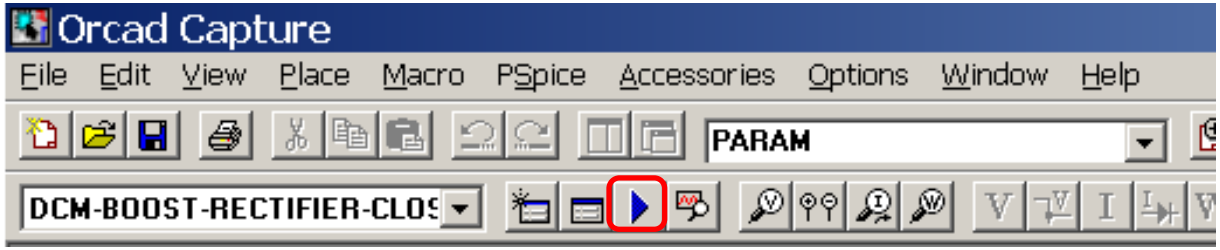


Step 1: simulate output voltage Vo, ripple Vr, and THDin

- ***start the PSpice simulation by selecting Run (equivalent to pressing F11)***

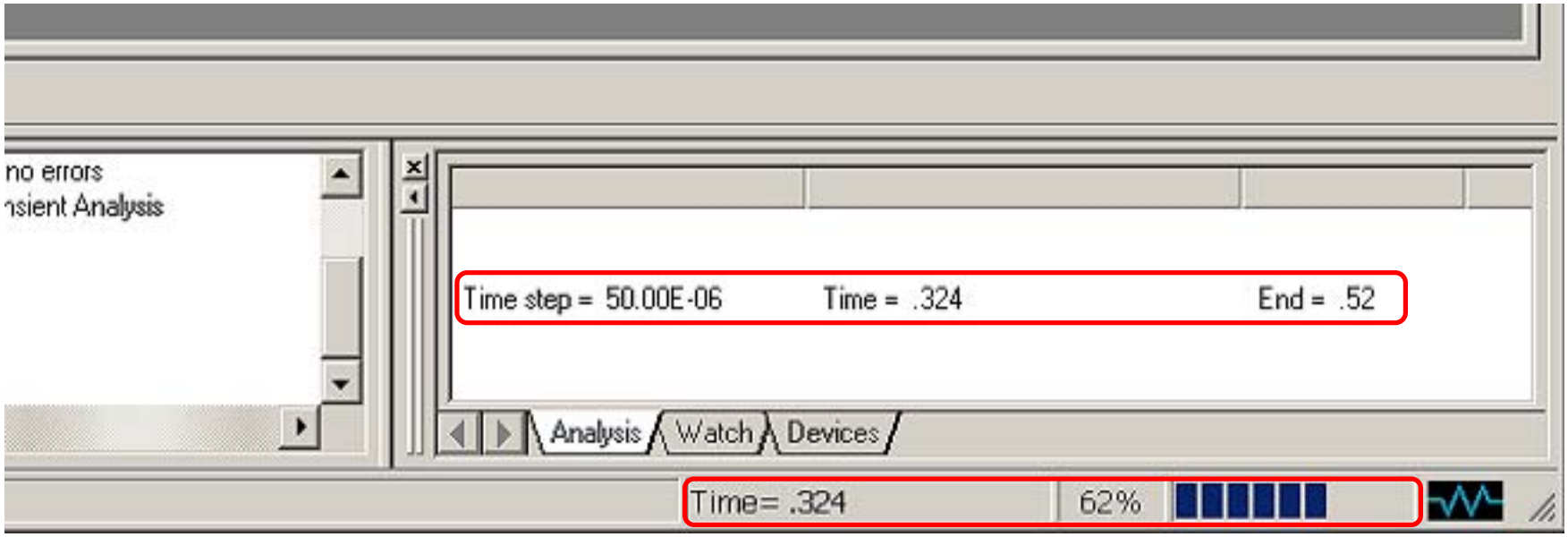


… or pressing the simulation start button



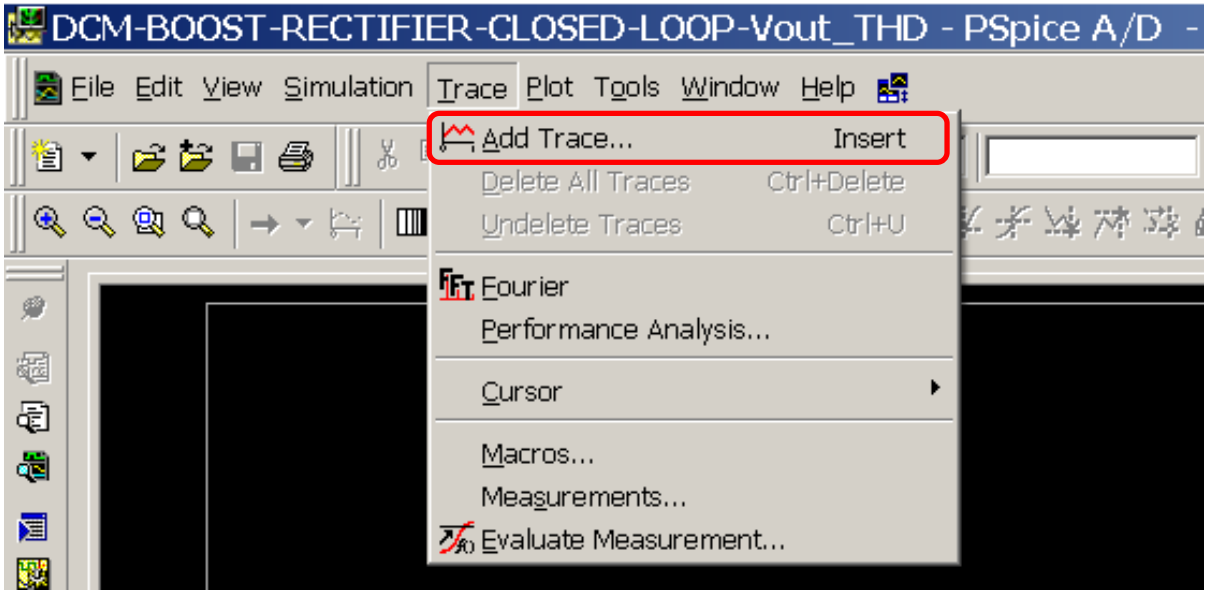
Step 1: simulate output voltage Vo, ripple Vr, and THDin

- ***PSpice will start and the viewer will pop up, showing the progress of the simulation***

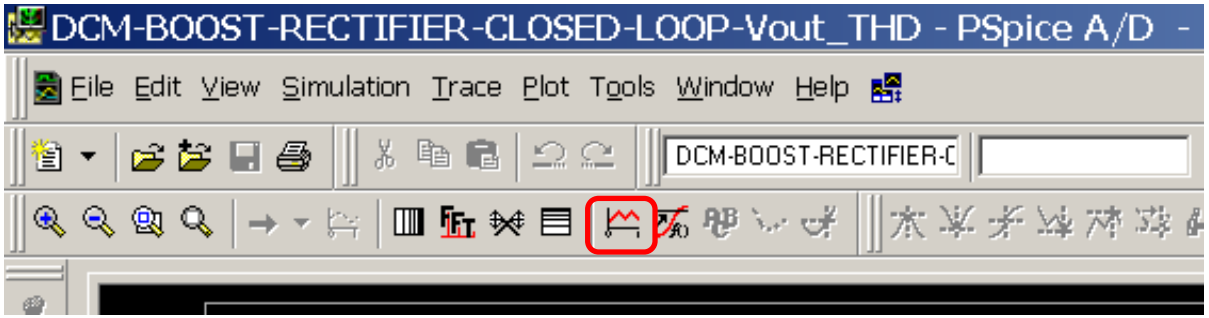


Step 1: simulate output voltage Vo, ripple Vr, and THDin

- ***add a trace to the empty plot by 'Add Trace …' (= pressing Insert)***

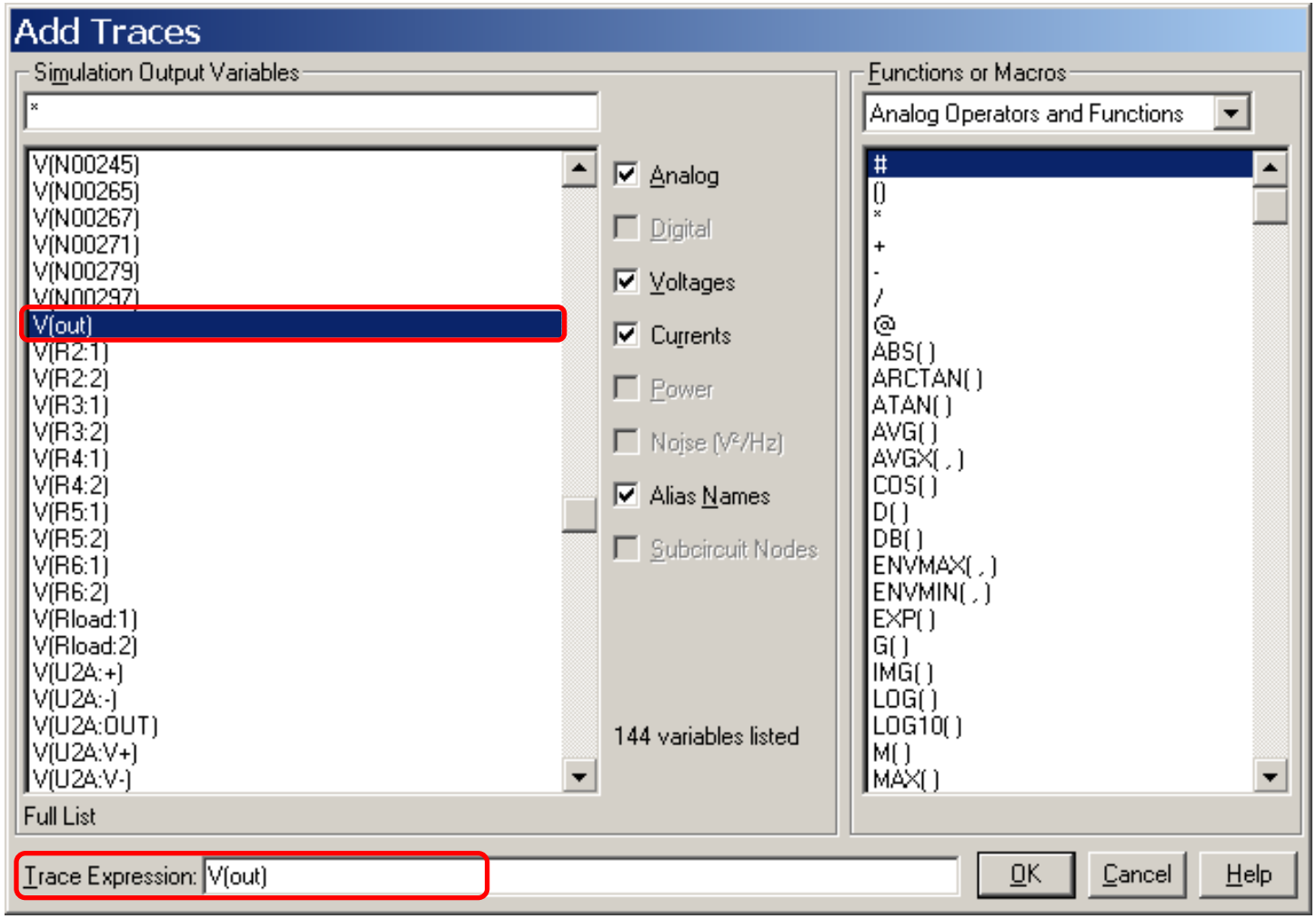


… or pressing the 'Add Trace' button



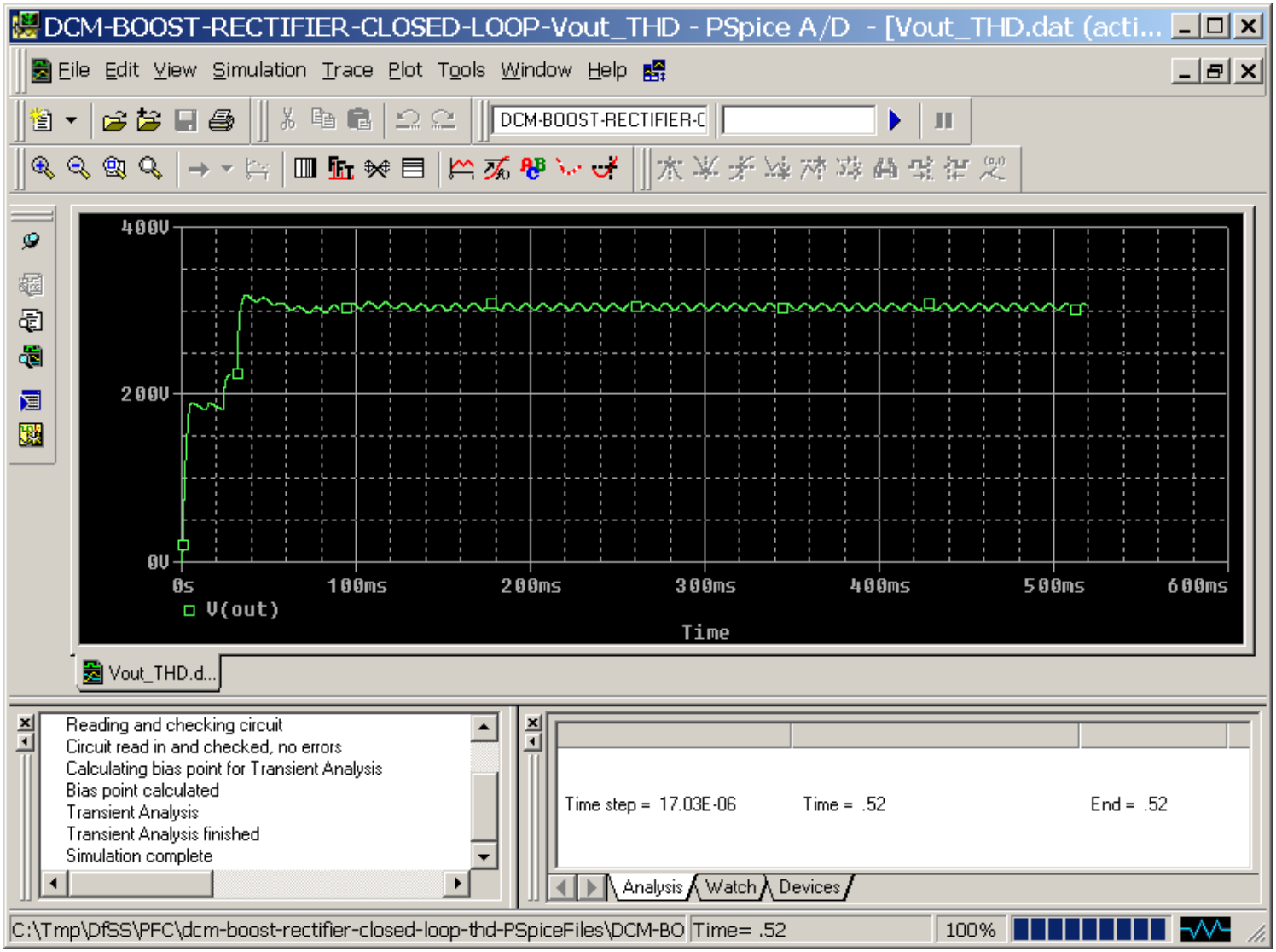
Step 1: simulate output voltage Vo, ripple Vr, and THDin

- ***select the trace V(out) … and press OK***



Step 1: simulate output voltage Vo, ripple Vr, and THDin

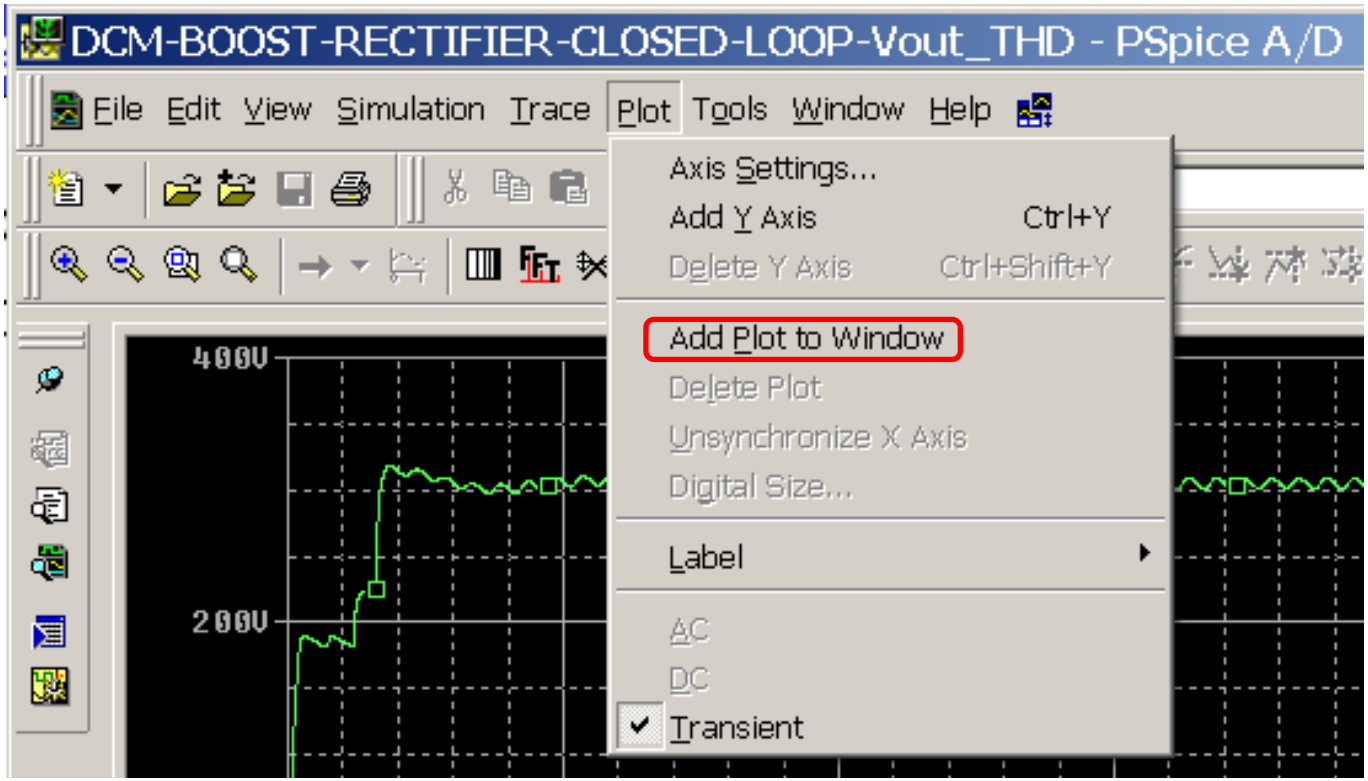
Result:



Step 1: simulate output voltage Vo, ripple Vr, and THDin

To show the current through the mains (=voltage source Vin)

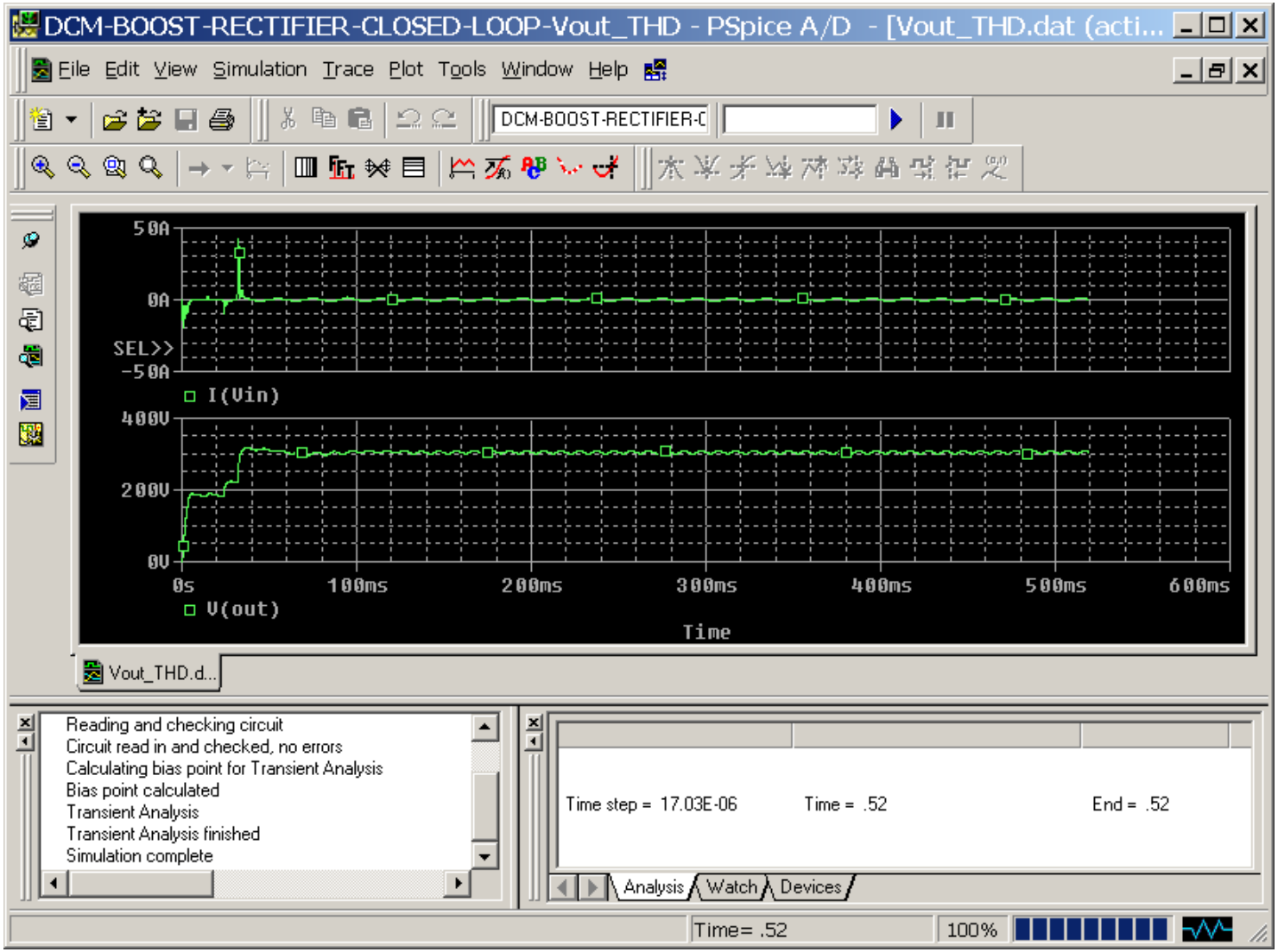
- ***add an additional plot to the window***



- ***and add trace 'i(Vin)' as show before***

Step 1: simulate output voltage Vo, ripple Vr, and THDin

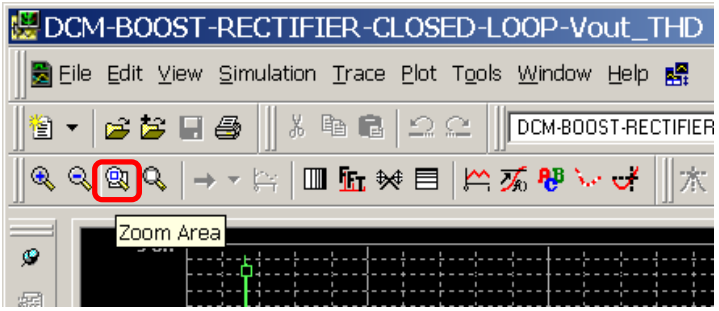
Result:



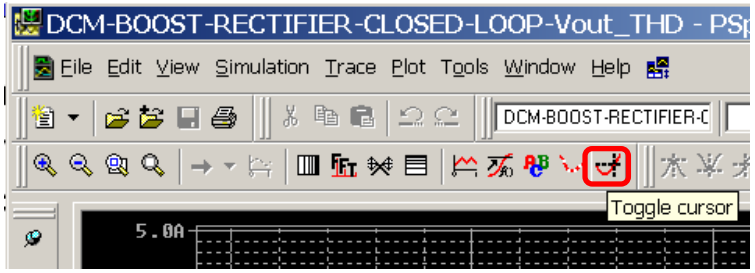
Step 1: simulate output voltage Vo, ripple Vr, and THDin

Determine Vo and Vr by hand by

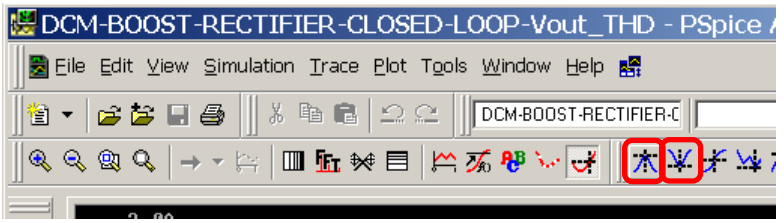
1. ***zoom in (Zoom Area button)***
2. ***select about the last 2 periods of V(out)***



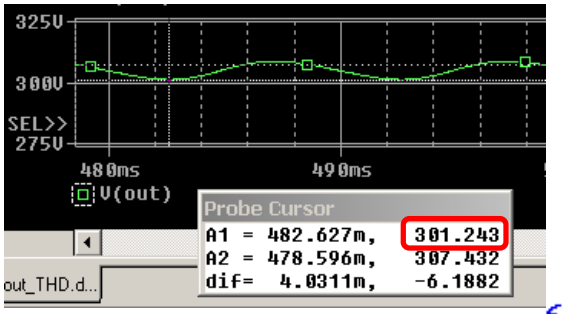
3. ***active the cursor (Toggle cursor button)***



4. ***search for the min and max by using the Cursor Peak and Trough buttons***



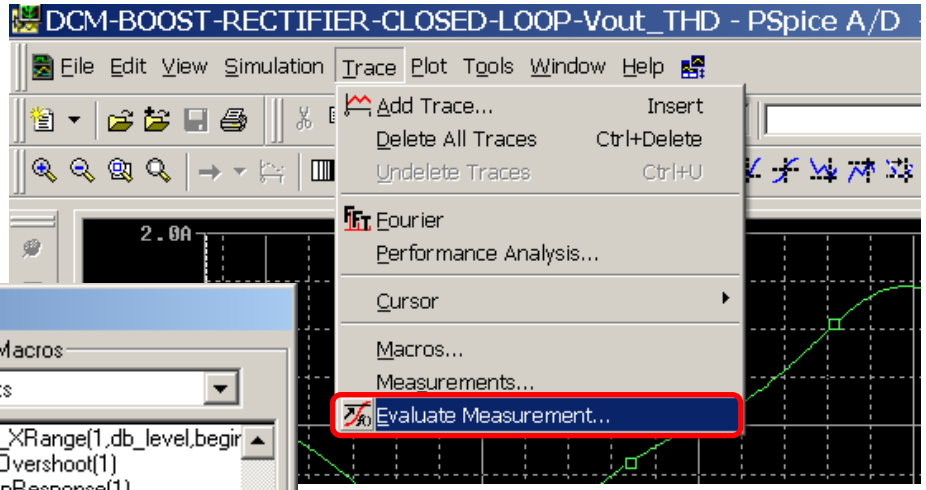
5. ***read the min and max value and determine Vo and Vr***

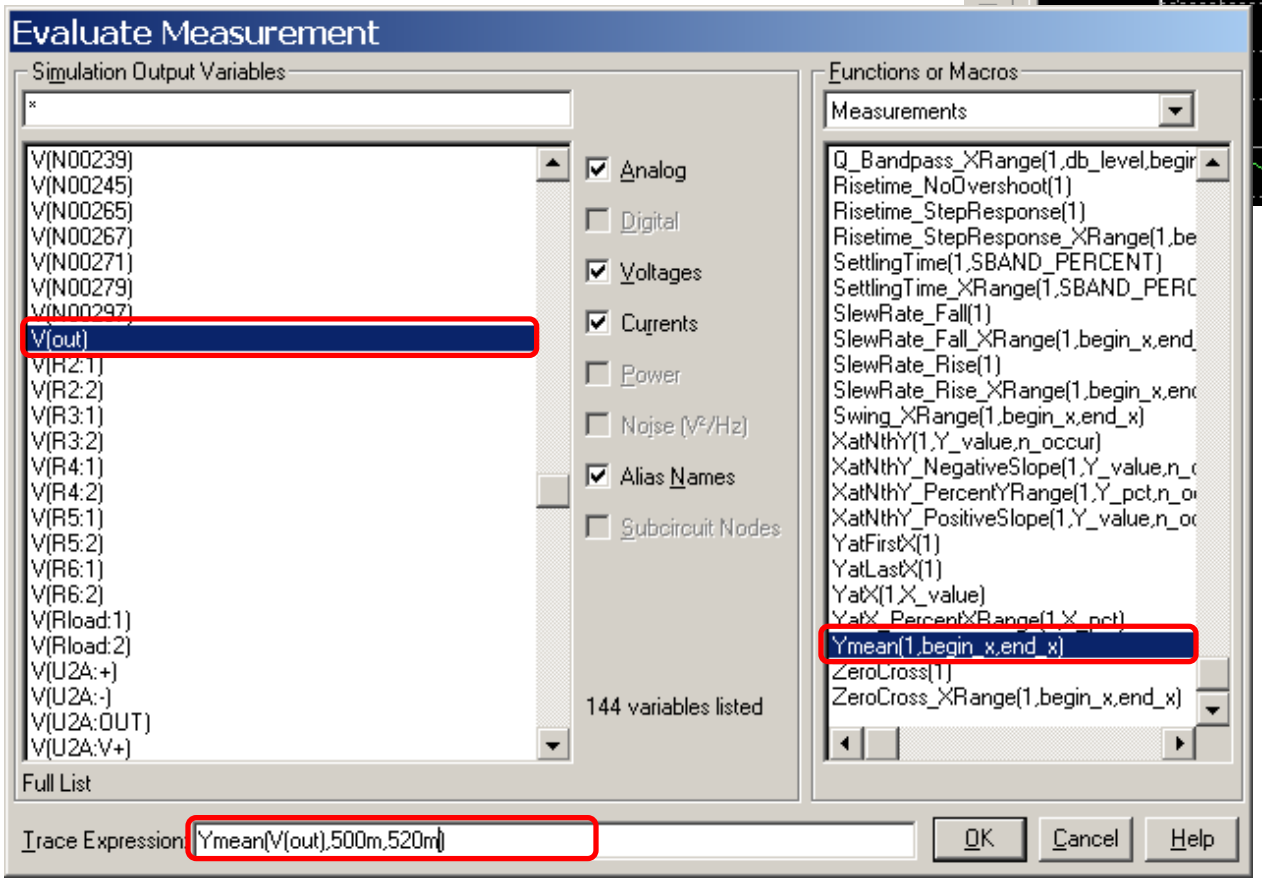


Step 1: simulate output voltage Vo, ripple Vr, and THDin

Automate measuring Vo and Vr

1. *choose Trace > Evaluate Measurement*





2. *select Ymean of V(out) from 500m to 520m seconds*

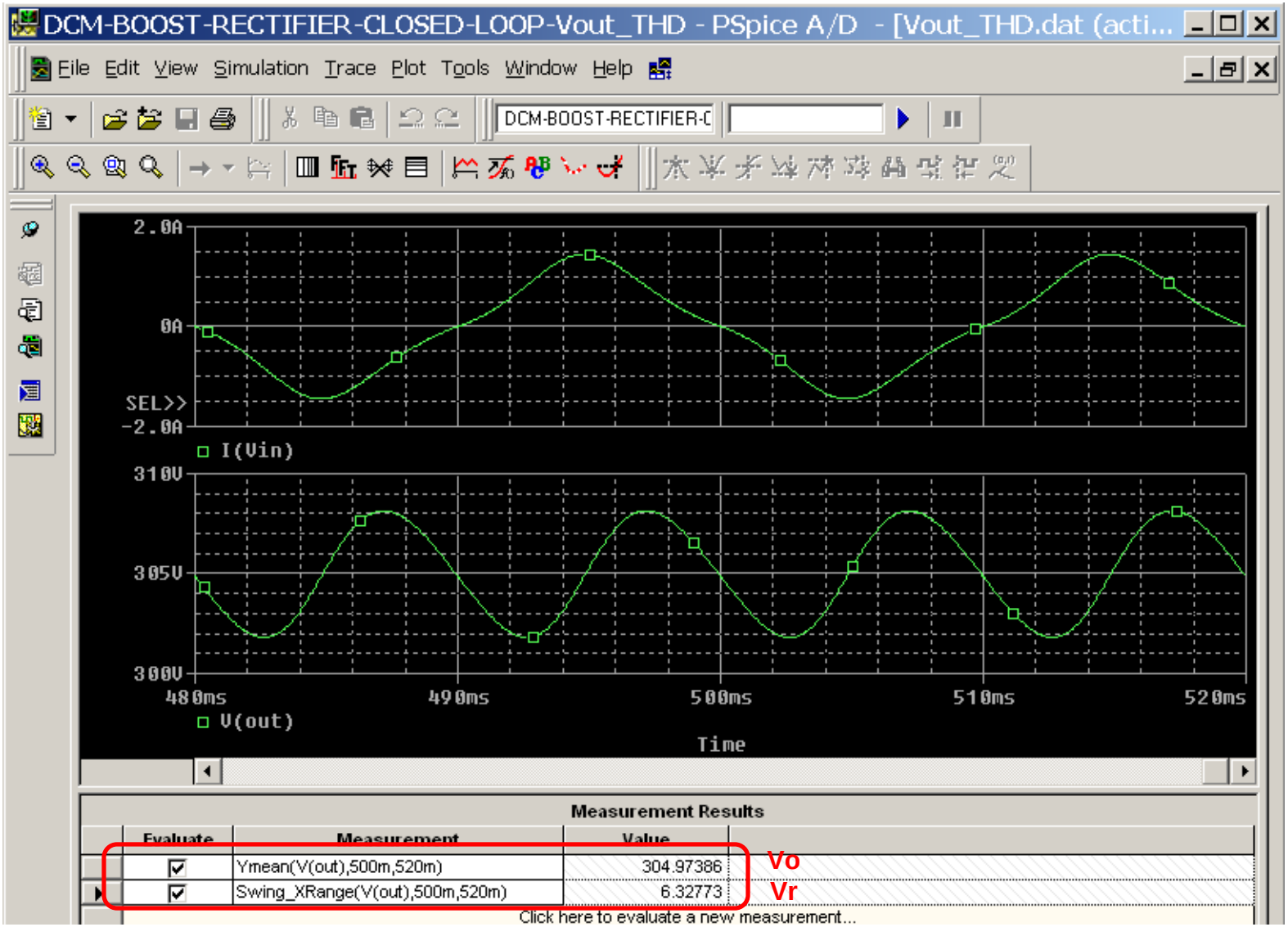
3. *… and press OK*

4. *in the same way add measurement*

Swing_XRange(V(out),500m,520m)

Step 1: simulate output voltage Vo, ripple Vr, and THDin

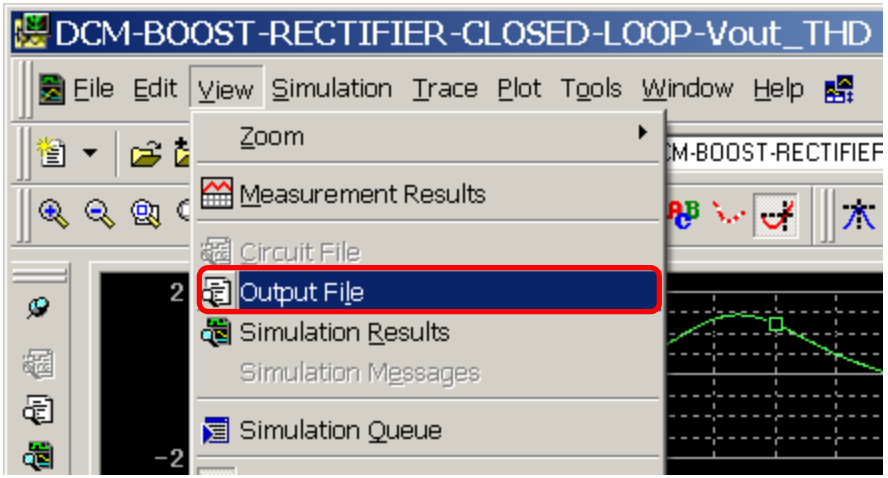
Result:



Step 1: simulate output voltage Vo, ripple Vr, and THDin

Determine THDin from the output file

1. view the output file



2. search (using e.g. Ctrl-F) for 'fourier components'

FOURIER COMPONENTS OF TRANSIENT RESPONSE I(V_Vin)

DC COMPONENT = 3.436798E-06

HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	5.000E+01	1.235E+00	1.000E+00	-1.786E+02	0.000E+00
2	1.000E+02	6.510E-06	5.272E-06	-7.891E+01	2.782E+02
3	1.500E+02	2.002E-01	1.621E-01	1.159E+01	5.473E+02
4	2.000E+02	9.325E-07	7.552E-07	-1.566E+02	5.577E+02
5	2.500E+02	1.182E-02	9.574E-03	-1.221E+02	7.707E+02
6	3.000E+02	1.640E-06	1.329E-06	-1.123E+02	9.591E+02
7	3.500E+02	4.677E-03	3.788E-03	1.469E+01	1.265E+03
8	4.000E+02	1.562E-06	1.265E-06	-1.189E+02	1.310E+03
9	4.500E+02	1.923E-03	1.557E-03	-6.276E+00	1.601E+03
10	5.000E+02	1.678E-06	1.359E-06	-1.293E+02	1.656E+03
11	5.500E+02	1.276E-03	1.033E-03	-3.263E-01	1.964E+03
12	6.000E+02	1.901E-06	1.539E-06	-1.389E+02	2.004E+03
13	6.500E+02	9.220E-04	7.467E-04	-7.389E-01	2.321E+03
14	7.000E+02	1.800E-06	1.458E-06	-1.381E+02	2.362E+03
15	7.500E+02	7.093E-04	5.745E-04	-3.621E-01	2.678E+03
16	8.000E+02	1.915E-06	1.551E-06	-1.435E+02	2.713E+03
17	8.500E+02	5.732E-04	4.642E-04	-1.251E-01	3.035E+03
18	9.000E+02	2.207E-06	1.788E-06	-1.507E+02	3.063E+03
19	9.500E+02	4.791E-04	3.881E-04	7.106E-02	3.393E+03
20	1.000E+03	2.226E-06	1.803E-06	-1.491E+02	3.422E+03
21	1.050E+03	4.108E-04	3.327E-04	2.558E-01	3.750E+03
22	1.100E+03	2.377E-06	1.925E-06	-1.484E+02	3.780E+03
23	1.150E+03	3.587E-04	2.905E-04	4.392E-01	4.107E+03
24	1.200E+03	2.848E-06	2.307E-06	-1.555E+02	4.130E+03
25	1.250E+03	3.187E-04	2.581E-04	5.804E-01	4.465E+03
26	1.300E+03	2.972E-06	2.407E-06	-1.565E+02	4.486E+03
27	1.350E+03	2.863E-04	2.319E-04	7.176E-01	4.822E+03
28	1.400E+03	2.910E-06	2.357E-06	-1.563E+02	4.843E+03
29	1.450E+03	2.598E-04	2.104E-04	8.252E-01	5.179E+03
30	1.500E+03	3.222E-06	2.609E-06	-1.596E+02	5.197E+03

TOTAL HARMONIC DISTORTION = 1.624535E+01 PERCENT

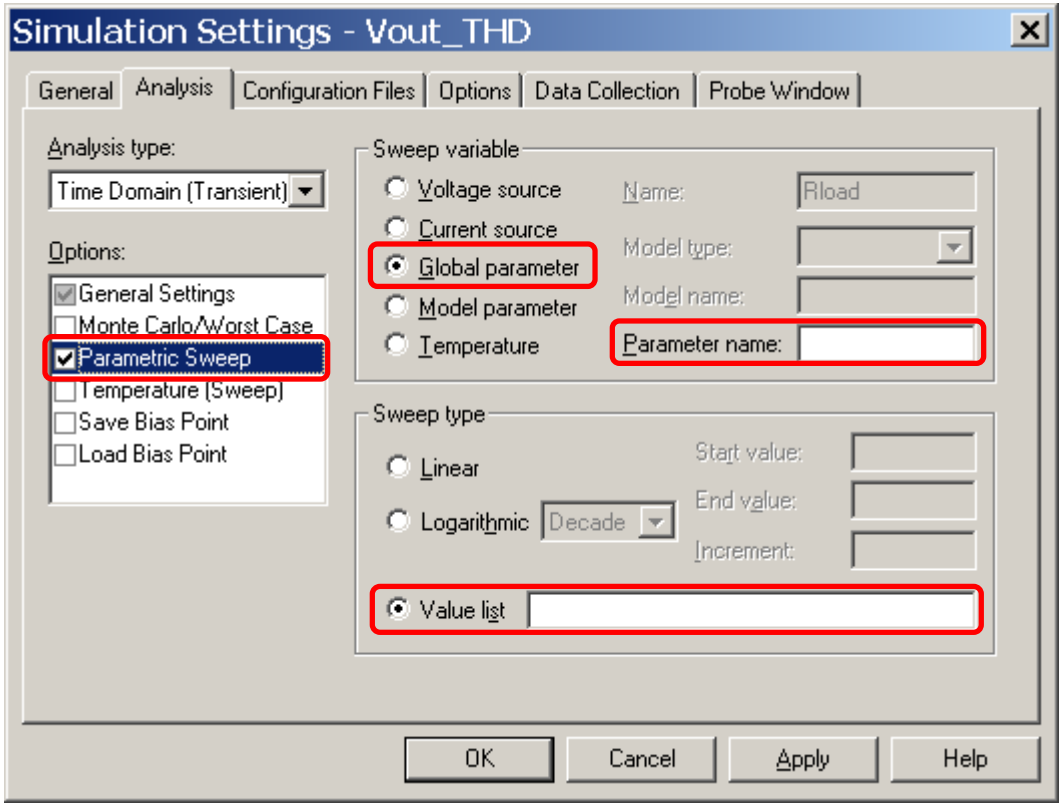
3. determine the phase shift of the first harmonic

4. determine the total harmonic distortion

Step 1: simulate output voltage Vo, ripple Vr, and THDin

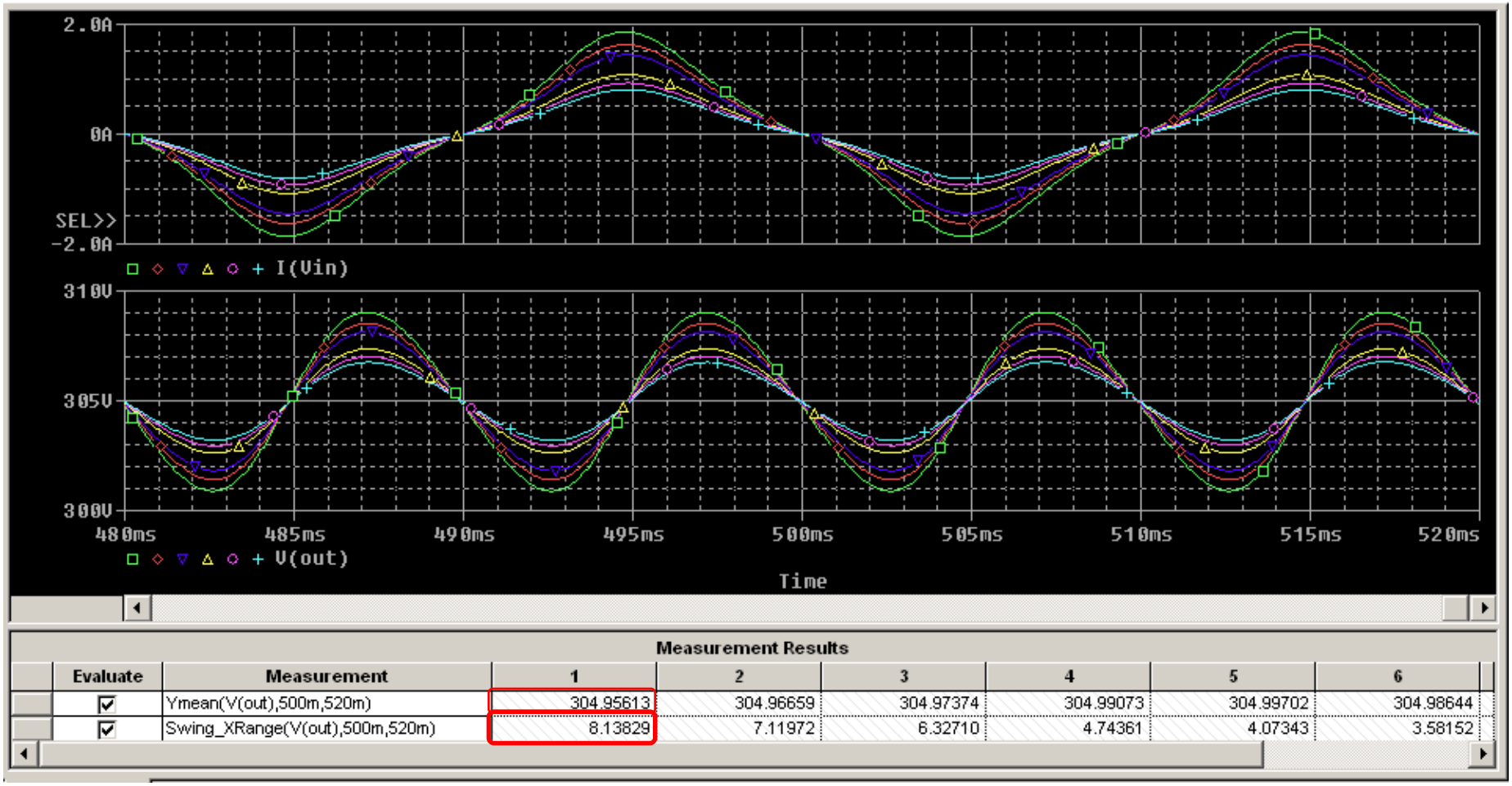
Determine Vo, Vr and THDin for the specified Rload range

- ***go to the simulation profile (in Orcad Capture: PSpice > Edit Simulation Profile)***
- ***select tab Analysis***
- ***check Parametric Sweep***
- ***select Global parameter***
- ***Parameter name: Rload***
- ***Value list:***
  700,800,900,1200,1400,1600
- ***… and press OK***
- ***perform a simulation (F11)***
  … and accept all sections



Step 1: simulate output voltage Vo, ripple Vr, and THDin

Vo and Vr results for Rload range



Measurement Results

Evaluate	Measurement	1	2	3	4	5	6
☑	Ymean(V(out),500m,520m)	304.95613	304.96659	304.97374	304.99073	304.99702	304.98644
☑	Swing_XRange(V(out),500m,520m)	8.13829	7.11972	6.32710	4.74361	4.07343	3.58152

Step 1: simulate output voltage Vo, ripple Vr, and THDin

THDin results for Rload range

Rload	THDin (%)
700	16.39249
800	16.31313
900	16.24482
1200	16.09614
1400	16.02859
1600	15.97218

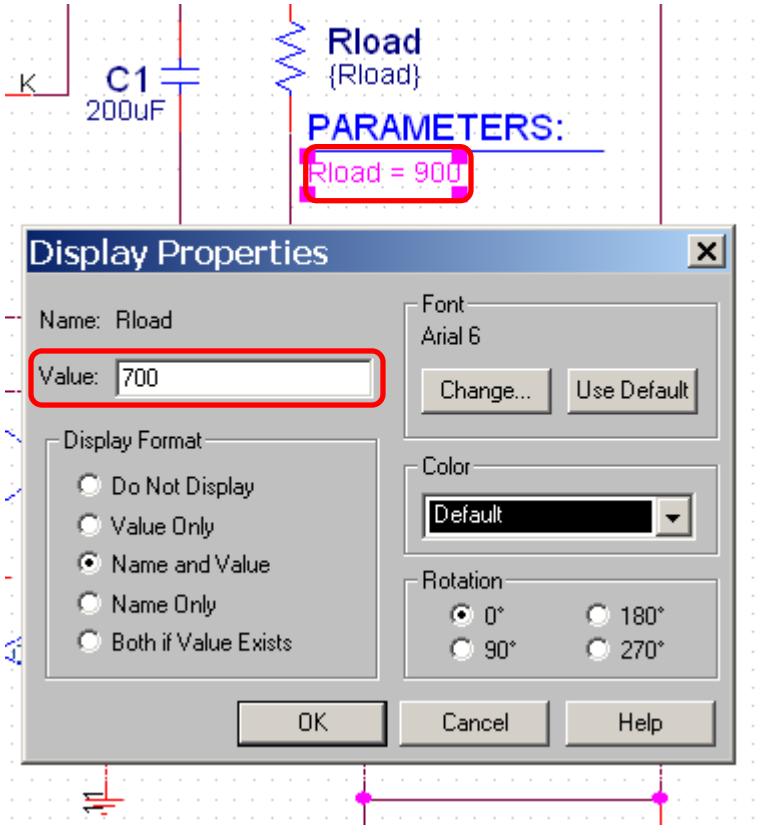
Conclusions

1. ***maximum Vr and THDin are reached for lowest Rload (meaning maximum load power)***
2. ***Within simulation accuracy Vo does not depend on Rload***

Step 1: simulate output voltage Vo, ripple Vr, and THDin

Determine Vo, Vr and THDin for the specified Vin range (Rload=700)

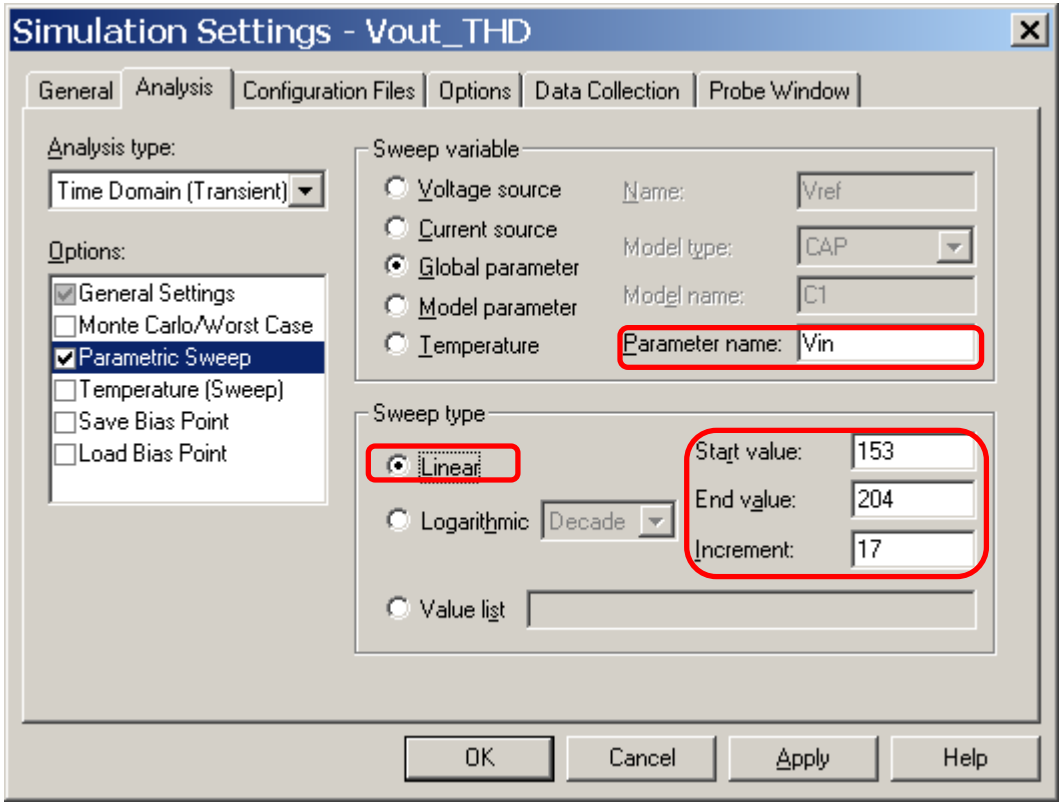
- ***in Orcad Capture: double click on 'Rload = 900' → a 'Display Properties' window will pop up***
- ***change the value of Rload to 700***
- ***… and press OK***



Step 1: simulate output voltage Vo, ripple Vr, and THDin

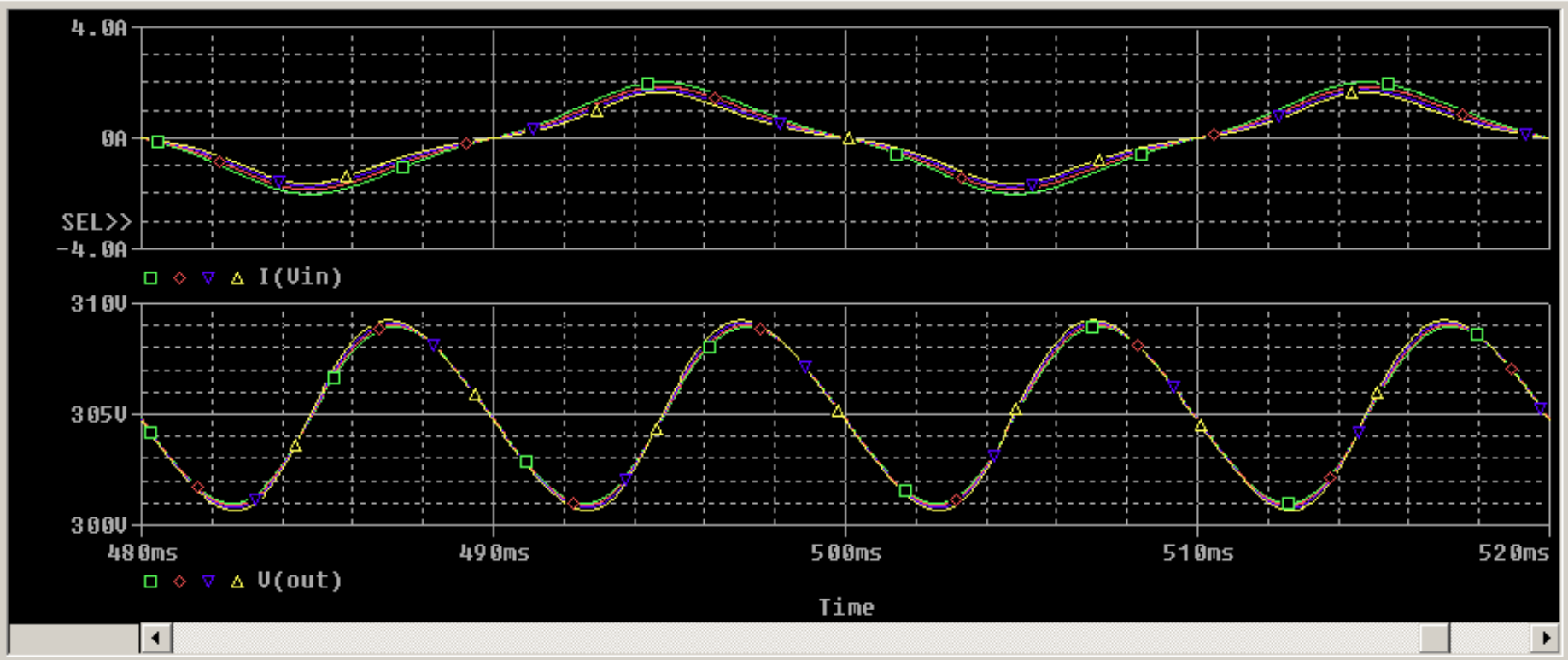
Determine Vo, Vr and THDin for the specified Vin range (Rload=700)

- ***go to the simulation profile (in Orcad Capture: PSpice > Edit Simulation Profile)***
- ***select tab Analysis***
- ***select Parametric Sweep***
- ***Parameter name:*** **Vin**
- ***Sweep type:*** **linear**
- ***Start value:*** **153**
  End value: **204**
  Increment: **17**
- ***… and press OK***
- ***perform a simulation (F11)***



Step 1: simulate output voltage Vo, ripple Vr, and THDin

Vo and Vr results for Vin range (Rload=700)



Measurement Results

Evaluate	Measurement	1	2	3	4
☑	Ymean(V(out),500m,520m)	304.96163	304.95606	304.94976	304.94344
☑	Swing_XRange(V(out),500m,520m)	7.96592	8.13860	8.33914	8.57781

Step 1: simulate output voltage Vo, ripple Vr, and THDin

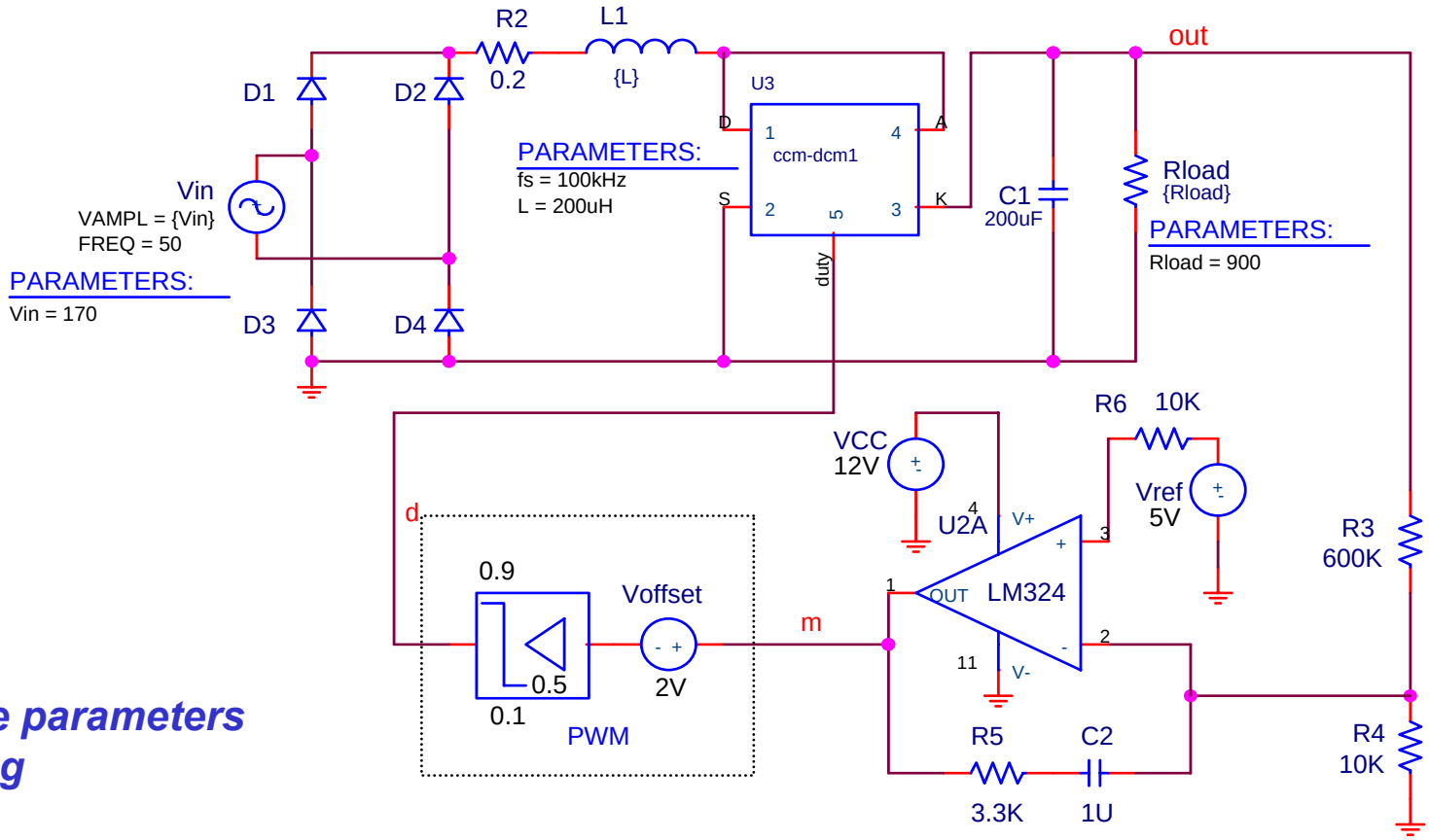
THDin results for Vin range (Rload=700)

Vin	THDin (%)
153	13.99117
170	16.39433
187	19.16852
204	22.44269

Conclusions

1. ***maximum Vr and THDin are reached for highest input voltage Vin (not expected)***
2. ***Within simulation accuracy Vo does not depend on Vin***

Step 2: the influencing factors (X)



Determine the parameters influencing

- ***Vo***
- ***Vr***
- ***THDin***

Step 2: the influencing factors (X)

Exercise: determine the important component values X

For determining the influence of a component value via PSpice

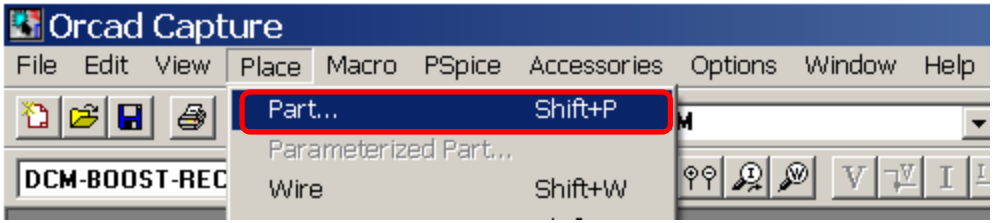
- ***define a parameter block with parameter 'val'***
- ***use 'val' as the value for a component to be varied***

Hint: set Vin to 204

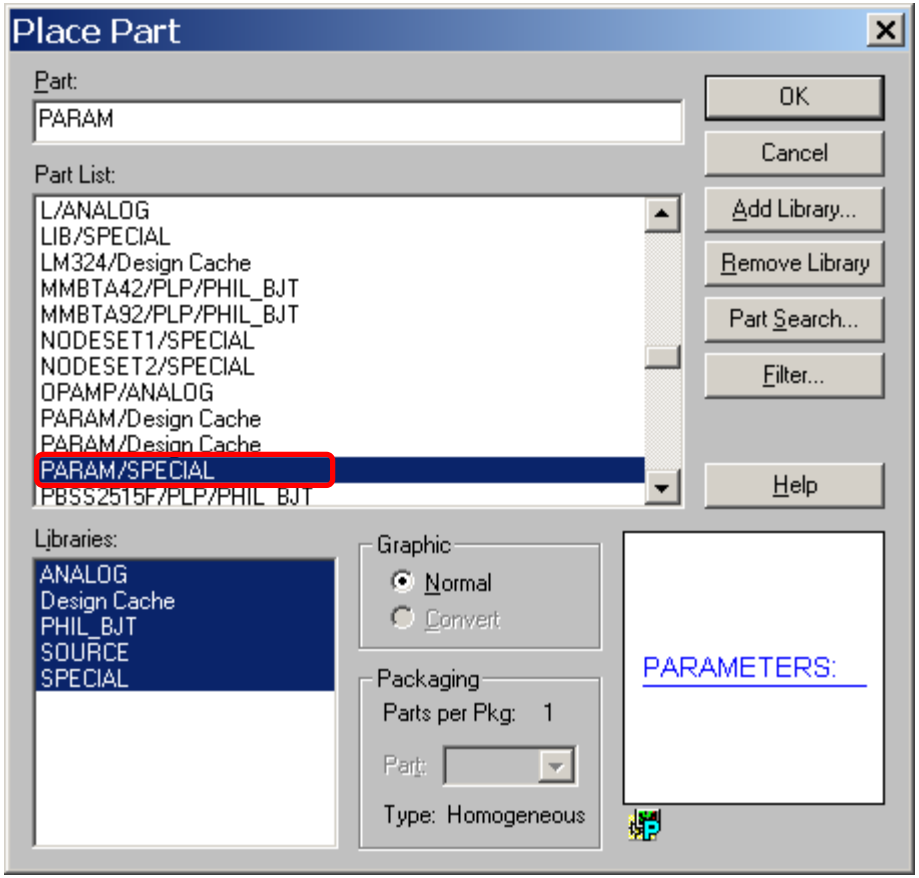
Step 2: the influencing factors (X)

Example for varying C1

1. ***place a part***



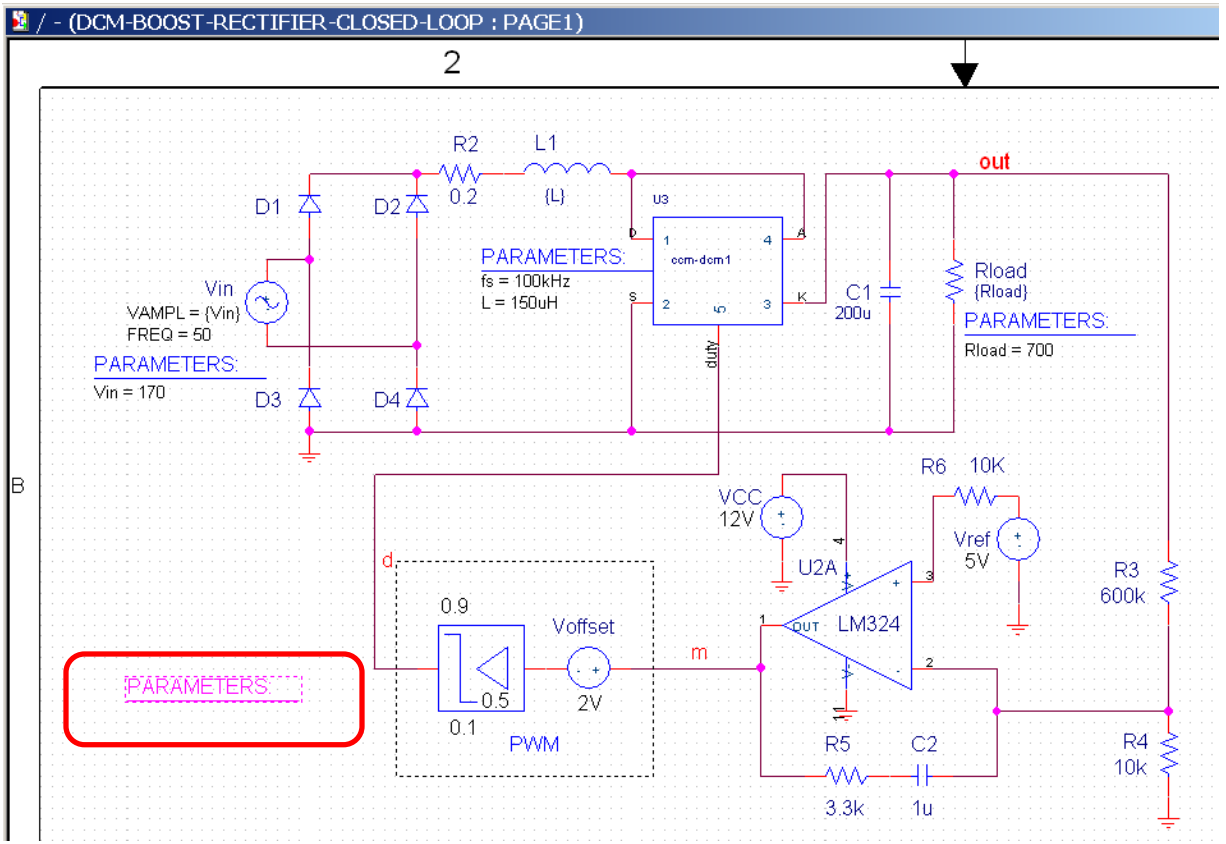
2. ***select part PARAM/SPECIAL … and press OK***



Step 2: the influencing factors (X)

3. ***place the PARAM block on the design (single click) … and press <Esc> to quit placing parts***

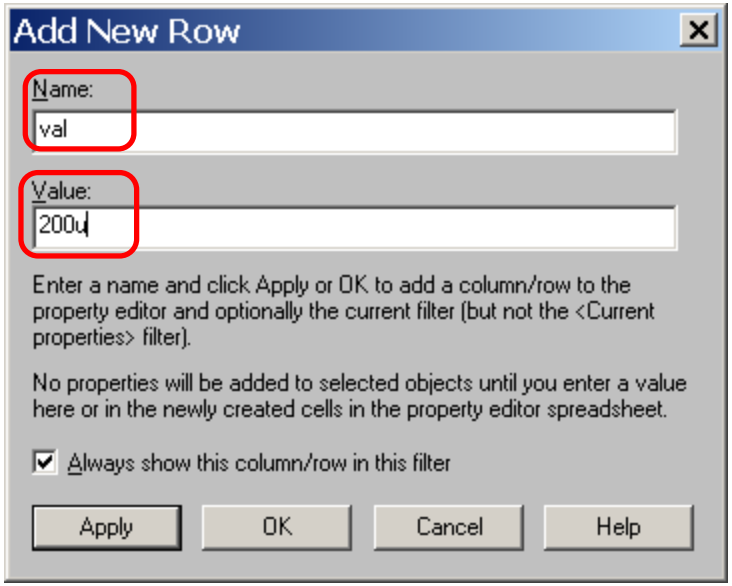
4. ***double-click on the new PARAM block to add new parameters and values: the Property Editor will pop up***

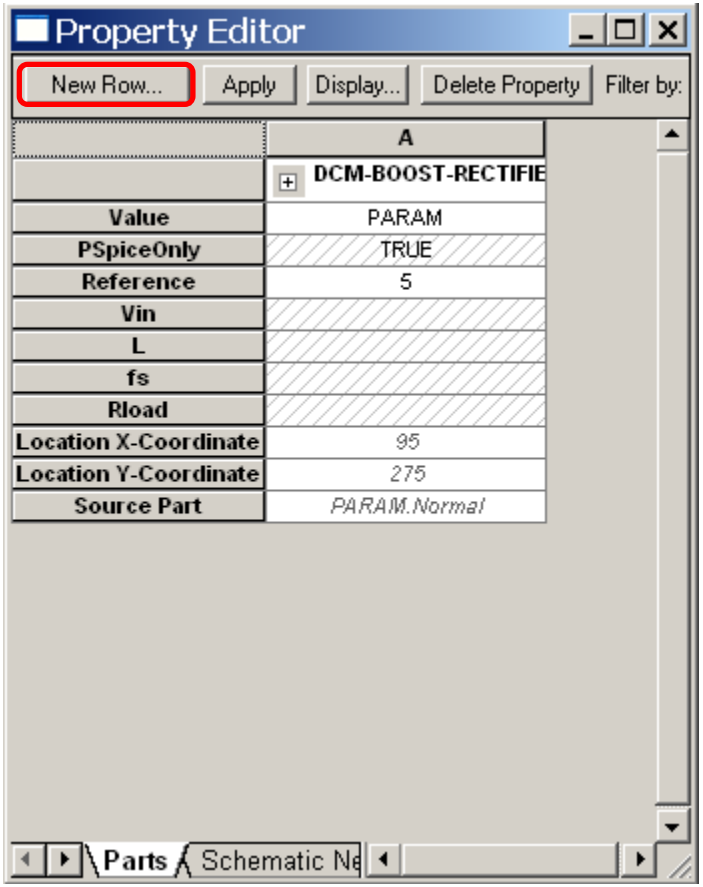


Step 2: the influencing factors (X)

5. add a New Row

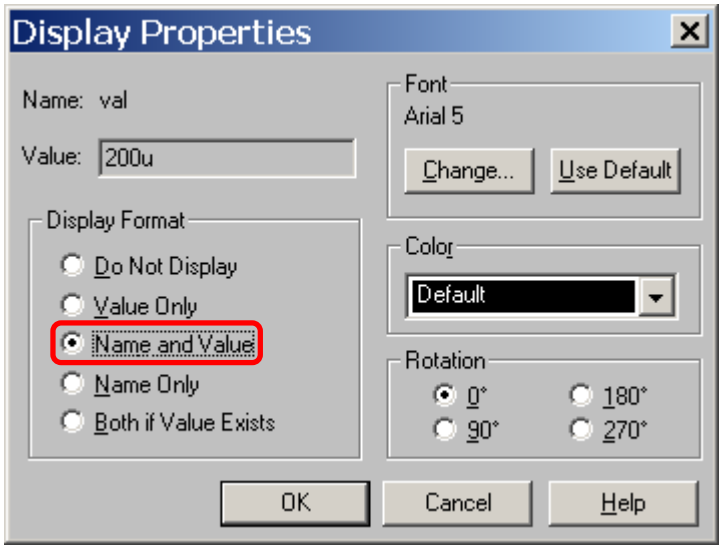
6. enter 'val' as name and '200u' as value and press OK

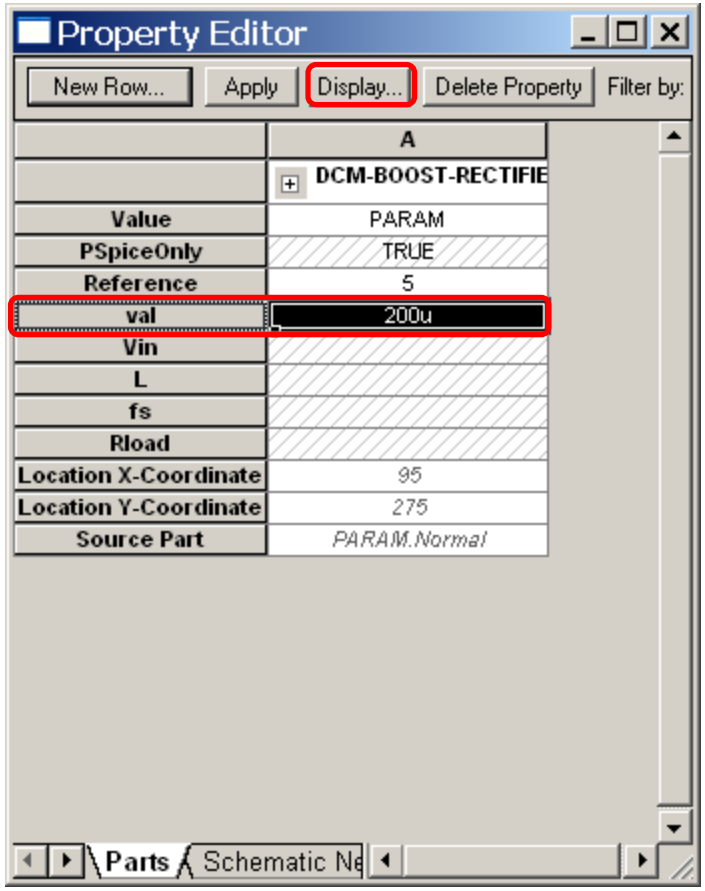




Step 2: the influencing factors (X)

7. ***select the 'val' row and click on 'Display…'***
8. ***select 'Name and Value' and press OK***



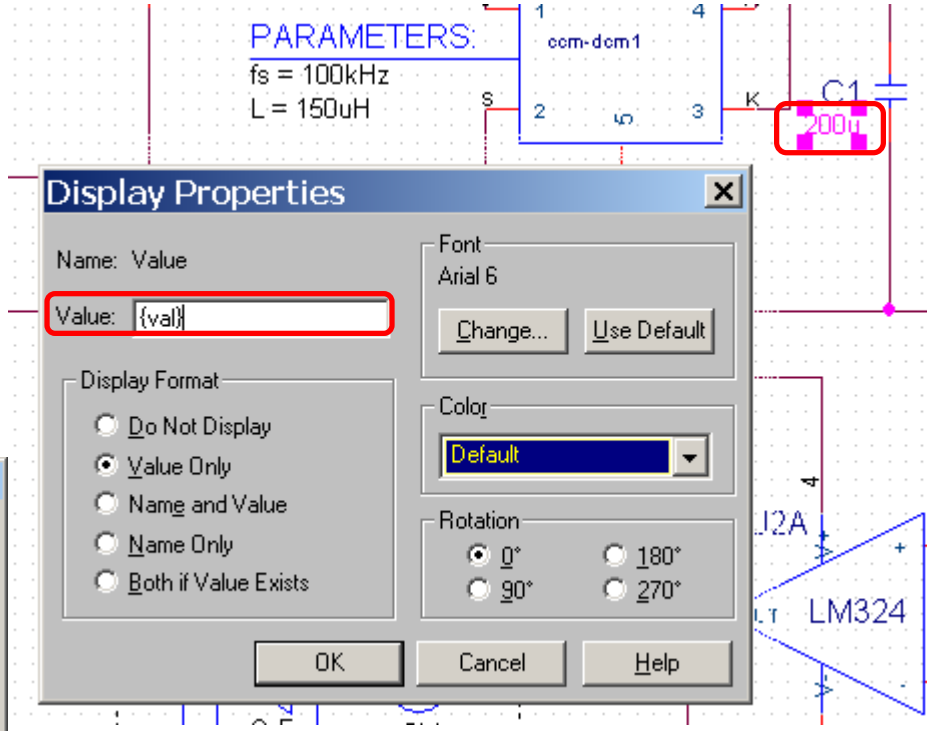


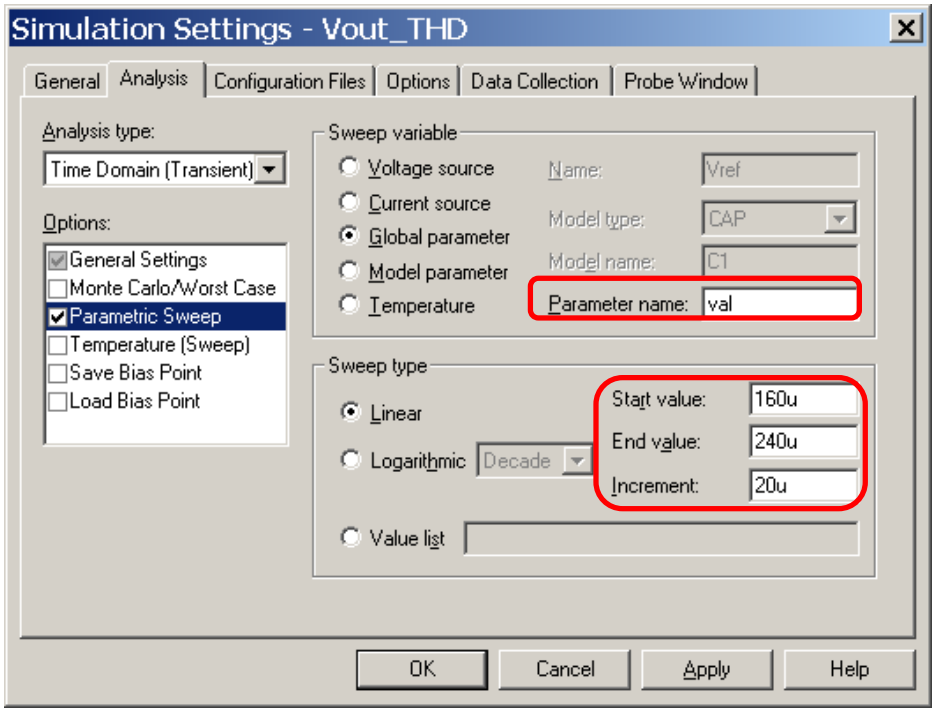
9. ***close the Property Editor***

Step 2: the influencing factors (X)

10. ***double-click on the C1 value field***

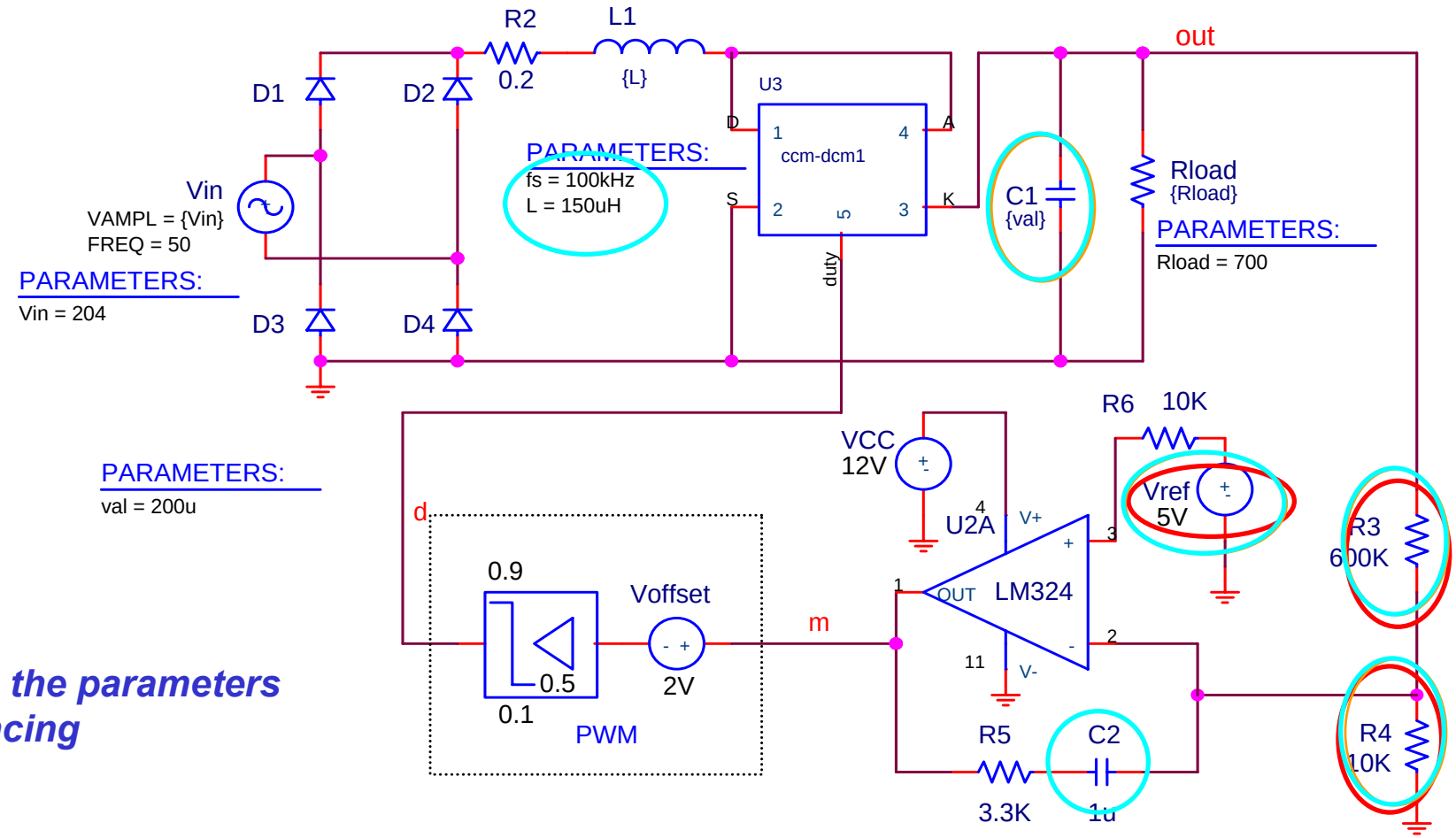
11. ***enter '{val}' in the Display Properties Value field … and press OK***





12. ***determine the influence of C1 by varying {val} between 160u and 240u and performing a simulation***

Step 2: the influencing factors (X)



Determine the parameters influencing

- ***Vo***
- ***Vr***
- ***THDin***

Step 2: the influencing factors (X)

The parameters influencing

- ***Vo:*** ***Vref, R3, R4***
  relation via formula: Vo = Vref * (R3+R4) / R4

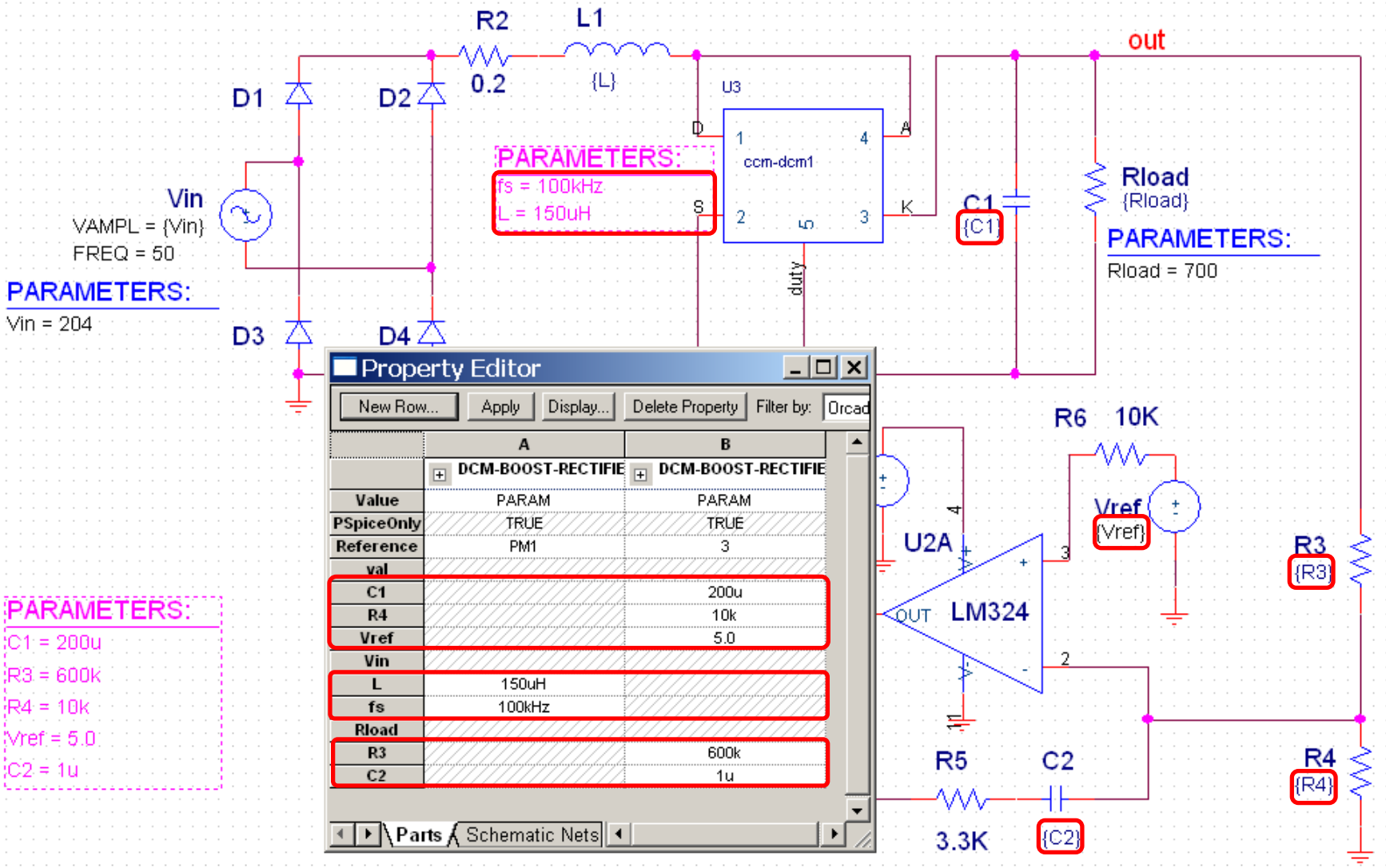
- ***Vr:*** ***C1, Vref, R3, R4***
  relation to be determined through simulations

- ***THDin:*** ***Vref, R3, R4, L, fs, C1, C2***
  relation to be determined through simulations

Step 3: setting up the DoE for the PFC (Minitab)

- ***start Minitab with a new worksheet***
- ***set up DoE with max. expected uniform spread of components (L: 10%, fs: 25%, C1: 20%, R3,4: 2%, Vref: 2%, C2: 10%)***
- ***add columns Vo, Vr and THDin***
- ***perform the PSpice simulations and transfer the results to Minitab (Hint: define C1, R3, R4, Vref, C2 as parameters in PSpice)***
- ***evaluate the influences of the Xs on the Ys***

Step 3: setting up the DoE for the PFC (Minitab)



Step 3: performing the DoE for the PFC

Results of the simulations

Run	Vo(V)	Vr(V)	THDin(%)
1.	298.792	10.6799	24.6405
2.	287.272	10.3648	25.6819
3.	299.007	10.6327	23.8611
4.	311.013	10.8547	21.6481
5.	299.054	7.0555	23.1825
6.	311.058	7.2495	21.7167
7.	298.868	7.0332	22.8081
8.	287.365	7.1695	29.6567
9.	323.476	11.1981	20.9451
10.	310.996	10.9280	22.5548
11.	298.814	10.5841	23.3799
12.	310.820	10.8778	21.9397
13.	298.859	7.0700	23.4817
14.	310.864	7.2229	21.3691
15.	323.553	7.4285	19.9526
16.	311.067	7.2092	21.0040
17.	304.943	8.5782	22.4400

Step 4: defining the transfer functions Y(X)

Factorial, linear, for Vo

Obs	StdOrder	Vo(V)	Fit	SE Fit	Residual	St Resid	
1	1	298.792	298.916	0.209	-0.124	-0.59	
2	2	287.272	286.916	0.209	0.356	1.71	
3	3	299.007	299.128	0.209	-0.121	-0.58	
4	4	311.013	311.130	0.209	-0.117	-0.56	
5	5	299.054	299.170	0.209	-0.116	-0.56	
6	6	311.058	311.179	0.209	-0.121	-0.58	
7	7	298.868	298.992	0.209	-0.124	-0.59	
8	8	287.365	286.998	0.209	0.367	1.76	
9	9	323.476	323.112	0.209	0.364	1.74	
10	10	310.996	311.117	0.209	-0.121	-0.58	
11	11	298.814	298.931	0.209	-0.118	-0.56	
12	12	310.820	310.939	0.209	-0.120	-0.57	
13	13	298.859	298.980	0.209	-0.120	-0.57	
14	14	310.864	310.982	0.209	-0.118	-0.57	
15	15	323.553	323.194	0.209	0.359	1.72	
16	16	311.067	311.194	0.209	-0.127	-0.61	
17	17	304.943	304.943	0.295	0.000		* X

Step 4: defining the transfer functions Y(X)

Factorial, linear, for Vr

Obs	StdOrder	Vr(V)	Fit	SE Fit	Residual	St Resid
1	1	10.6799	10.6898	0.0859	-0.0099	-0.11
2	2	10.3648	10.4585	0.0859	-0.0938	-1.09
3	3	10.6327	10.6953	0.0859	-0.0626	-0.73
4	4	10.8547	10.8468	0.0859	0.0080	0.09
5	5	7.0555	7.0432	0.0859	0.0122	0.14
6	6	7.2495	7.3230	0.0859	-0.0736	-0.86
7	7	7.0332	7.0430	0.0859	-0.0098	-0.11
8	8	7.1695	6.9401	0.0859	0.2294	2.67R
9	9	11.1981	11.0047	0.0859	0.1934	2.25R
10	10	10.9280	10.9018	0.0859	0.0262	0.31
11	11	10.5841	10.6217	0.0859	-0.0376	-0.44
12	12	10.8778	10.9015	0.0859	-0.0238	-0.28
13	13	7.0700	7.0980	0.0859	-0.0280	-0.33
14	14	7.2229	7.2495	0.0859	-0.0266	-0.31
15	15	7.4285	7.4862	0.0859	-0.0578	-0.67
16	16	7.2092	7.2550	0.0859	-0.0459	-0.53
17	17	8.5782	8.5782	0.1215	-0.0000	* X

Step 4: defining the transfer functions Y(X)

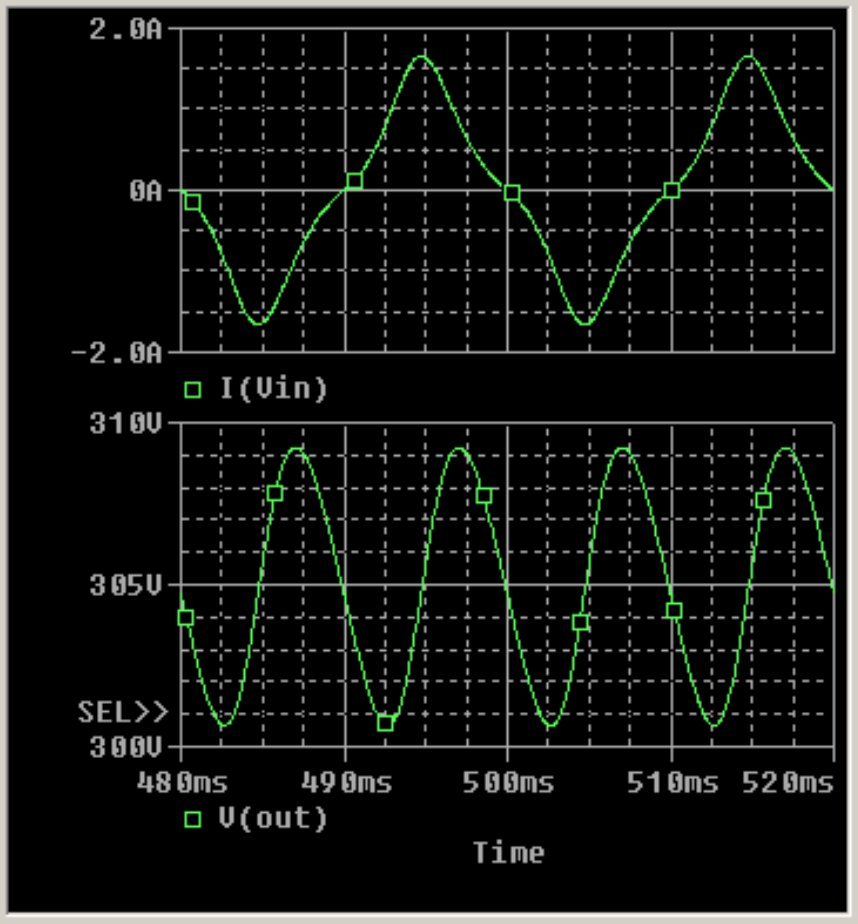
Factorial, linear, for THDin

Obs	StdOrder	THDin(%)	Fit	SE Fit	Residual	St Resid
1	1	24.6405	24.4980	0.9326	0.1424	0.15
2	2	25.6819	26.1627	0.9326	-0.4807	-0.52
3	3	23.8611	24.5440	0.9326	-0.6829	-0.73
4	4	21.6481	21.7630	0.9326	-0.1149	-0.12
5	5	23.1825	23.3012	0.9326	-0.1187	-0.13
6	6	21.7167	22.4664	0.9326	-0.7497	-0.80
7	7	22.8081	23.4247	0.9326	-0.6166	-0.66
8	8	29.6567	27.0356	0.9326	2.6211	2.81R
9	9	20.9451	18.9422	0.9326	2.0029	2.15R
10	10	22.5548	22.5531	0.9326	0.0016	0.00
11	11	23.3799	23.5114	0.9326	-0.1315	-0.14
12	12	21.9397	22.6766	0.9326	-0.7369	-0.79
13	13	23.4817	24.2148	0.9326	-0.7331	-0.79
14	14	21.3691	21.4338	0.9326	-0.0647	-0.07
15	15	19.9526	19.8151	0.9326	0.1375	0.15
16	16	21.0040	21.4798	0.9326	-0.4758	-0.51
17	17	22.4400	22.4400	1.3189	-0.0000	* X

Step 4: defining the transfer functions Y(X)

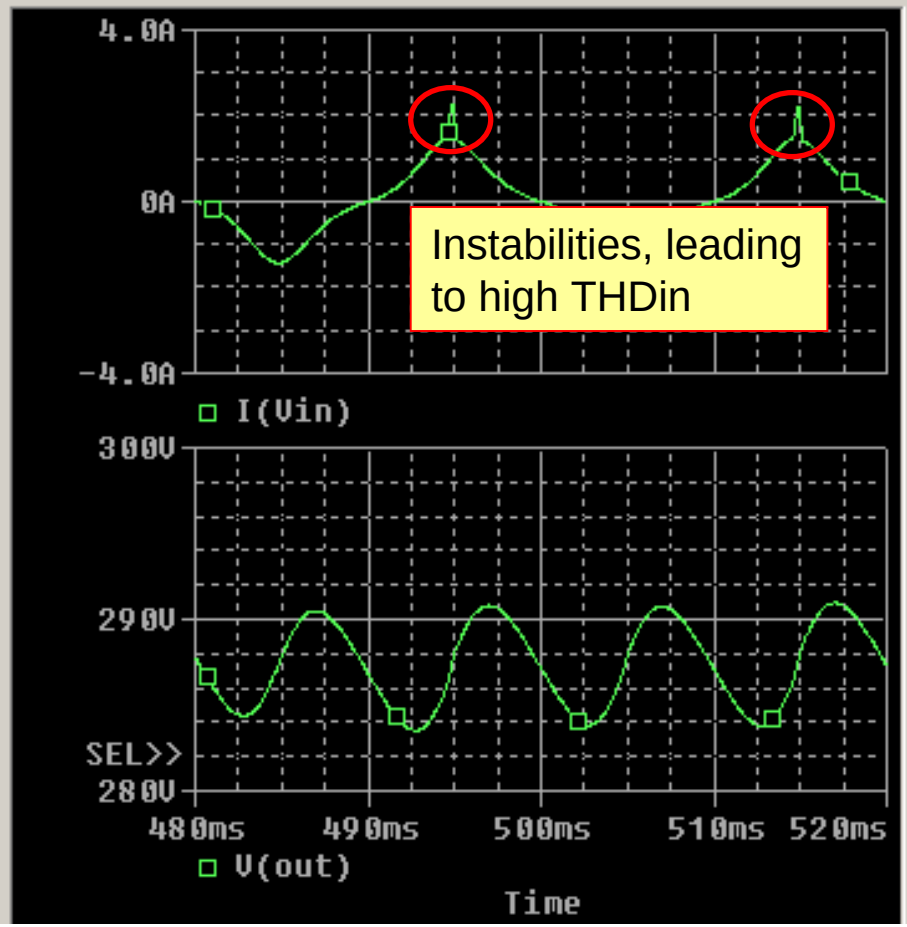
nominal:

THDin = 22.4%

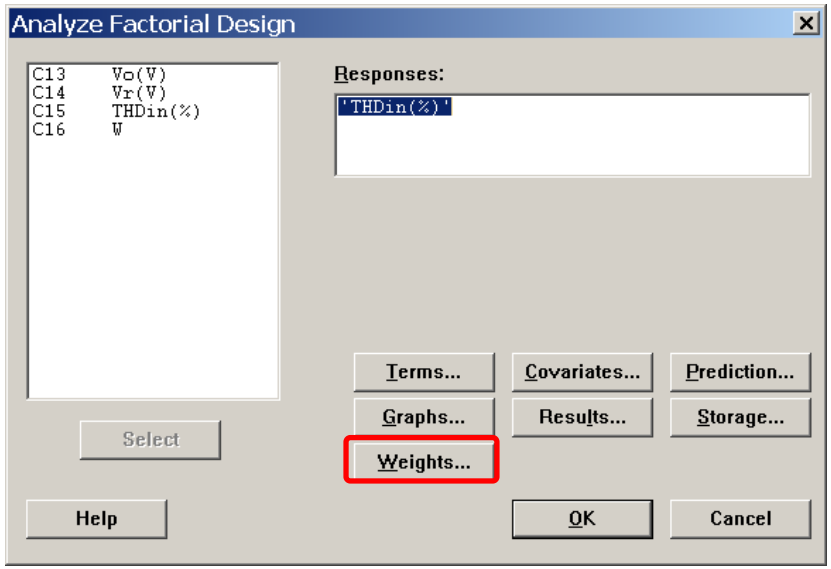


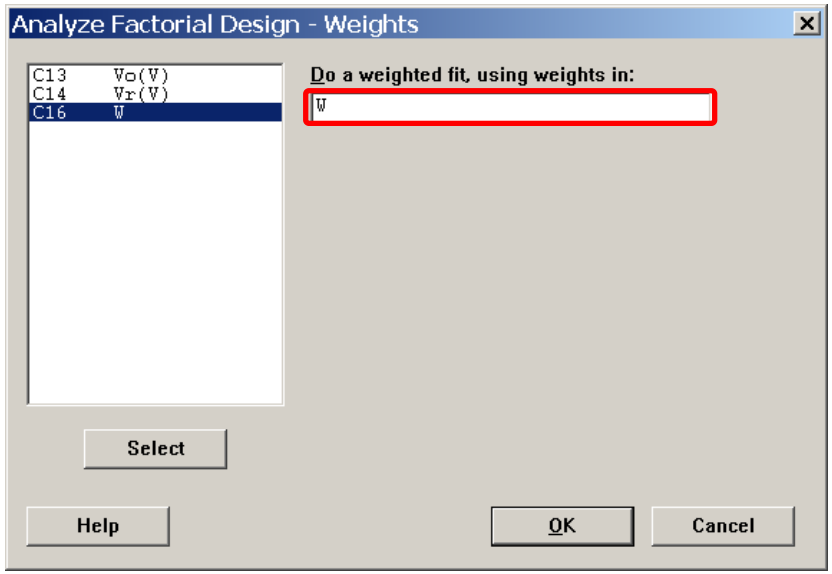
run 8 (exceptional):

THDin = 29.7% !!

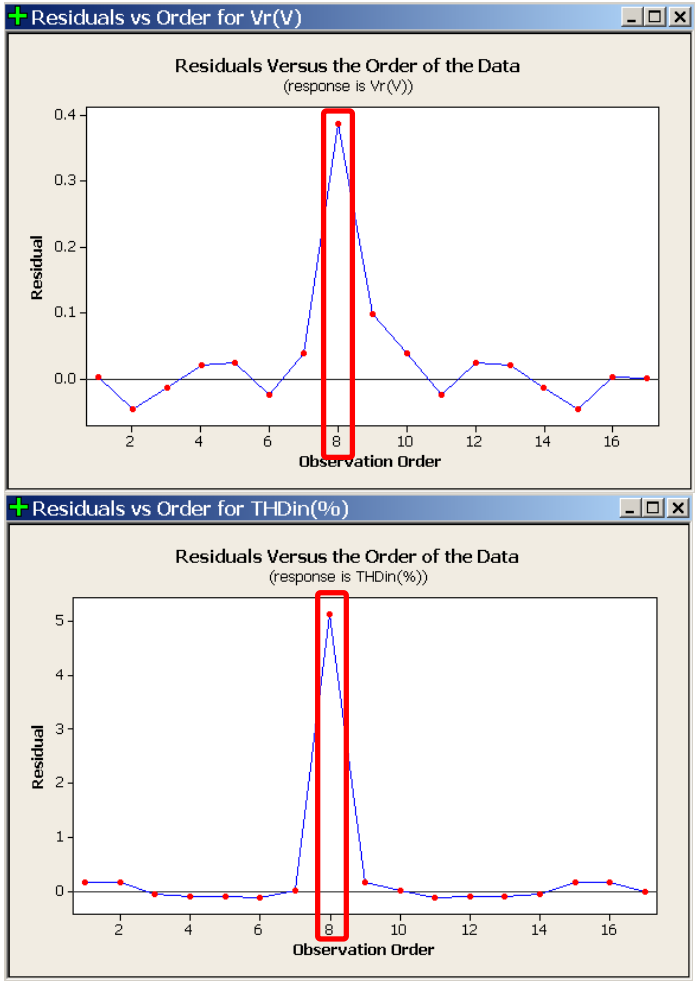


Step 4: defining the transfer functions Y(X)





use weight 0.0001 for run 8 and 9: run 8 is the exception



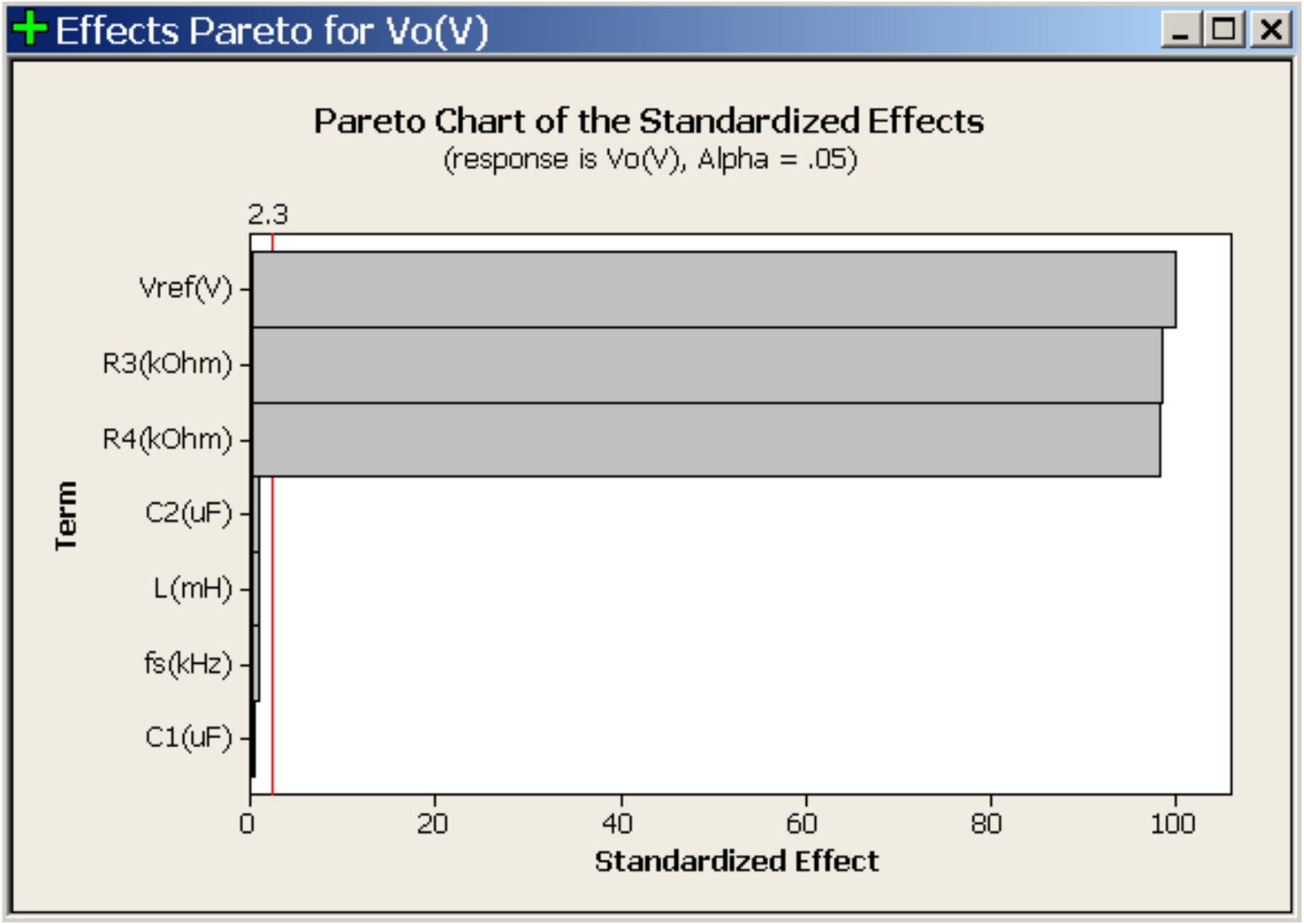
Step 4: defining the transfer functions Y(X)

Factorial effects linear analysis

Estimated Effects and Coefficients for Vo(V) (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		305.009	0.06138	4969.30	0.000
L(mH)	-0.088	-0.044	0.06138	-0.71	0.495
fs(kHz)	-0.075	-0.037	0.06138	-0.61	0.559
C1(uF)	-0.029	-0.015	0.06138	-0.24	0.817
R3(kOhm)	12.094	6.047	0.06138	98.52	0.000
R4(kOhm)	-12.093	-6.047	0.06138	-98.51	0.000
Vref(V)	12.288	6.144	0.06138	100.10	0.000
C2(uF)	0.089	0.044	0.06138	0.72	0.490
Ct Pt		-0.065	0.23948	-0.27	0.791

Step 4: defining the transfer functions Y(X)



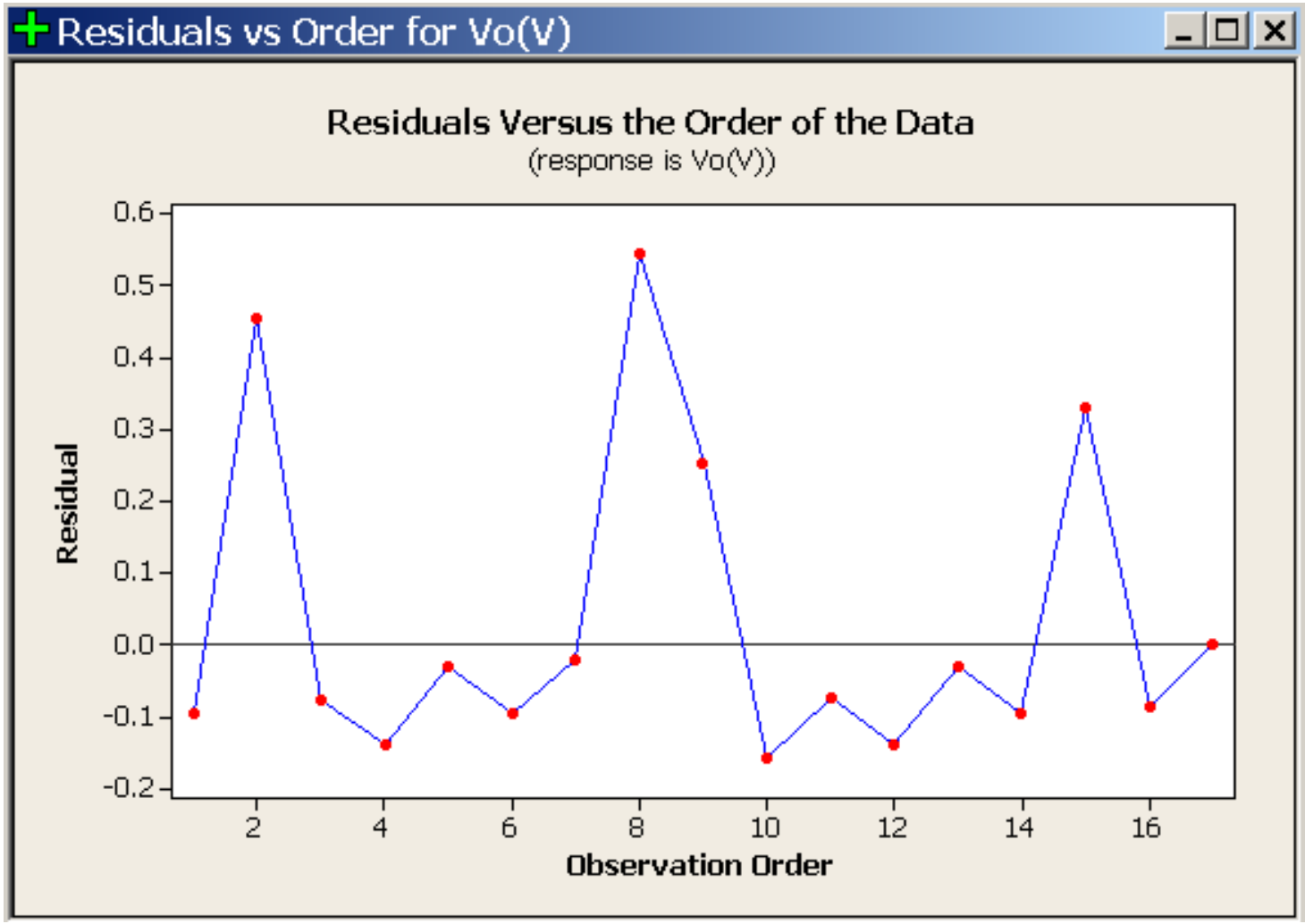
Step 4: defining the transfer functions Y(X)

Factorial effects linear analysis

Estimated Effects and Coefficients for Vo(V) (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		305.021	0.05261	5797.56	0.000
R3(kOhm)	12.071	6.035	0.05261	114.72	0.000
R4(kOhm)	-12.070	-6.035	0.05261	-114.70	0.000
Vref(V)	12.265	6.132	0.05261	116.56	0.000
Ct Pt		-0.077	0.20893	-0.37	0.718

Step 4: defining the transfer functions Y(X)



relative residual: 0.6/30 = 2%

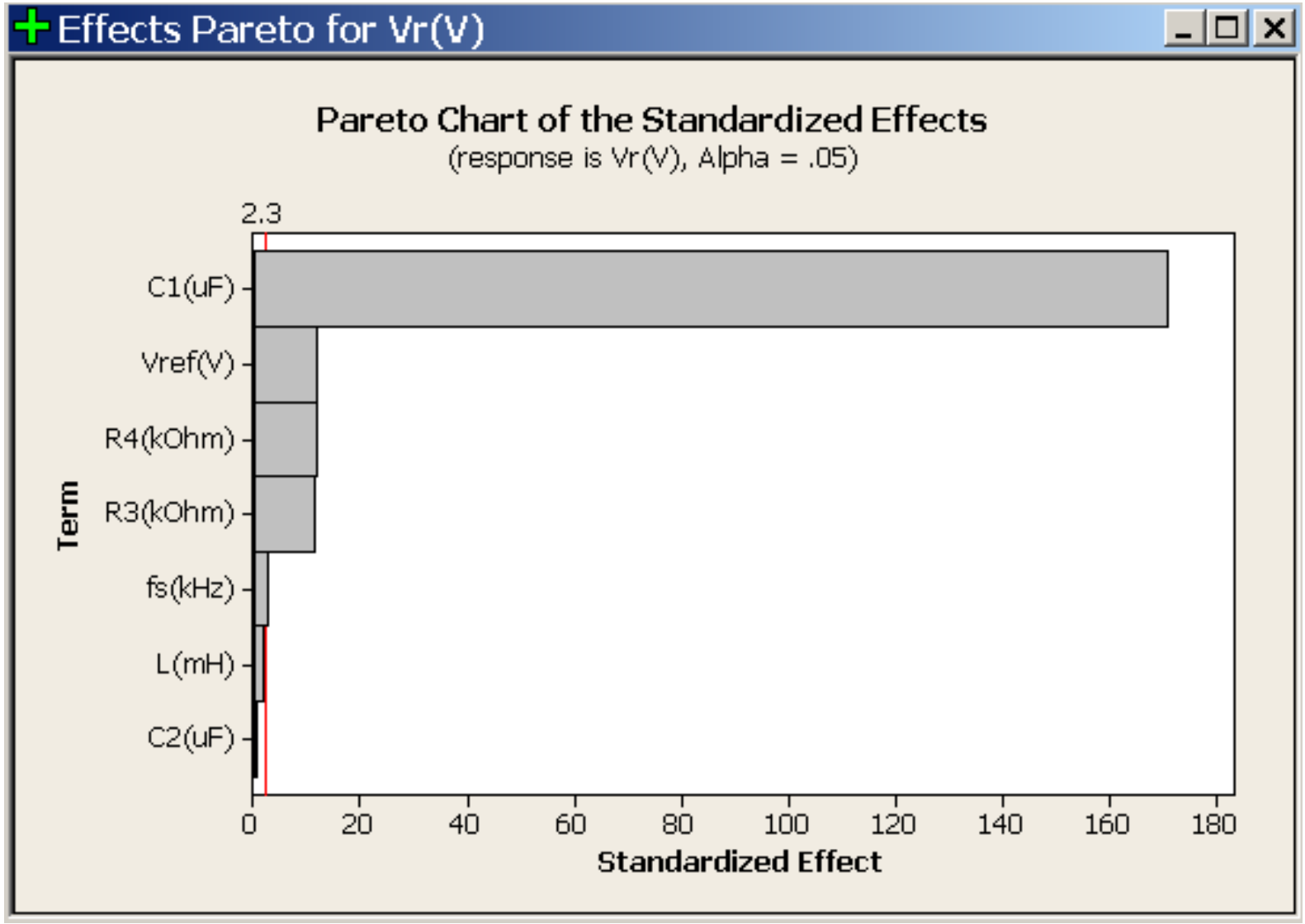
Step 4: defining the transfer functions Y(X)

Factorial effects linear analysis

Estimated Effects and Coefficients for Vr(V) (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		8.944	0.01066	838.91	0.000
L(mH)	-0.033	-0.017	0.01066	-1.55	0.160
fs(kHz)	-0.055	-0.027	0.01066	-2.57	0.033
C1(uF)	-3.643	-1.821	0.01066	-170.84	0.000
R3(kOhm)	0.242	0.121	0.01066	11.36	0.000
R4(kOhm)	-0.249	-0.124	0.01066	-11.66	0.000
Vref(V)	0.252	0.126	0.01066	11.80	0.000
C2(uF)	-0.007	-0.003	0.01066	-0.32	0.757
Ct Pt		-0.366	0.04160	-8.79	0.000

Step 4: defining the transfer functions Y(X)



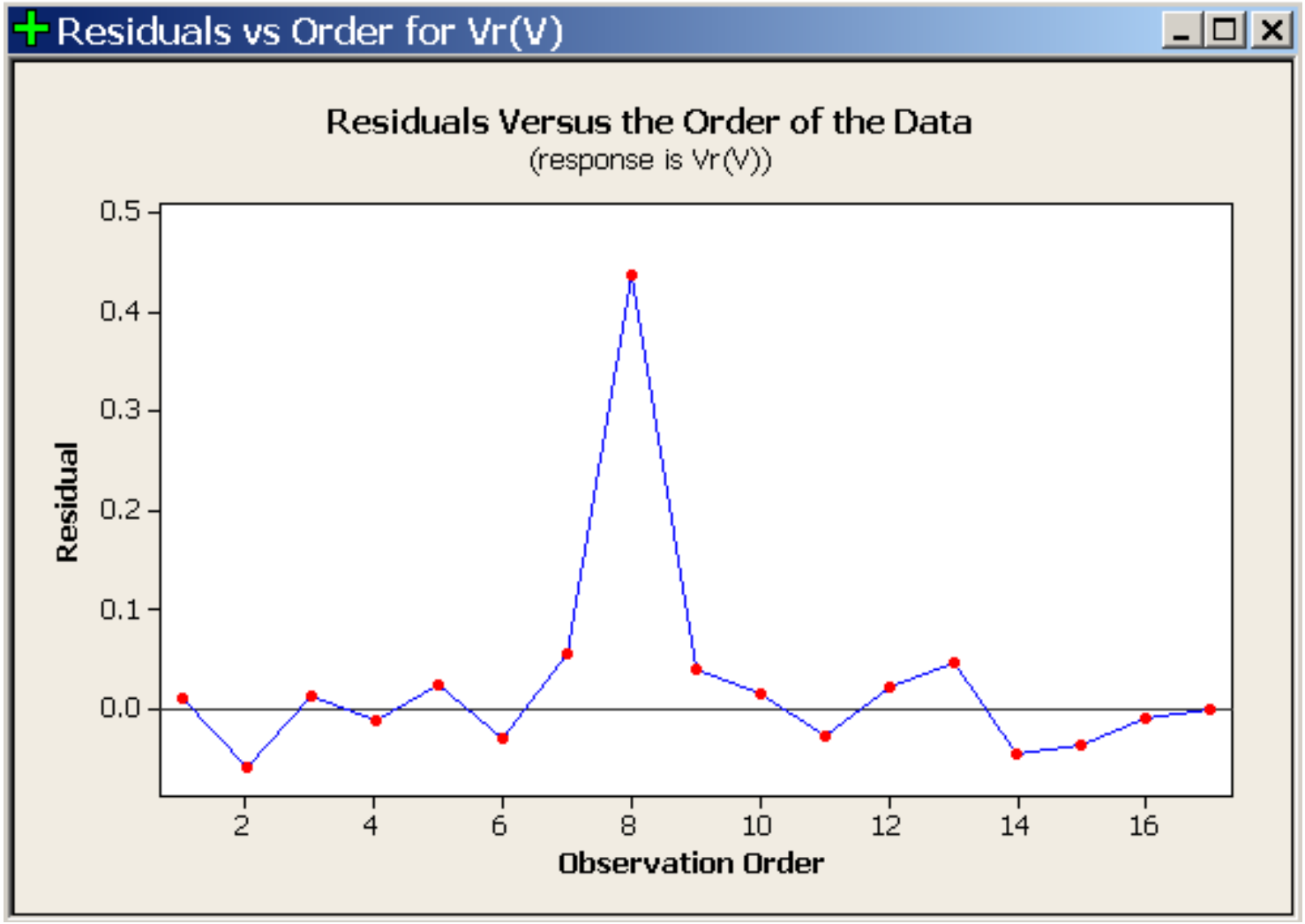
Step 4: defining the transfer functions Y(X)

Factorial effects linear analysis

Estimated Effects and Coefficients for Vr(V) (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		8.945	0.01088	822.32	0.000
fs(kHz)	-0.052	-0.026	0.01088	-2.39	0.038
C1(uF)	-3.640	-1.820	0.01088	-167.31	0.000
R3(kOhm)	0.240	0.120	0.01088	11.01	0.000
R4(kOhm)	-0.246	-0.123	0.01088	-11.31	0.000
Vref(V)	0.249	0.124	0.01088	11.44	0.000
Ct Pt		-0.367	0.04289	-8.55	0.000

Step 4: defining the transfer functions Y(X)



relative residual: 0.1/10 = 1%

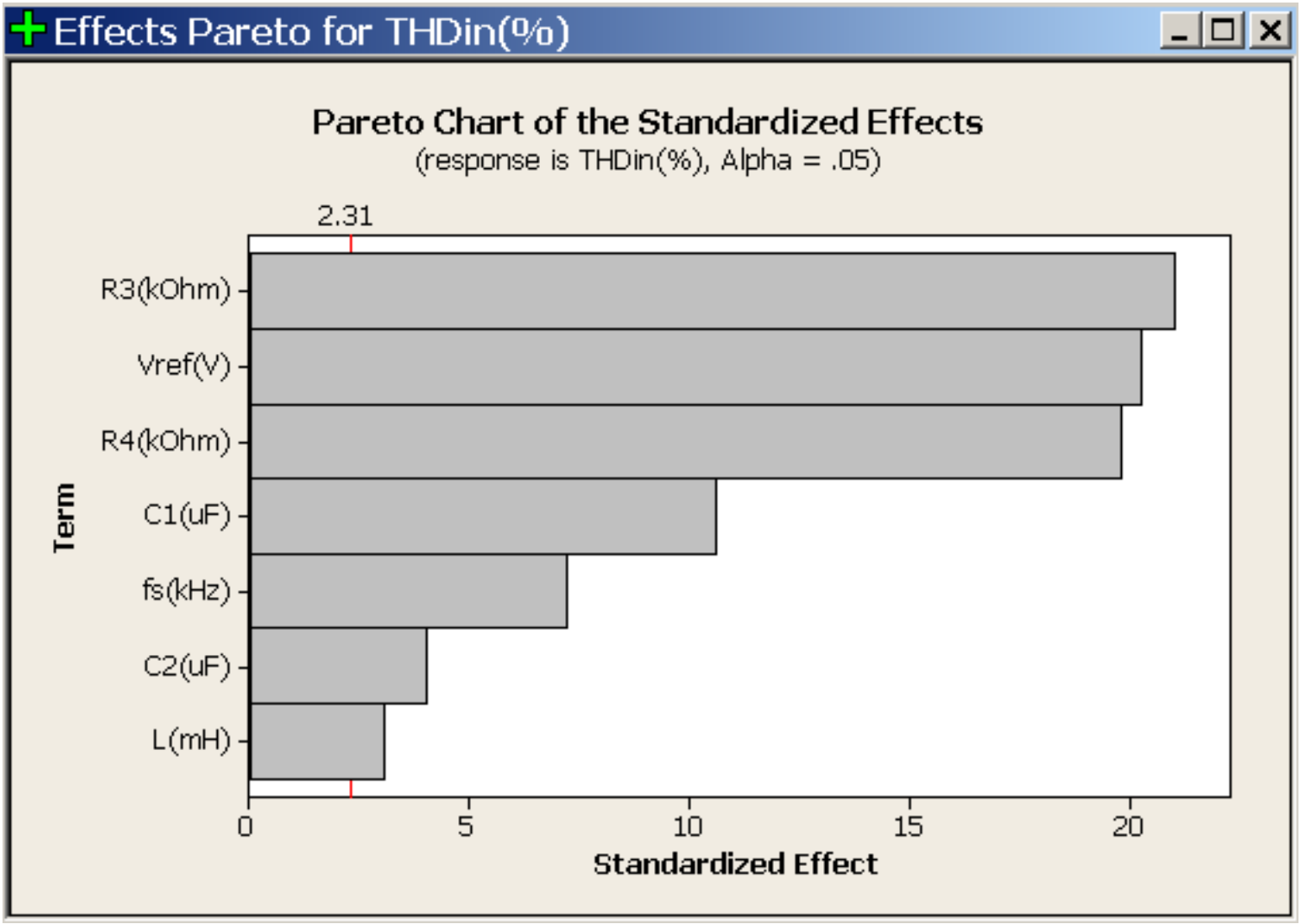
Step 4: defining the transfer functions Y(X)

Factorial effects linear analysis

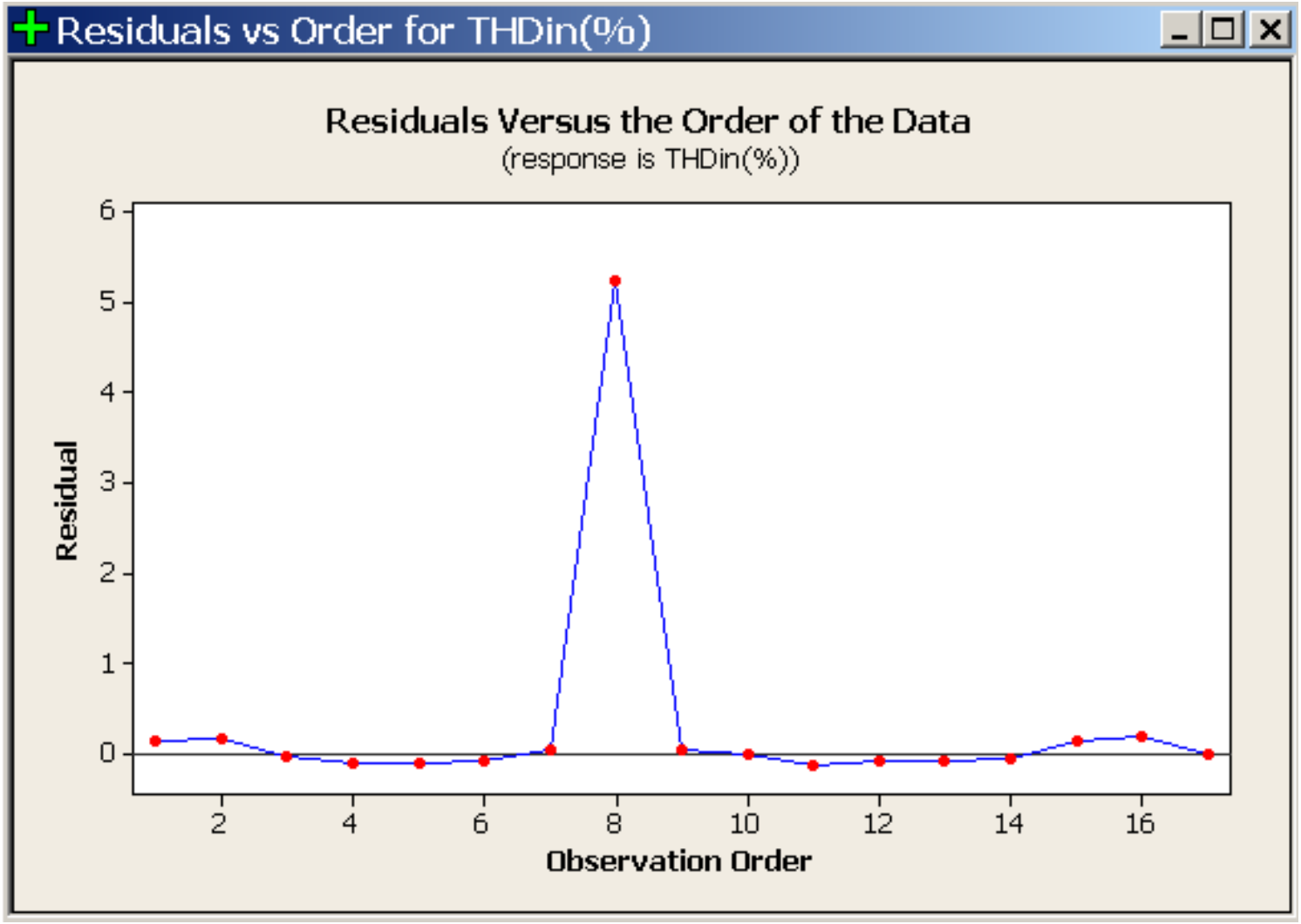
Estimated Effects and Coefficients for THDin(%) (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		22.6613	0.03963	571.87	0.000
L(mH)	-0.2402	-0.1201	0.03963	-3.03	0.016
fs(kHz)	-0.5704	-0.2852	0.03963	-7.20	0.000
C1(uF)	-0.8401	-0.4200	0.03963	-10.60	0.000
R3(kOhm)	-1.6660	-0.8330	0.03963	-21.02	0.000
R4(kOhm)	1.5677	0.7838	0.03963	19.78	0.000
Vref(V)	-1.6064	-0.8032	0.03963	-20.27	0.000
C2(uF)	-0.3180	-0.1590	0.03963	-4.01	0.004
Ct Pt		-0.2213	0.15461	-1.43	0.190

Step 4: defining the transfer functions Y(X)



Step 4: defining the transfer functions Y(X)



relative residual: 0.3/25 = 1.2%

Step 5: optimize the component spread for the CtQs