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Effect of Package Trace and Termination Resistance on Tx Specification

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IEEE P802.3cd Task Force
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Background

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- I have reported that we may need to revise package trace impedance (Zc, 90Ω) and termination resistance (Rd, 55Ω) in the COM parameters, because they do not necessarily cover corner cases (hidaka_100516_3cd_adhoc.pdf)

- There was a concern that Tx-related COM parameters such as signal amplitude and SNR_{TX} may have to be changed consistently with package parameters, because Tx output amplitude and Tx SNDR will be also affected by the package trace impedance and termination resistance

- Hence, I have studied the effect of package trace impedance and termination resistance on Tx output amplitude and Tx SNDR

Simulated Package Parameters

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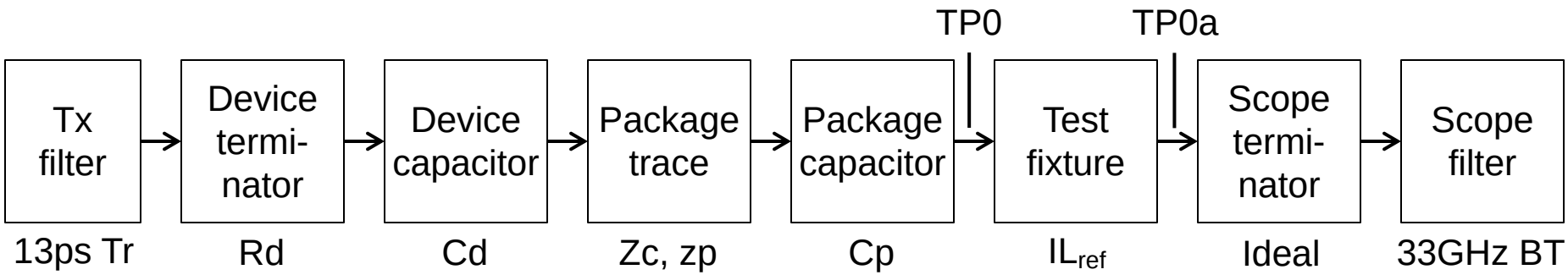
- The following 10 combinations of parameters were simulated

Case	zp Package trace length	Rd Termination resistance	Zc Package trace impedance
#1	12 mm	45 Ω	90 Ω
#2			110 Ω
#3		55 Ω	90 Ω
#4			110 Ω
#5	30 mm	45 Ω	90 Ω
#6			110 Ω
#7		55 Ω	90 Ω
#8			110 Ω
#9	12 mm	50 Ω	100 Ω
#10	30 mm		

- The conditions proposed in hidaka_100516_3cd_adhoc.pdf were #2/#3/#4 and #6/#7/#8

Simulated Model

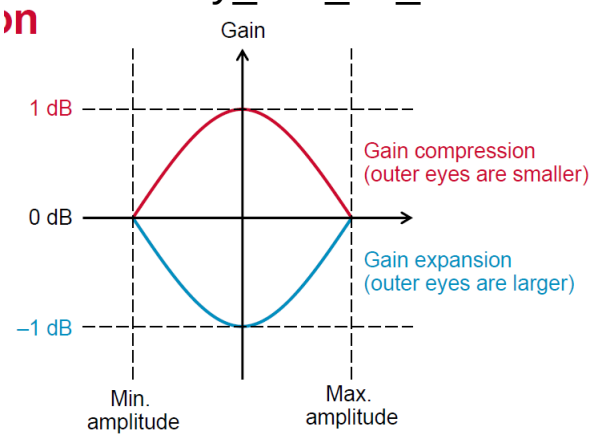


- Tx filter: $S_{21} = (\mathrm{EQ93A{-}46} | T_r = 13\mathrm{ps}, \beta = 2)$ (i.e. 13ps 20-80% Tr)
- Device terminator: $S_{21} = 1, S_{22} = \frac{Rd - 50\Omega}{Rd + 50\Omega}$
- Device capacitor: $S = (\mathrm{EQ93A{-}8} | C = C_d)$
- Package trace: $S = \left(\mathrm{EQ93A{-}13,14} \middle| \mathrm{Table93A{-}3\ except}\ Z_c, z_p\right)$
- Package capacitor: $S = \left(\mathrm{EQ93A{-}8} \middle| C = C_p\right)$
- Test fixture: $|S_{21}| = 10^{-(\mathrm{EQ93-1})/20}, \angle S_{21} = \mathrm{minimum\ phase}(|S_{21}|)$
- Scope terminator: $S_{21} = 1, S_{11} = 0$ (i.e. ideal)
- Scope filter: 4-th order Bessel-Thomson LPF with 33GHz 3dB BW
  - $\omega_0 = 98.28967142447435\ \mathrm{G\ rad/s}$

Simulation Methodology

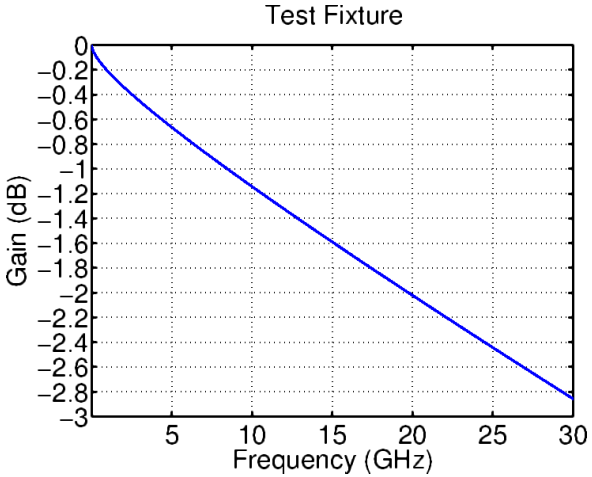
1. Get S_{21} of the entire model from 1MHz to f_{max} with 1MHz step
   - $f_{max} = 26.5625\text{GHz} \times M \div 2$, where $M = 32$
2. Get a single-bit pulse response
3. Get a linear cycle response of PRBS13Q with ideal levels
4. Cancel the DC offset of the linear cycle response of PRBS13Q
5. Get a non-linear cycle response of PRBS13Q by gain expansion / compression (similar to a methodology in healey_3bs_02_0916)
   - Simulated from -1.0dB to +1.0dB with 0.2dB step
6. Get V0, V1, V2, and V3 per 120D.3.1.2.1
7. Get Vmid, ES1, and ES2 per 120D.3.1.2
8. Get ES=(ES1+ES2)/2 per 120D.3.1.3
9. Get linear fit pulse p(k) and error e(k) per 120D.3.1.3, 94.3.12.5.2, 85.8.3.3.5
   - Dp=2 and Np=200
10. Get steady-state voltage v_f and linear fit pulse peak p_{max} per 120D.3.1.4
11. Get σ_e from e(k), then get SNDR per 120D.3.1.6
    - σ_n is always set to $p_{max} \times 10^{(-50/20)}$ (i.e. -50dB) to have noise floor

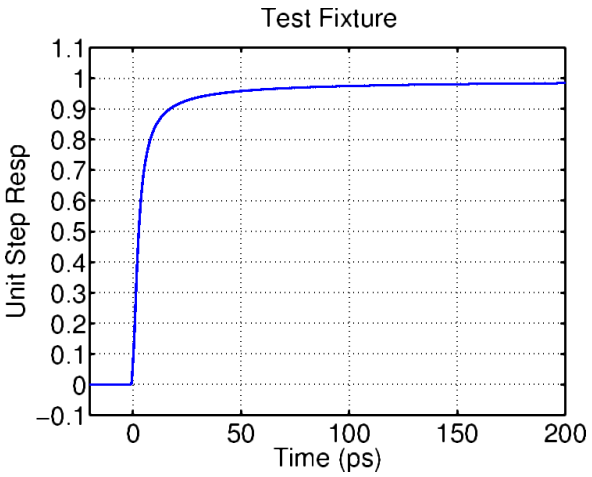
From healey_3bs_02_0916

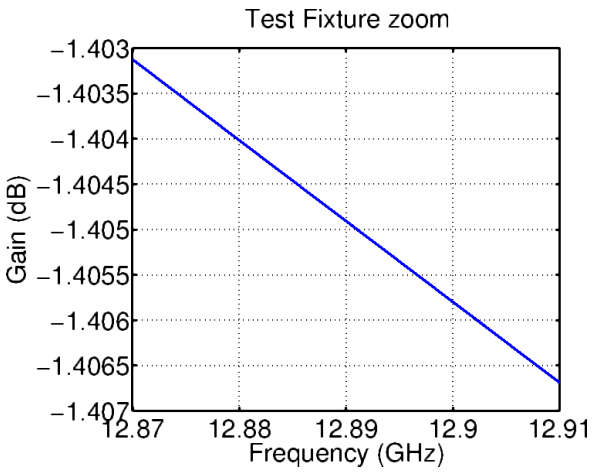


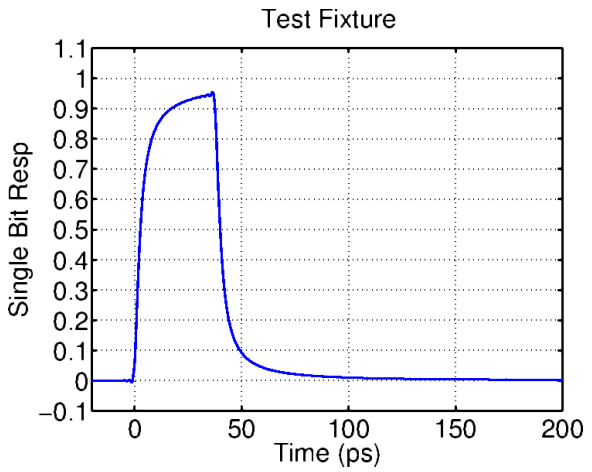
Test Fixture

- The reference insertion loss of the test fixture is defined by
  - $IL_{ref}(f) = -0.0015 + 0.144\sqrt{f} + 0.069f$ (93-1)
    - 1.4049dB at 12.89GHz



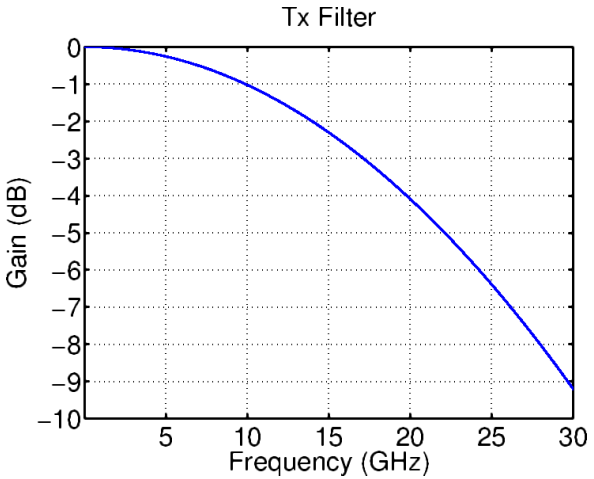


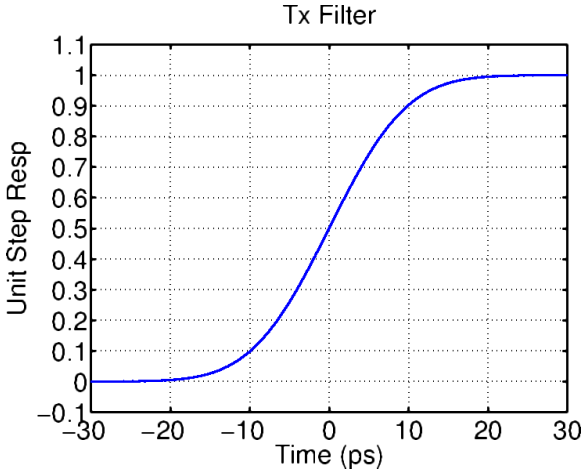


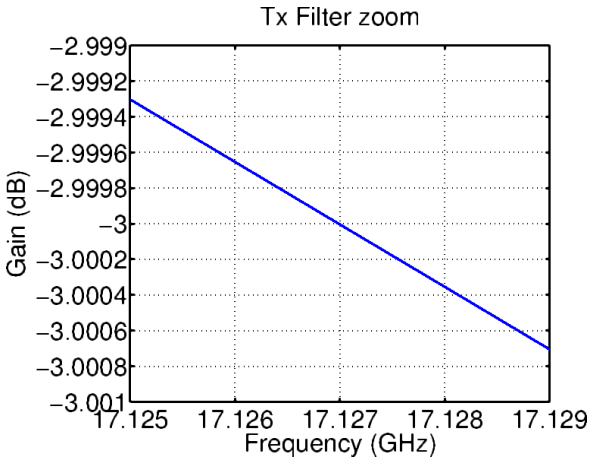


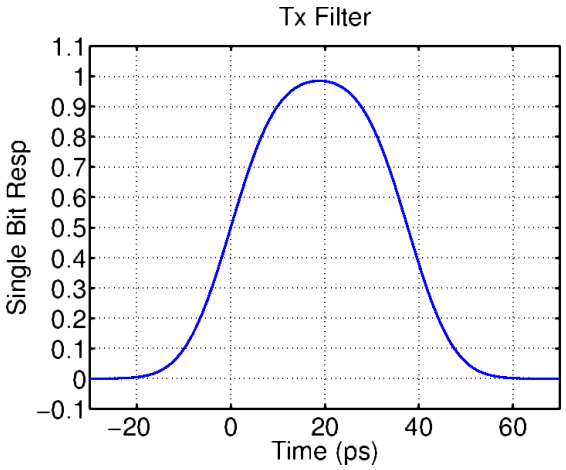
Tx Transition Time Filter

- Tx Transition Time Filter (per 802.3by) is defined by
  - $H_t(f) = \exp(-\beta(\pi f T_r/1.6832)^2)$ (93A-46)
    - with $\beta = 2, T_r = 13ps$



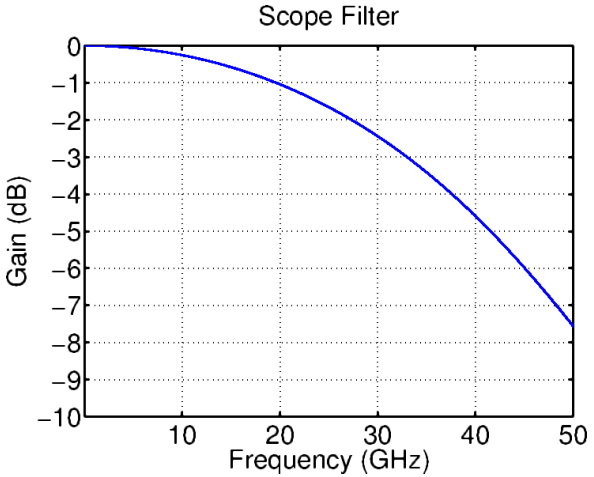


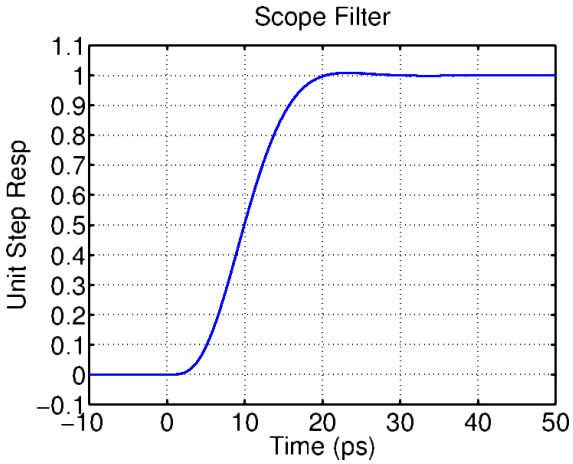


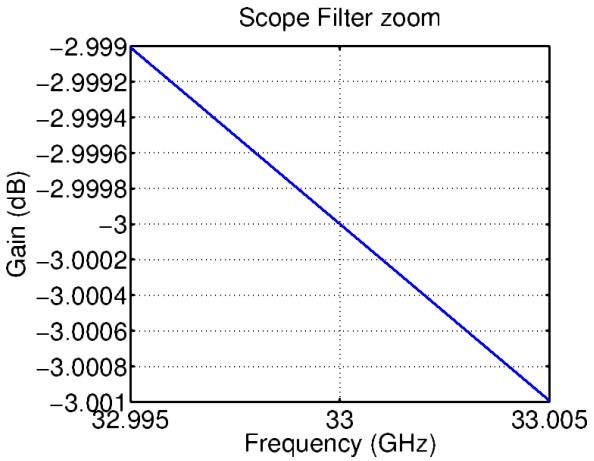


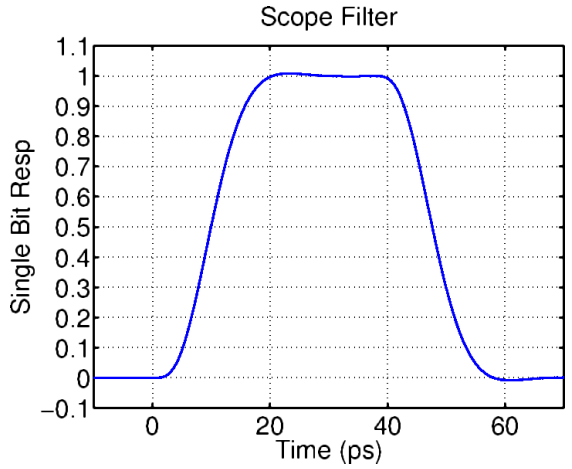
Scope Filter (4th-order Bessel-Thomson LPF)

- A 4th-order BT LPF with 33GHz 3dB Bandwidth is defined by
  - $H(s) = \theta_4(0)/\theta_4(s/\omega_0)$ where $\theta_4(s) = s^4 + 10s^3 + 45s^2 + 105s + 105$ and $\omega_0 = 98.28967142447435\ \mathrm{G\ rad/s}$









TDR of Entire Path from Scope (zp=12mm)

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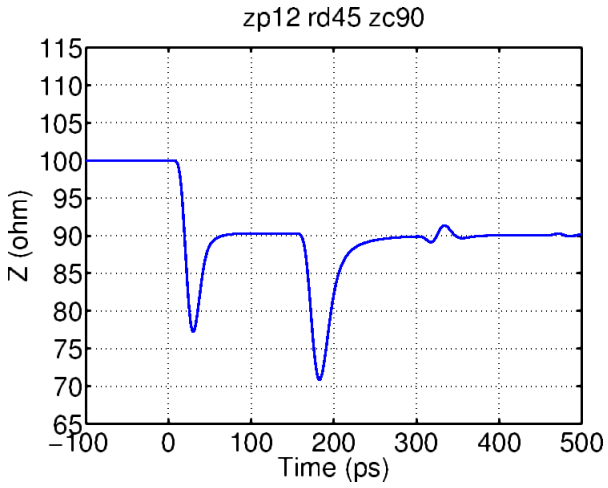
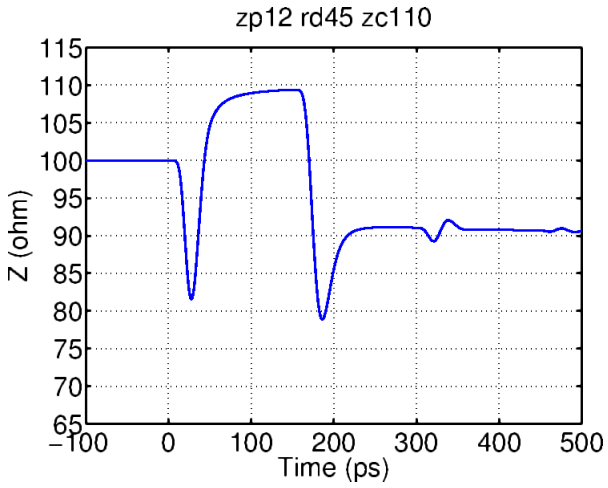
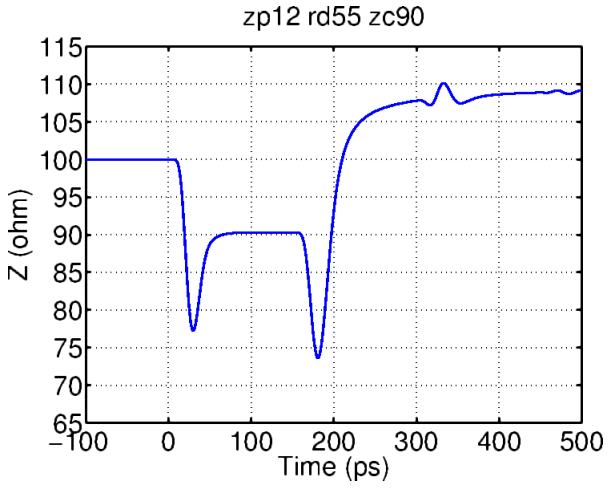
#1: Rd=45, Zc=90



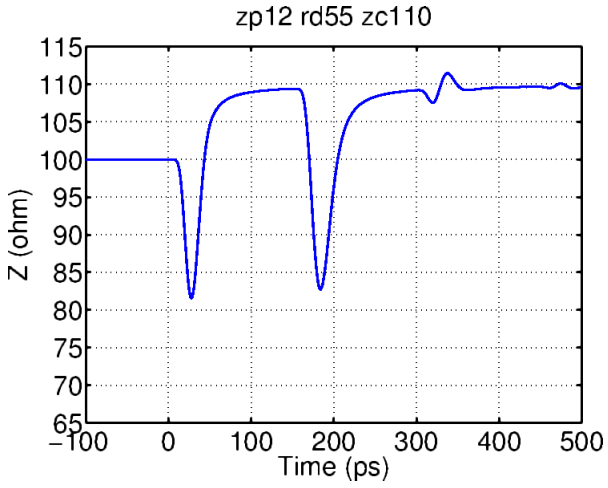
#2: Rd=45, Zc=110



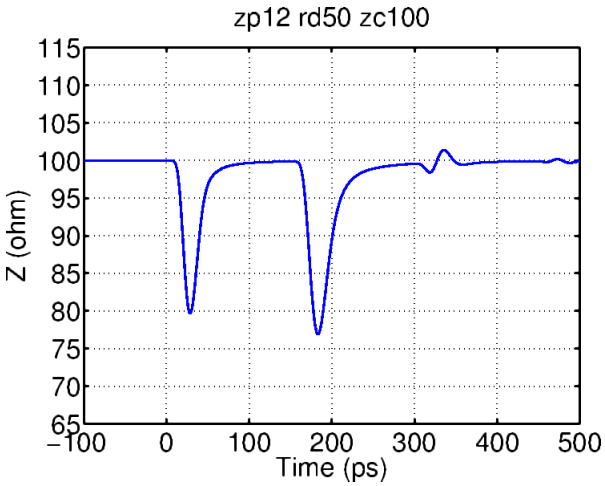
#3: Rd=55, Zc=90



#4: Rd=55, Zc=110



#9: Rd=50, Zc=100



TDR of Entire Path from Scope (zp=30mm)

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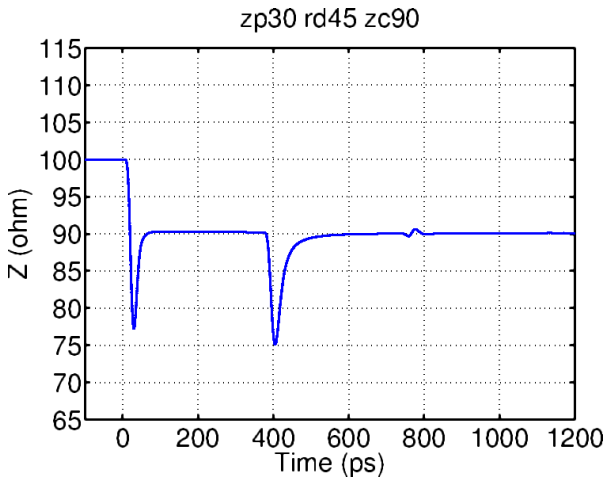
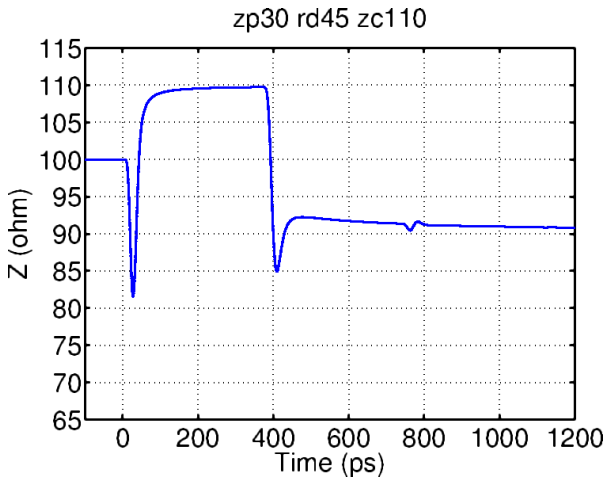
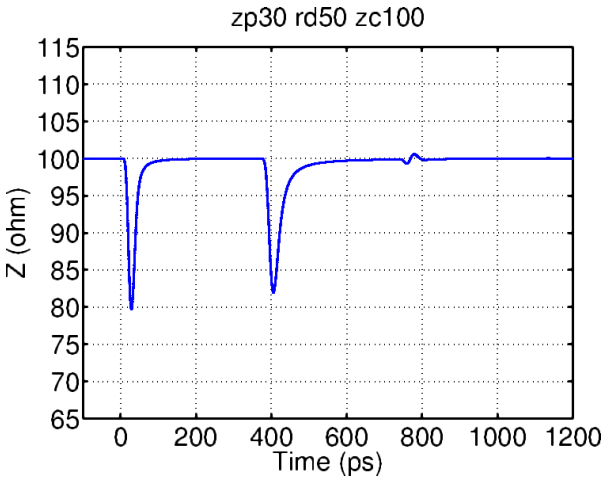
#5: Rd=45, Zc=90



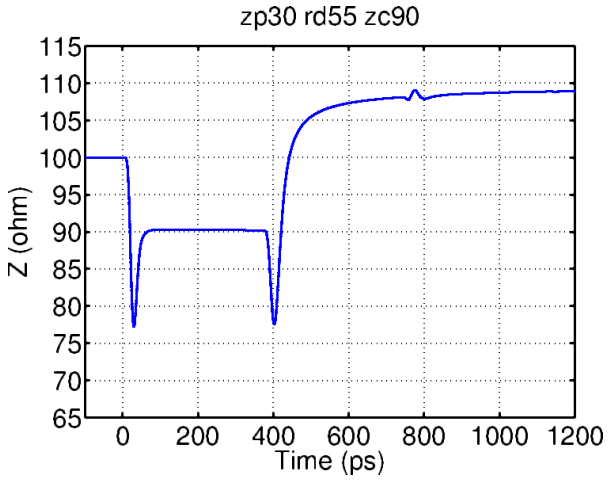
#6: Rd=45, Zc=110



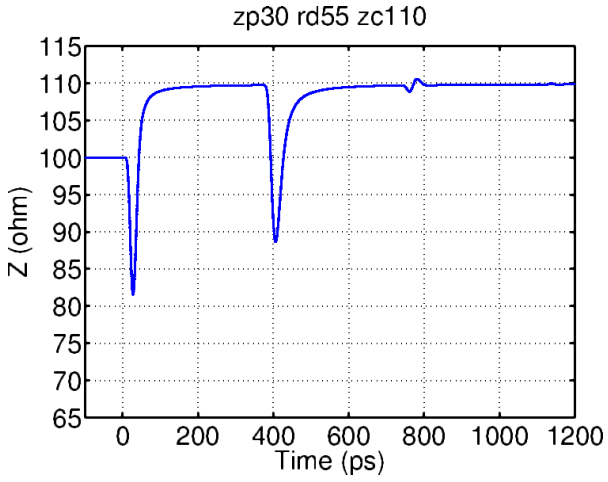
#10: Rd=50, Zc=100



#7: Rd=55, Zc=90



#8: Rd=55, Zc=110



SBR of Entire Path (zp=12mm)

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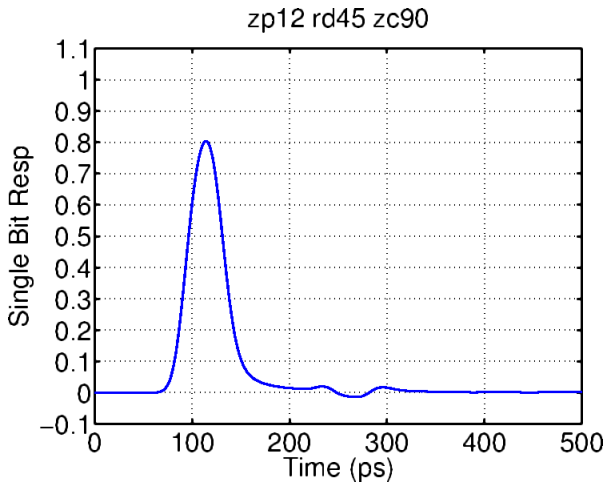
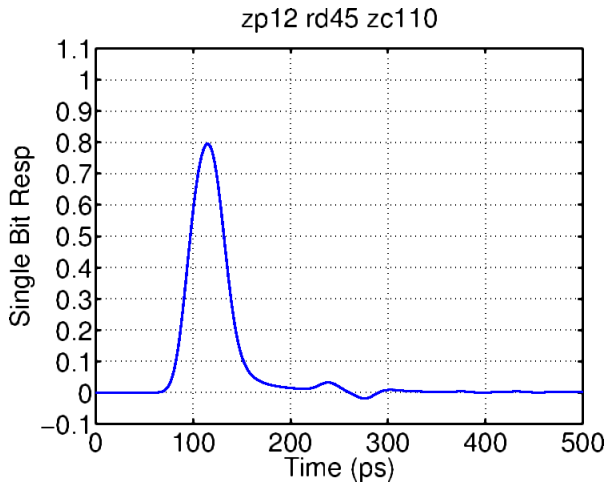
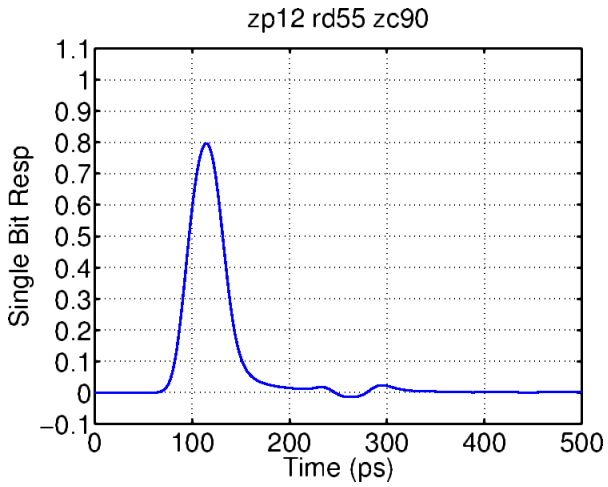
#1: Rd=45, Zc=90



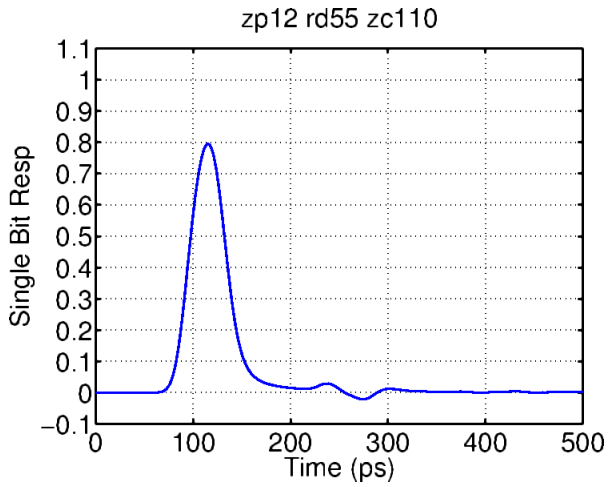
#2: Rd=45, Zc=110



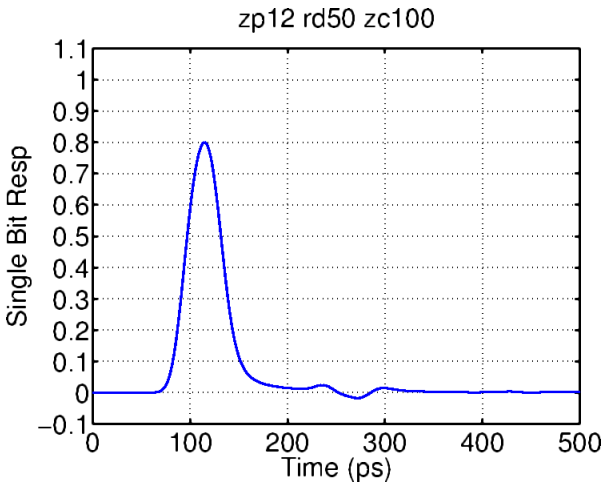
#3: Rd=55, Zc=90



#4: Rd=55, Zc=110



#9: Rd=50, Zc=100



SBR of Entire Path (zp=30mm)

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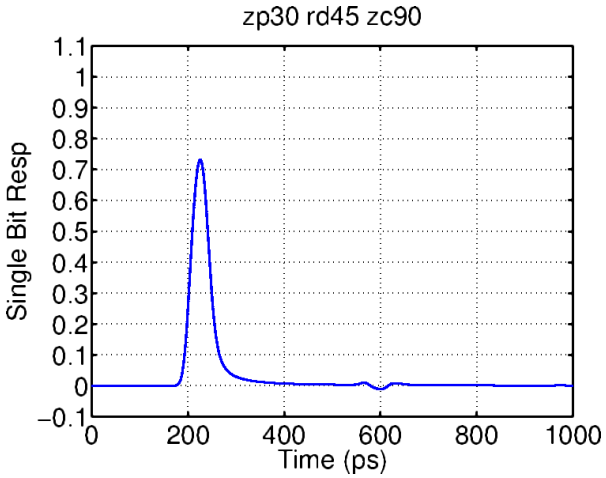
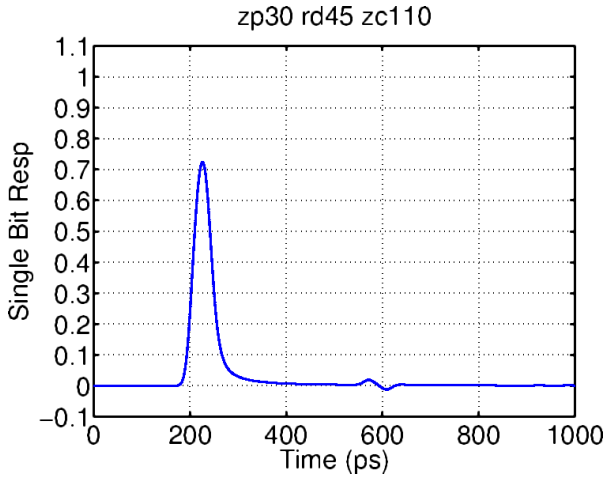
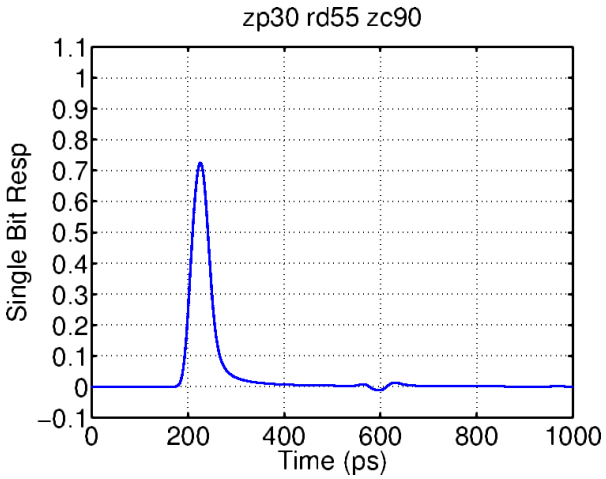
#5: Rd=45, Zc=90



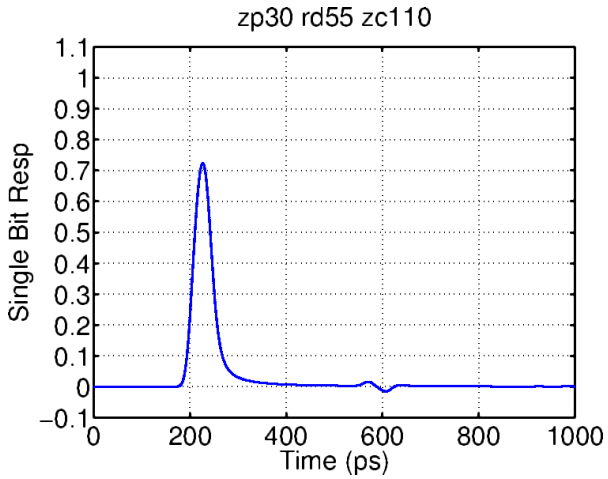
#6: Rd=45, Zc=110



#7: Rd=55, Zc=90



#8: Rd=55, Zc=110



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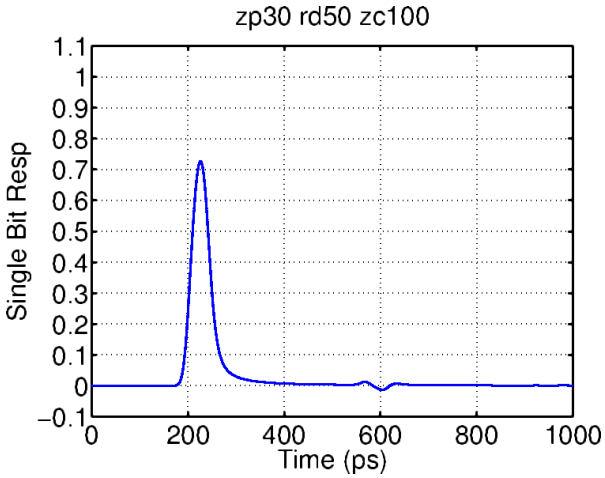

Step Response of Entire Path (zp=12mm)

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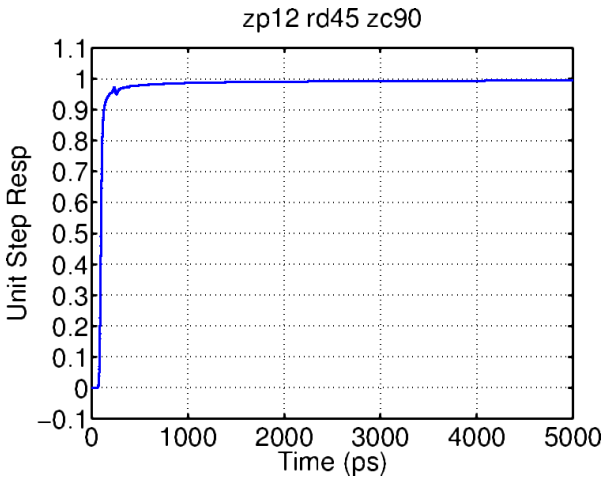
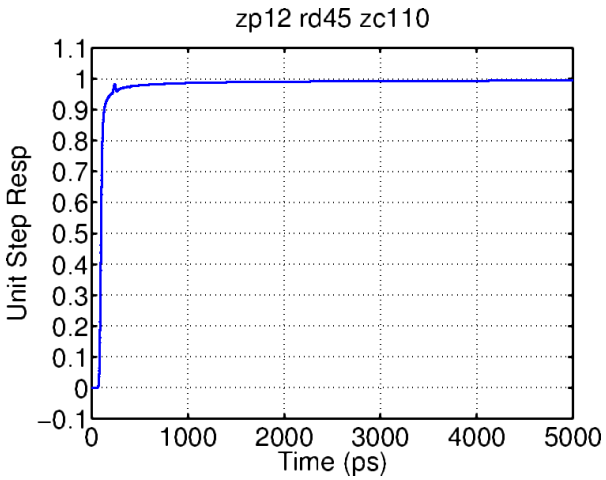
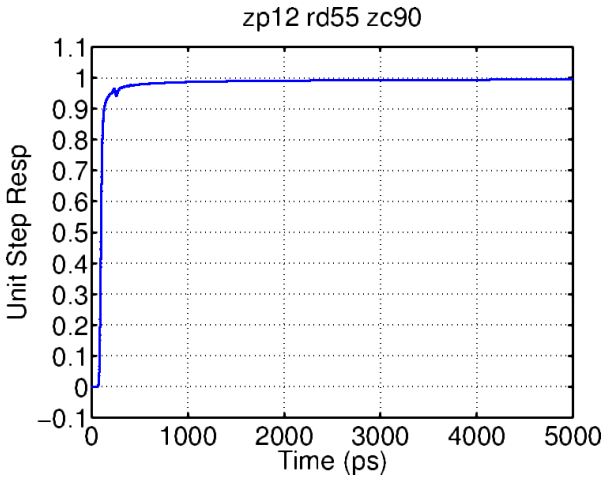
#1: Rd=45, Zc=90



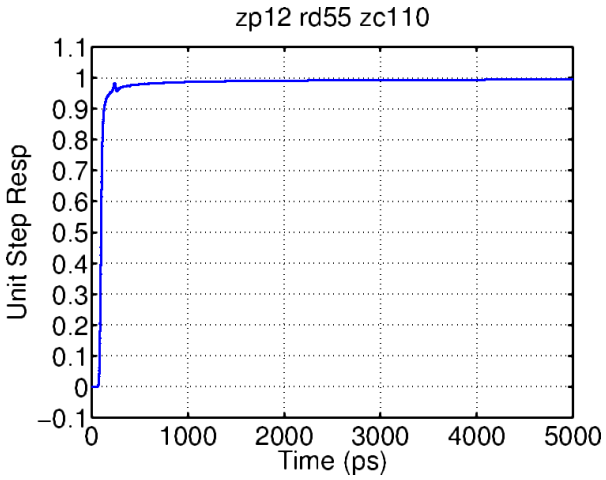
#2: Rd=45, Zc=110



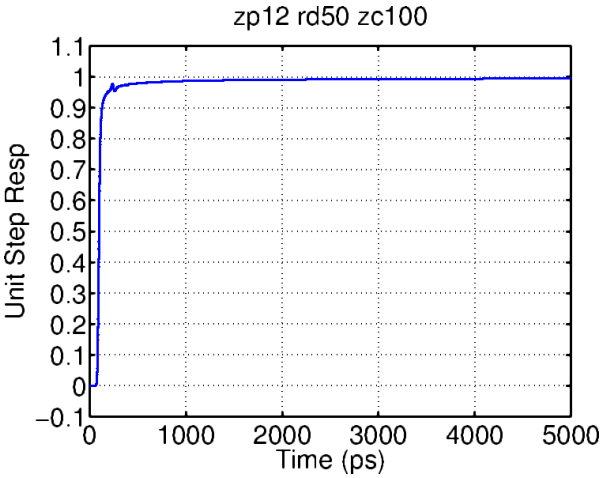
#3: Rd=55, Zc=90



#4: Rd=55, Zc=110



#9: Rd=50, Zc=100



Step Response of Entire Path (zp=30mm)

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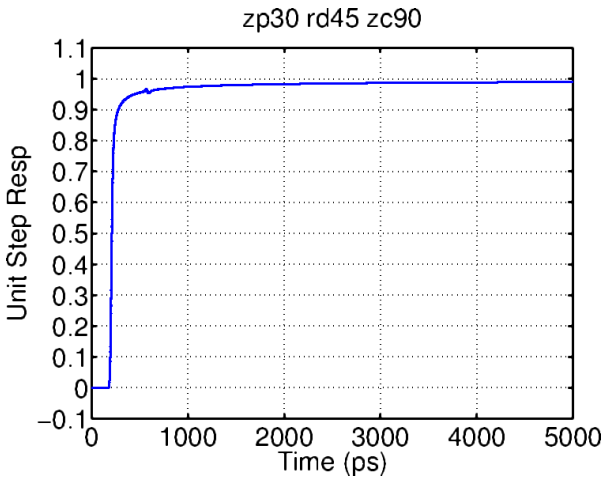
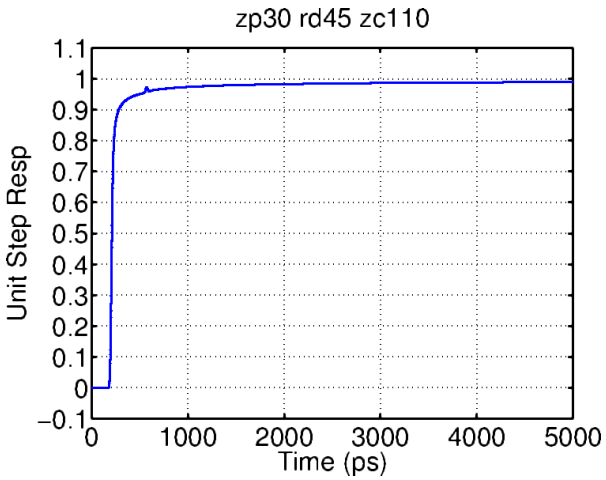
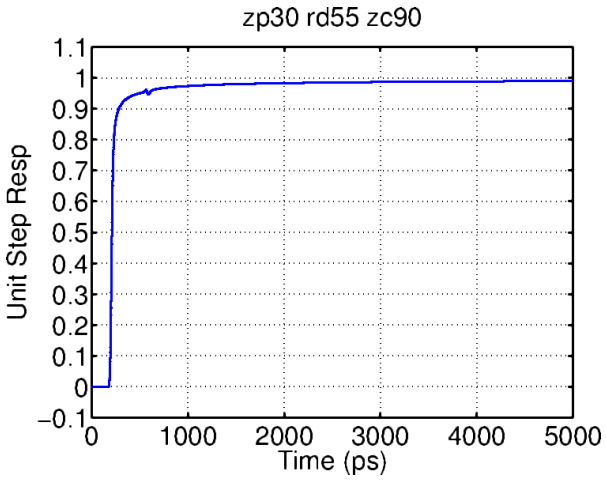
#5: Rd=45, Zc=90



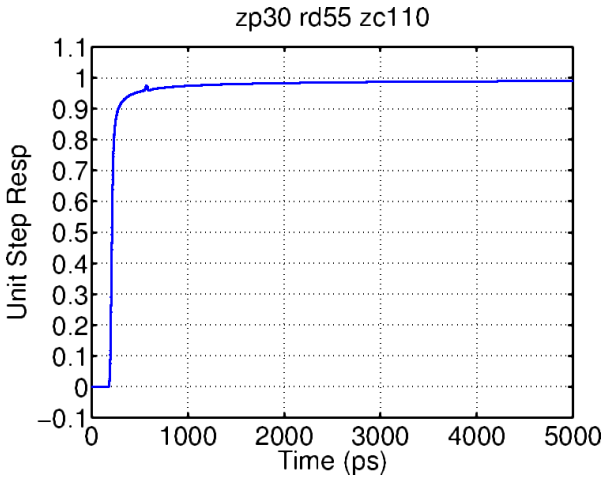
#6: Rd=45, Zc=110



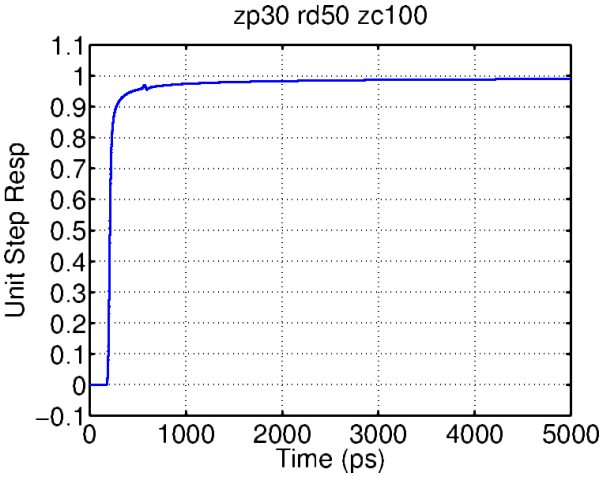
#7: Rd=55, Zc=90



#8: Rd=55, Zc=110



#10: Rd=50, Zc=100



Effect on the Ratio of p_{max} to v_f (Np=200)

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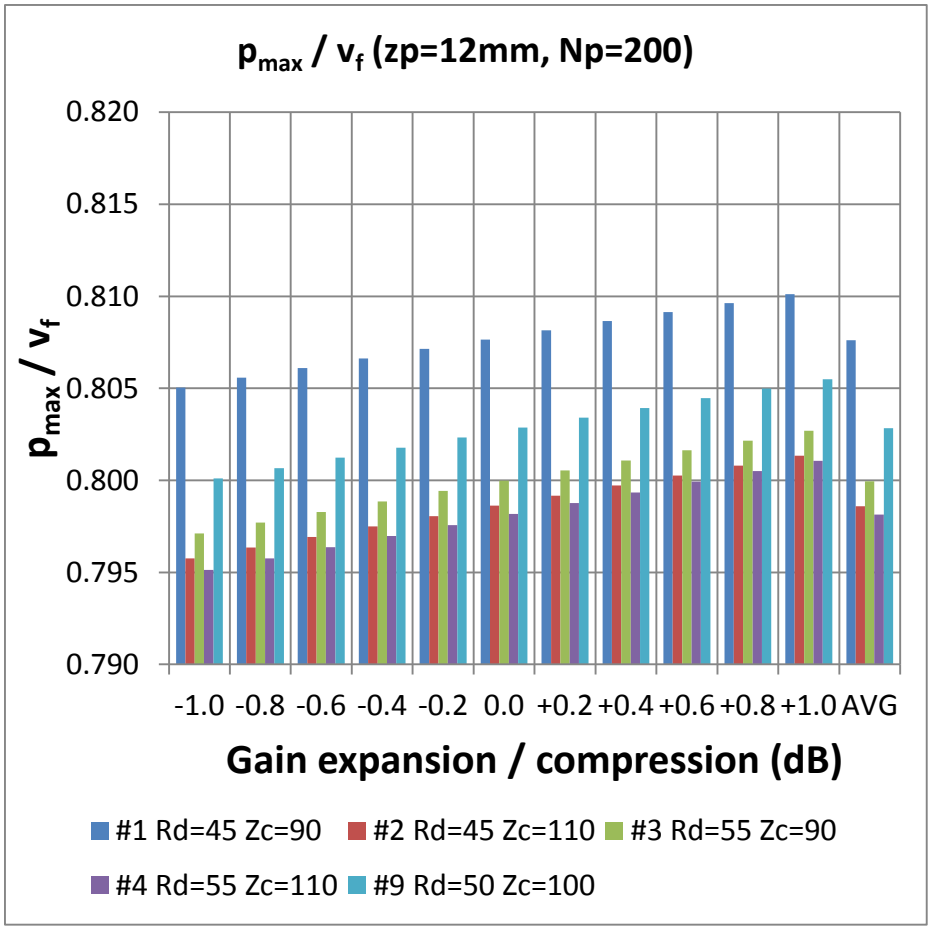
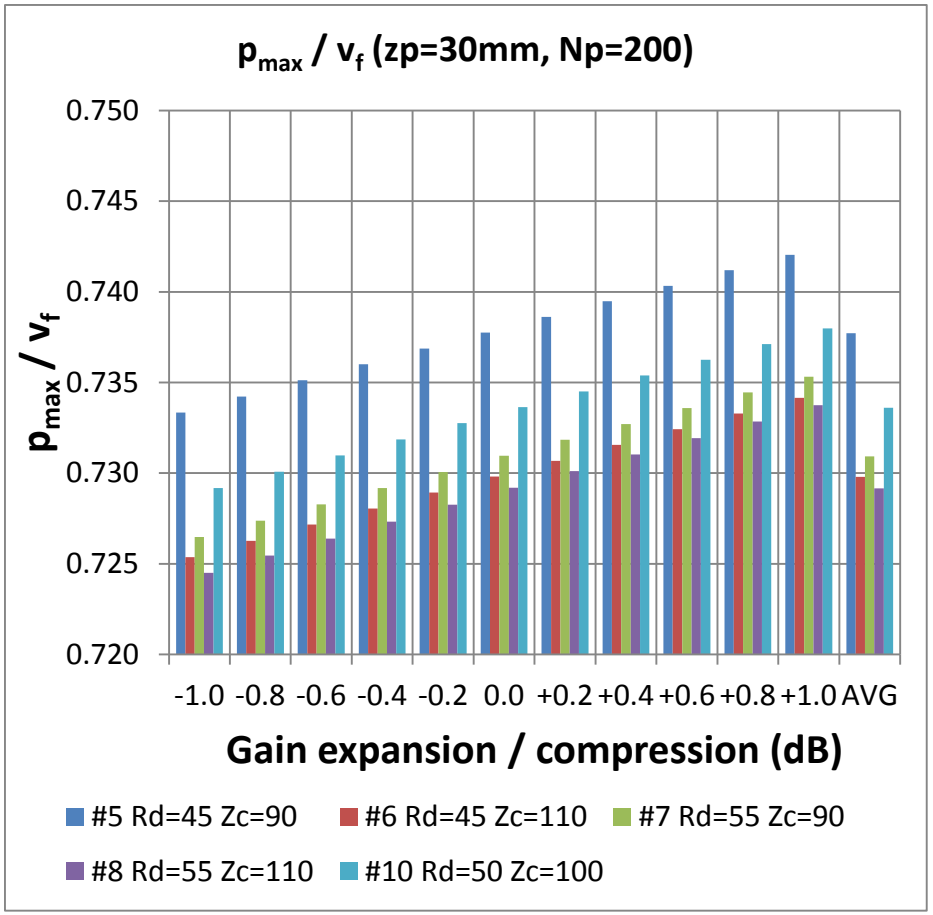
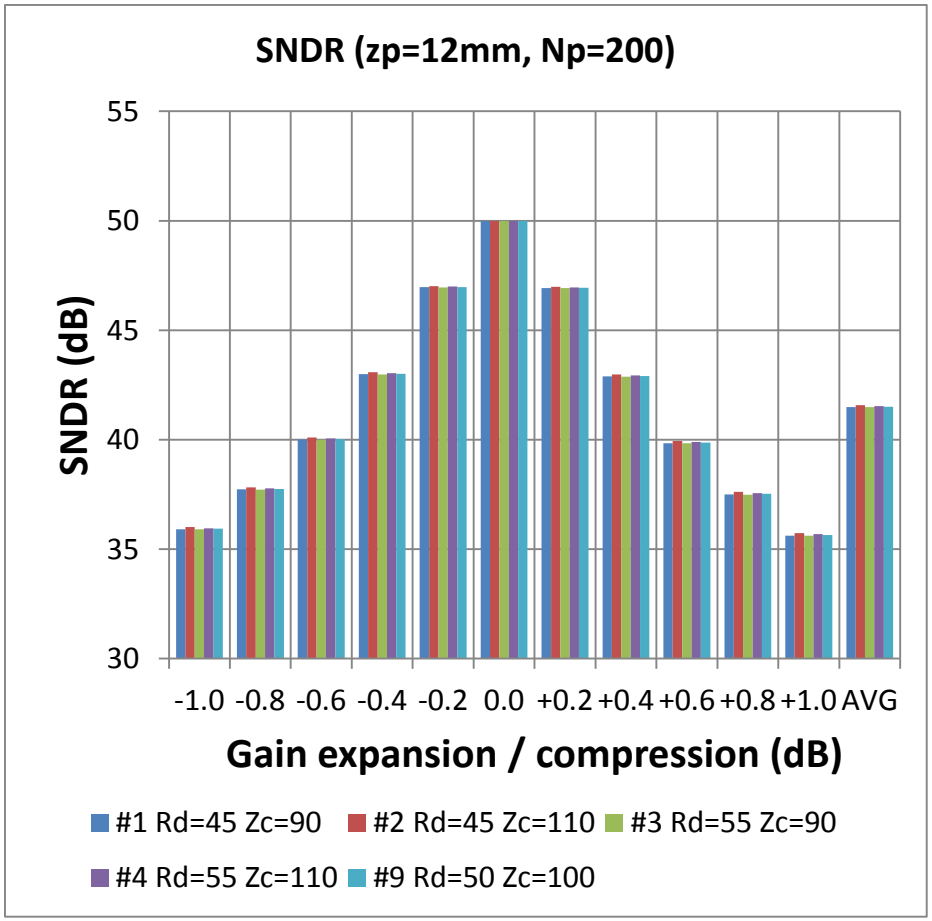
- Between proposed conditions (#2/3/4, #6/7/8), the effect is rather small

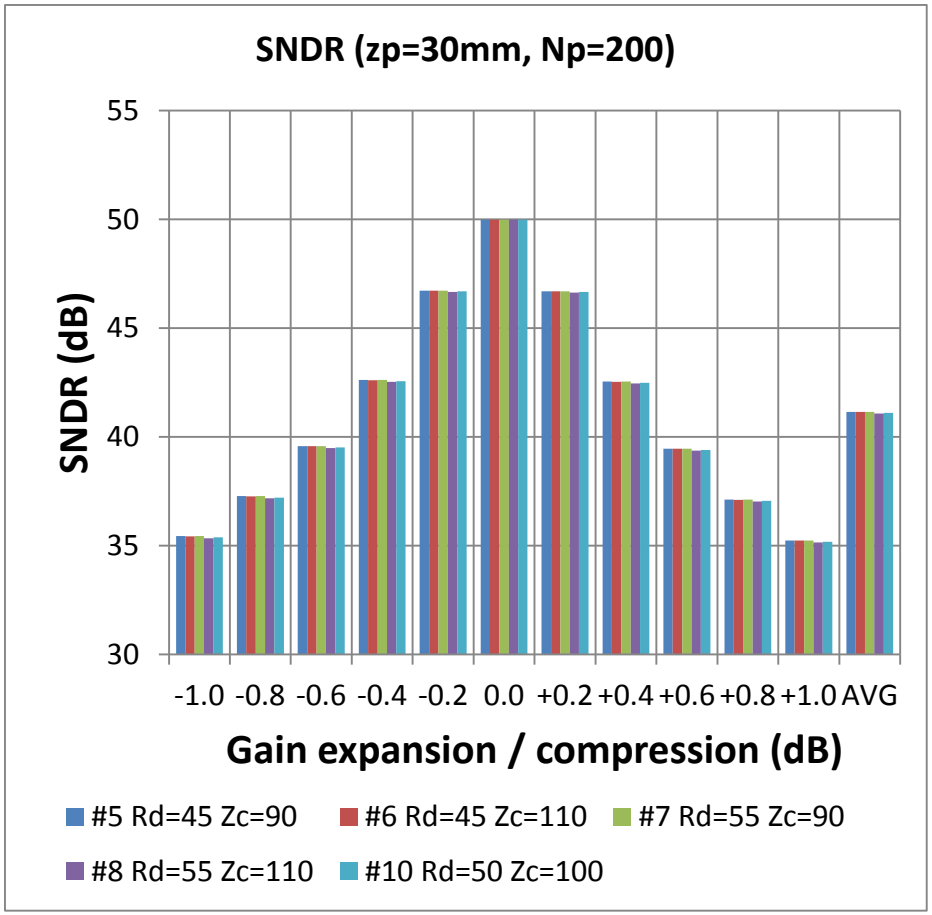




Effect on SNDR (Np=200)

- The effect is very little





Conclusion

- The effects on the p_{max}-to-v_f ratio and the SNDR are rather small

Back up Slides

- Linear Fit in 85.8.3.3.5
- Linear Fit Pulse Response p(k) and Error Response e(k)
- Results for Np=13
- Results of p_{max}
- Results of v_f
- Results of σ_e
- Result Value Tables

Linear Fit in 85.8.3.3.5

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- $$Y = \begin{bmatrix} y(1) & y(M+1) & \cdots & y(M(N-1)+1) \\ y(2) & y(M+2) & \cdots & y(M(N-1)+2) \\ \cdots & \cdots & \cdots & \cdots \\ y(M) & y(2M) & \cdots & y(MN) \end{bmatrix}$$ (85-4)
- $$x_r = \begin{bmatrix} x(D_p+1) & x(D_p+2) & \cdots & x(N) & x(1) & \cdots & x(D_p) \end{bmatrix}$$ (85-5)
- $$X = \begin{bmatrix} x_r(1) & x_r(2) & \cdots & x_r(N) \\ x_r(N) & x_r(1) & \cdots & x_r(N-1) \\ \cdots & \cdots & \cdots & \cdots \\ x_r(2) & x_r(3) & \cdots & x_r(1) \end{bmatrix}$$ (85-6)
- $$X_1 = \begin{bmatrix} X(1{:}N_p,\ :) \\ \text{ones}(1,\ N) \end{bmatrix}$$
- $$P = Y{X_1}^T\left(X_1{X_1}^T\right)^{-1}$$ (85-7)
- $$E = PX_1 - Y = \begin{bmatrix} e(1) & e(M+1) & \cdots & e(M(N-1)+1) \\ e(2) & e(M+2) & \cdots & e(M(N-1)+2) \\ \cdots & \cdots & \cdots & \cdots \\ e(M) & e(2M) & \cdots & e(MN) \end{bmatrix}$$ (85-8)
- $$P_1 = P(:,\ 1{:}N_p) = \begin{bmatrix} p(1) & p(M+1) & \cdots & p(M(N-1)+1) \\ p(2) & p(M+2) & \cdots & p(M(N-1)+2) \\ \cdots & \cdots & \cdots & \cdots \\ p(M) & p(2M) & \cdots & p(MN) \end{bmatrix}$$ (85-9)

Linear Fit Pulse & Error (zp=12mm, Linear)

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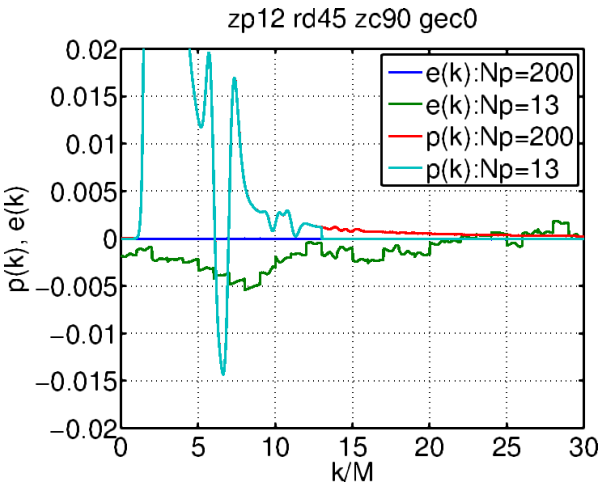
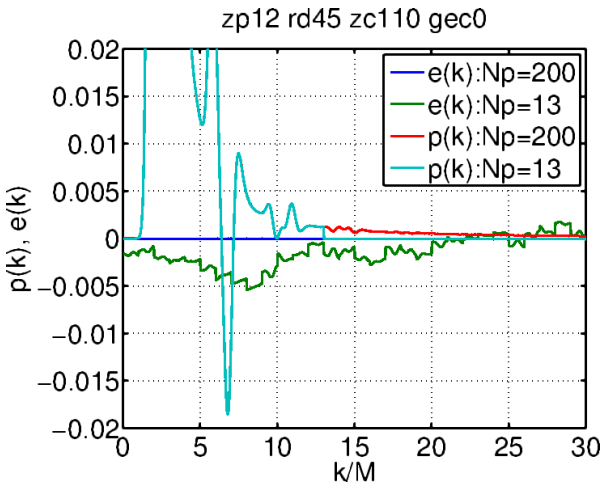
#1: Rd=45, Zc=90

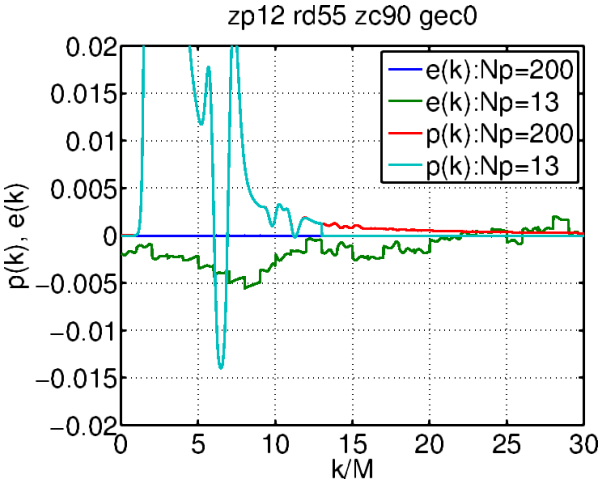


#2: Rd=45, Zc=110

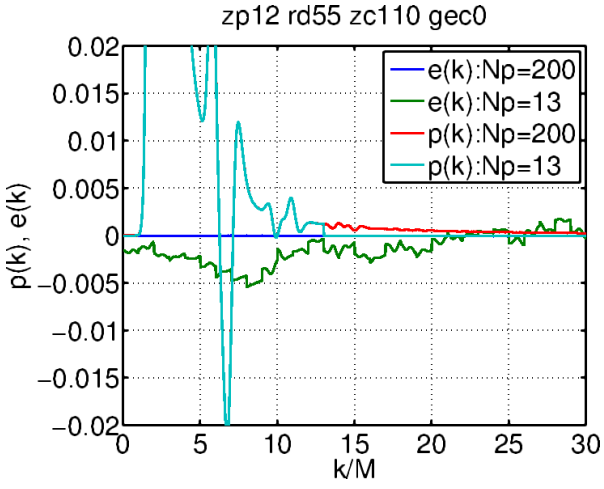


For Np=200,
e(k) is almost zero

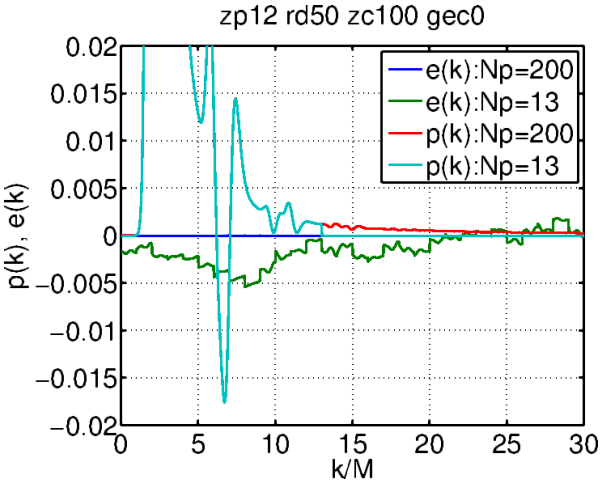
#3: Rd=55, Zc=90



#4: Rd=55, Zc=110



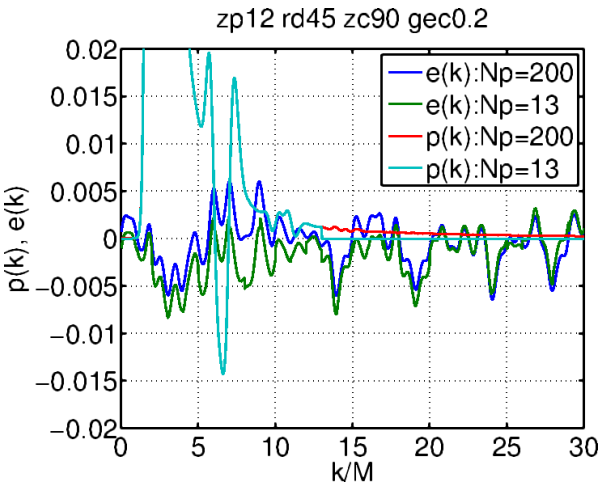
#9: Rd=50, Zc=100



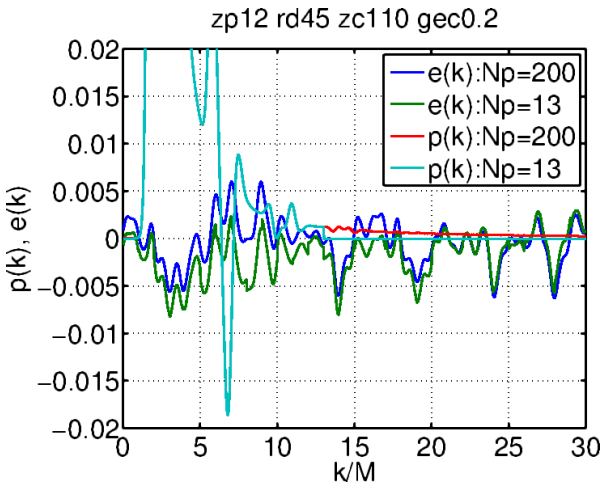
Linear Fit Pulse & Error (zp=12mm, Non-Linear)

FUJITSU

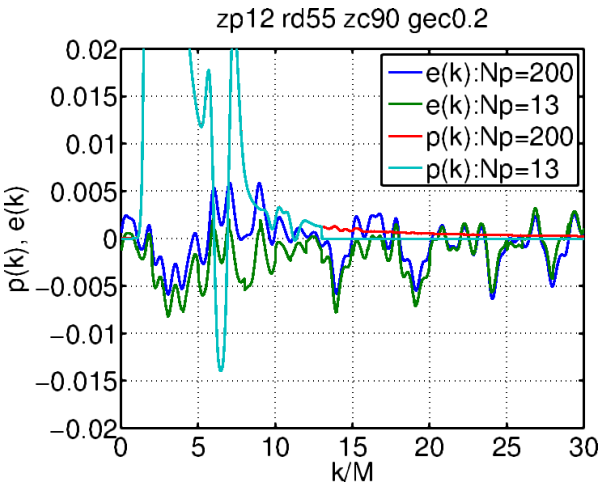
#1: Rd=45, Zc=90



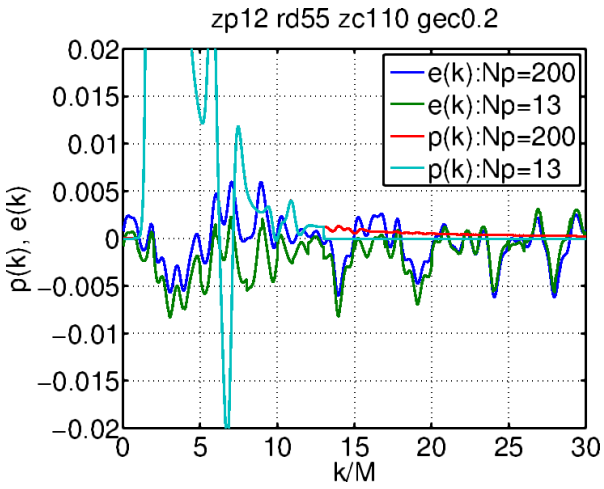
#2: Rd=45, Zc=110



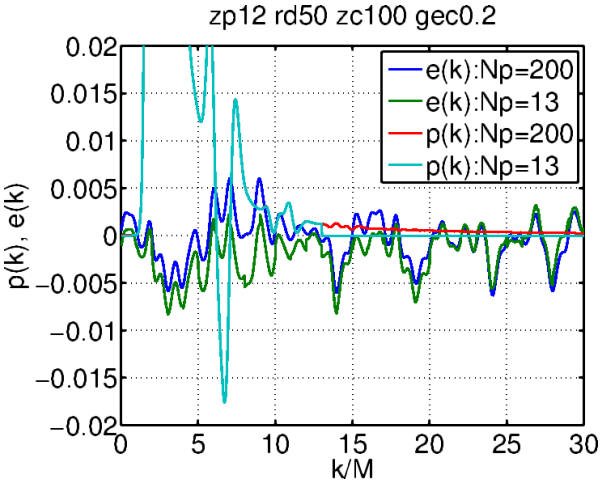
#3: Rd=55, Zc=90



#4: Rd=55, Zc=110



#9: Rd=50, Zc=100



Linear Fit Pulse & Error (zp=30mm, Linear)

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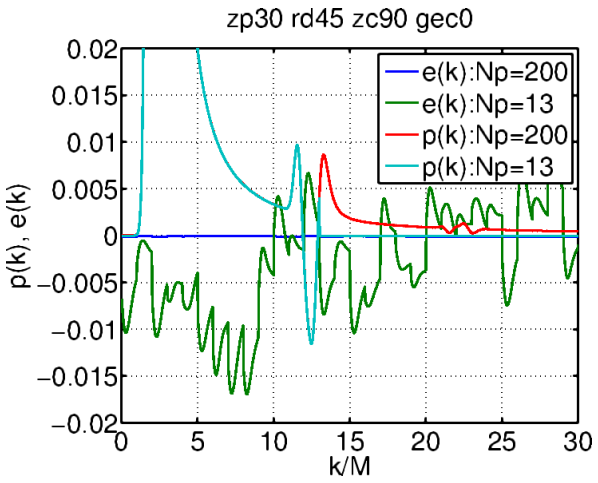
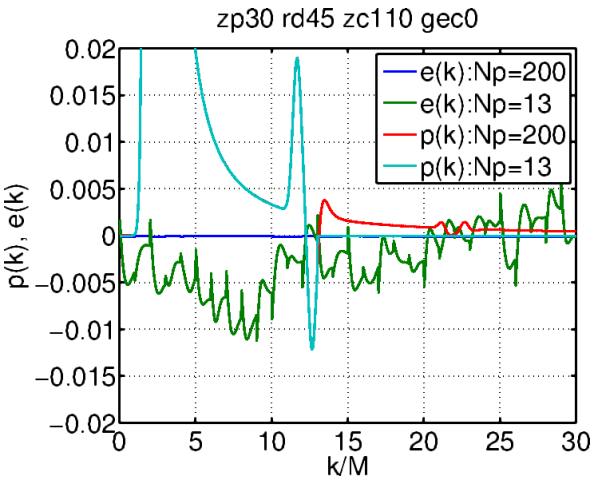
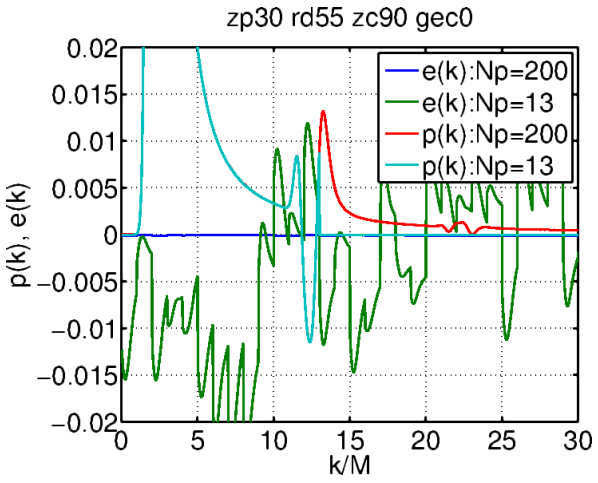
#5: Rd=45, Zc=90



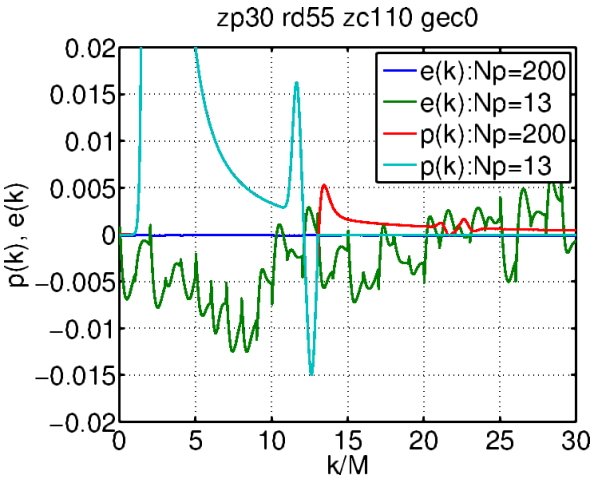
#6: Rd=45, Zc=110



#7: Rd=55, Zc=90



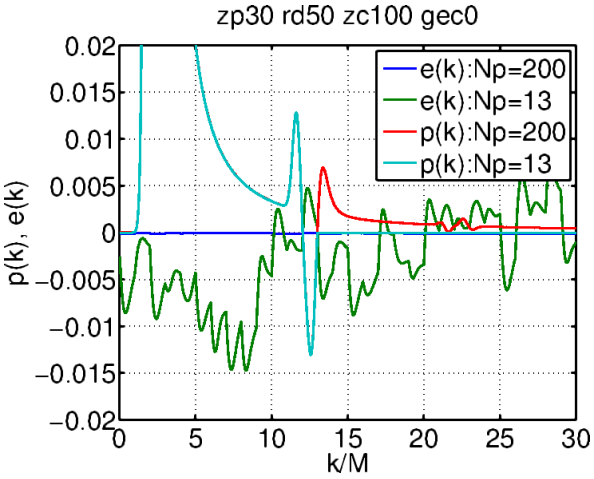
#8: Rd=55, Zc=110



For Np=200,
e(k) is almost zero

Different shape of reflection just after 13 UI

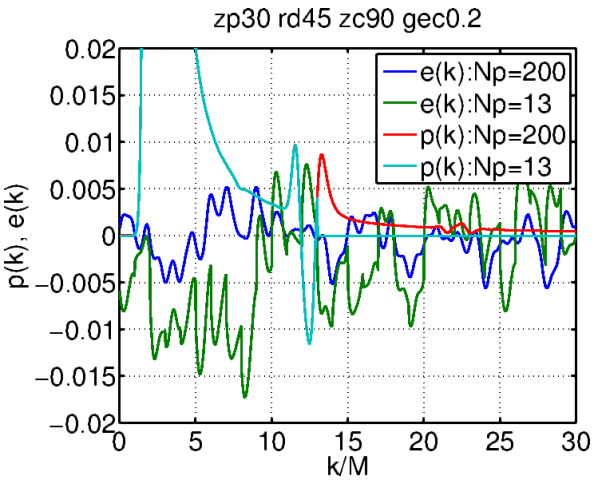
#10: Rd=50, Zc=100



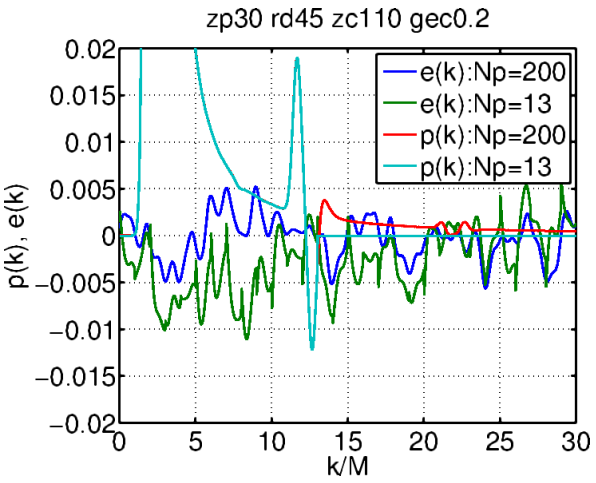
Linear Fit Pulse & Error (zp=30mm, Non-Linear)

FUJITSU

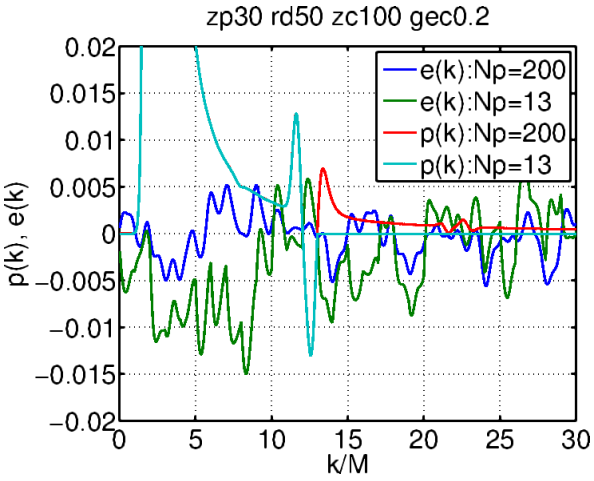
#5: Rd=45, Zc=90



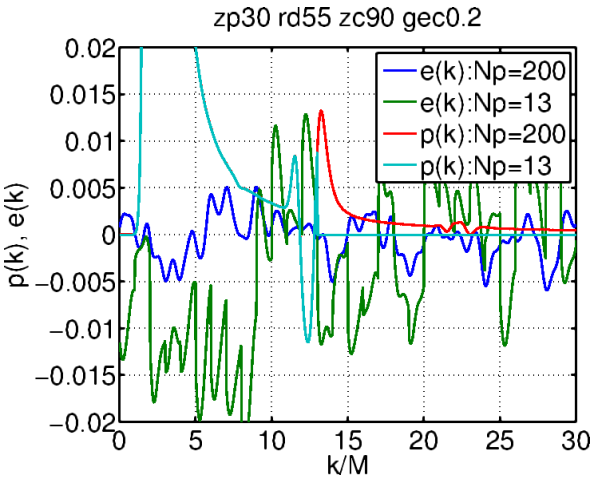
#6: Rd=45, Zc=110



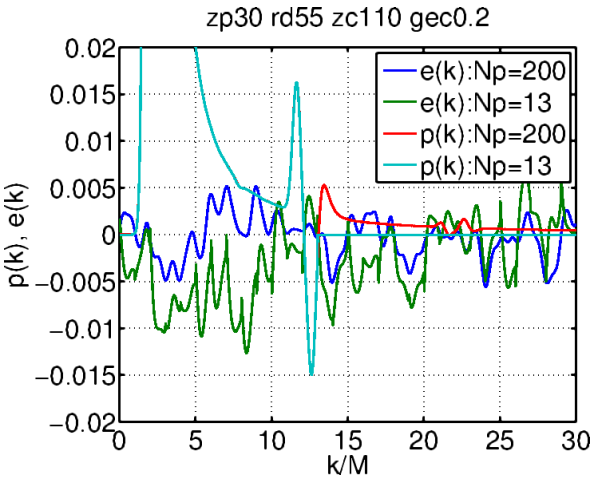
#10: Rd=50, Zc=100



#7: Rd=55, Zc=90



#8: Rd=55, Zc=110



Effect on the Ratio of p_{max} to v_f (Np=13)

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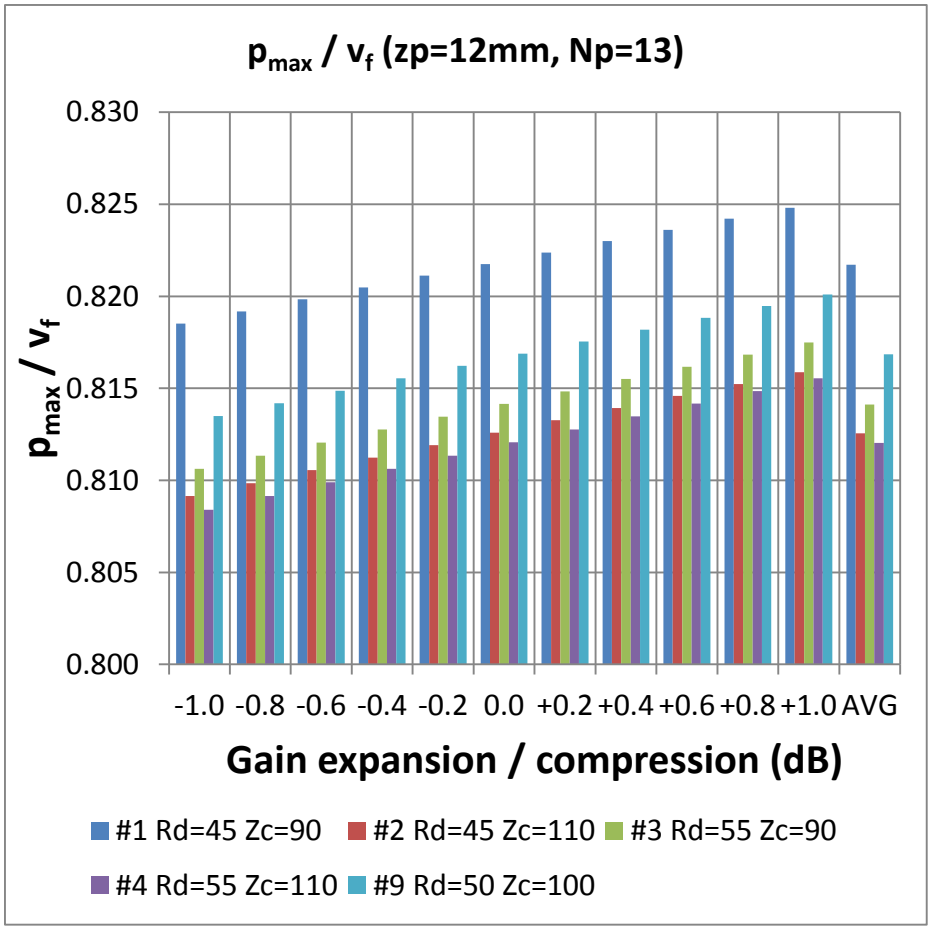
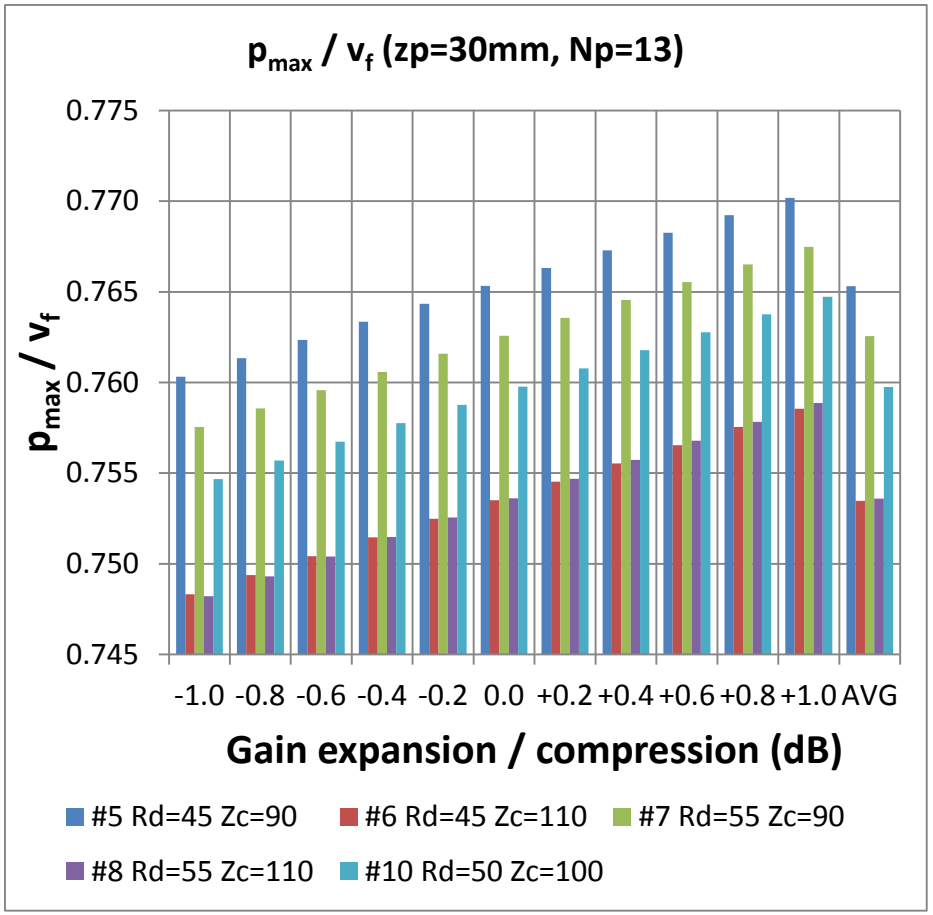
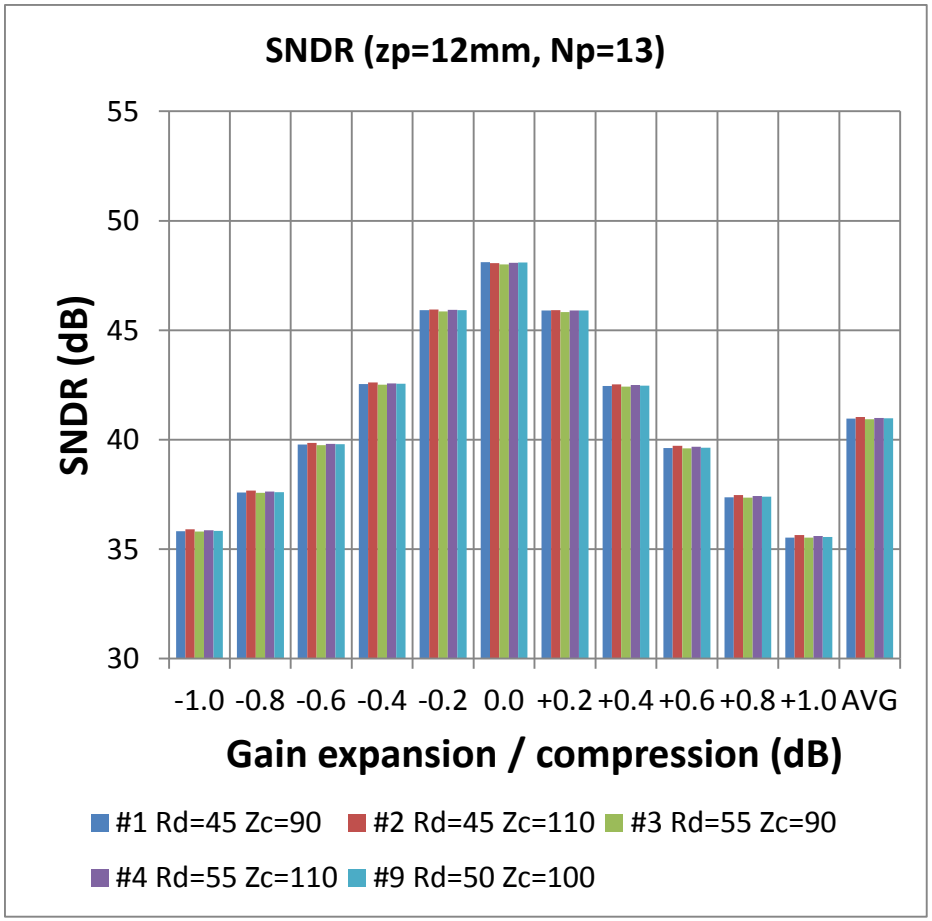
- The effect gets larger with zp=30mm (right graph)
  - The ratio of p_{max} to v_f is lower with Zc=110Ω (#6,#8) than Zc=90Ω (#7)

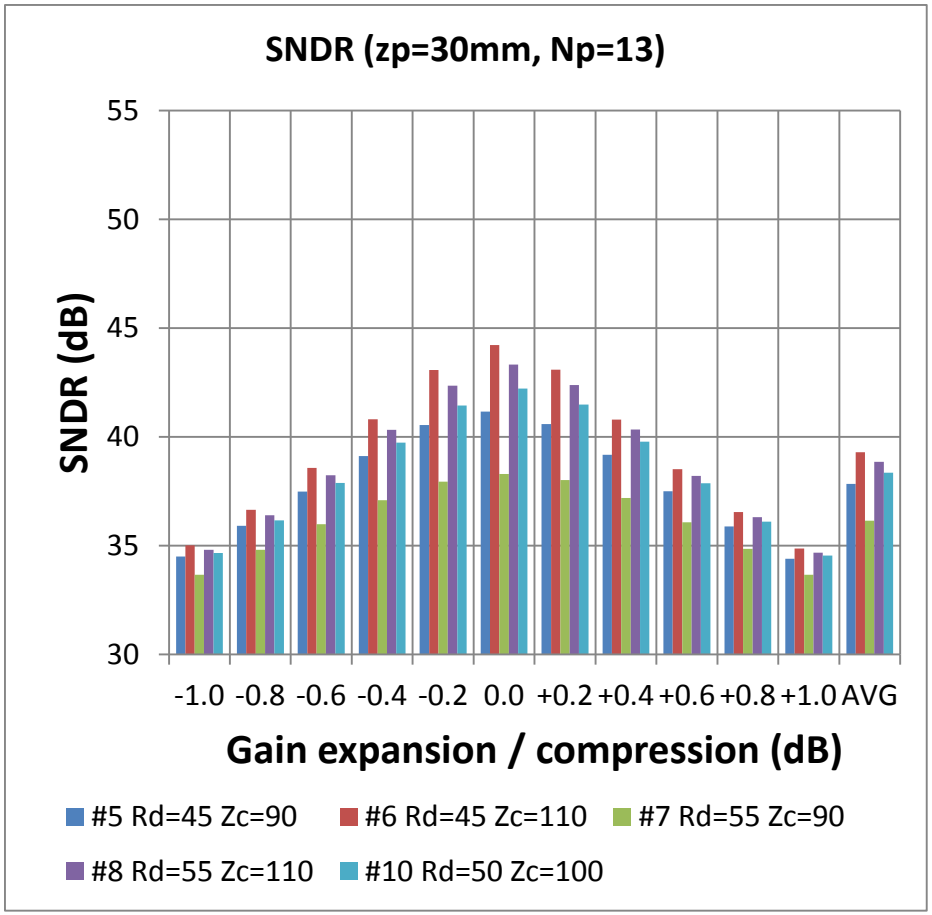




Effect on SNDR (Np=13)

- The effect gets larger with zp=30mm (right graph)
  - SNDR is higher with Zc=110Ω (#6,#8) than Zc=90Ω (#7)





Result Table for the Ratio of p_{max} to v_f

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Ratio of Linear Fit Pulse Peak p_{max} to Steady-State Voltage v_f (Dp=2, Np=200)											
Case		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
zp		12				30				12	30
Rd		45		55		45		55		50	50
Zc		90	110	90	110	90	110	90	110	100	100
Gain expansion / compression (dB)	-1.0	0.8050	0.7958	0.7971	0.7951	0.7333	0.7254	0.7265	0.7245	0.8001	0.7292
	-0.8	0.8056	0.7963	0.7977	0.7957	0.7342	0.7263	0.7274	0.7255	0.8007	0.7301
	-0.6	0.8061	0.7969	0.7983	0.7964	0.7351	0.7272	0.7283	0.7264	0.8012	0.7310
	-0.4	0.8066	0.7975	0.7989	0.7970	0.7360	0.7280	0.7292	0.7273	0.8018	0.7319
	-0.2	0.8071	0.7981	0.7994	0.7976	0.7369	0.7289	0.7301	0.7283	0.8023	0.7328
	0.0	0.8076	0.7986	0.8000	0.7982	0.7377	0.7298	0.7309	0.7292	0.8029	0.7336
	0.2	0.8082	0.7992	0.8005	0.7988	0.7386	0.7307	0.7318	0.7301	0.8034	0.7345
	0.4	0.8086	0.7997	0.8011	0.7993	0.7395	0.7316	0.7327	0.7310	0.8039	0.7354
	0.6	0.8091	0.8003	0.8016	0.7999	0.7403	0.7324	0.7336	0.7319	0.8045	0.7363
	0.8	0.8096	0.8008	0.8022	0.8005	0.7412	0.7333	0.7345	0.7328	0.8050	0.7371
	1.0	0.8101	0.8013	0.8027	0.8011	0.7420	0.7341	0.7353	0.7338	0.8055	0.7380
Average		0.8076	0.7986	0.7999	0.7981	0.7377	0.7298	0.7309	0.7292	0.8028	0.7336

Ratio of Linear Fit Pulse Peak p_{max} to Steady-State Voltage v_f (Dp=2, Np=13)											
Case		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
zp		12				30				12	30
Rd		45		55		45		55		50	50
Zc		90	110	90	110	90	110	90	110	100	100
Gain expansion / compression (dB)	-1.0	0.8185	0.8091	0.8106	0.8084	0.7603	0.7483	0.7575	0.7482	0.8135	0.7547
	-0.8	0.8192	0.8098	0.8113	0.8092	0.7613	0.7494	0.7586	0.7493	0.8142	0.7557
	-0.6	0.8198	0.8105	0.8121	0.8099	0.7623	0.7504	0.7596	0.7504	0.8149	0.7567
	-0.4	0.8205	0.8112	0.8128	0.8106	0.7634	0.7515	0.7606	0.7515	0.8155	0.7578
	-0.2	0.8211	0.8119	0.8135	0.8113	0.7643	0.7525	0.7616	0.7525	0.8162	0.7588
	0.0	0.8218	0.8126	0.8141	0.8121	0.7653	0.7535	0.7626	0.7536	0.8169	0.7598
	0.2	0.8224	0.8133	0.8148	0.8128	0.7663	0.7545	0.7636	0.7547	0.8175	0.7608
	0.4	0.8230	0.8139	0.8155	0.8135	0.7673	0.7555	0.7646	0.7557	0.8182	0.7618
	0.6	0.8236	0.8146	0.8162	0.8142	0.7683	0.7565	0.7655	0.7568	0.8188	0.7628
	0.8	0.8242	0.8152	0.8168	0.8149	0.7692	0.7575	0.7665	0.7578	0.8195	0.7638
	1.0	0.8248	0.8159	0.8175	0.8155	0.7702	0.7585	0.7675	0.7589	0.8201	0.7647
Average		0.8217	0.8126	0.8141	0.8120	0.7653	0.7535	0.7626	0.7536	0.8168	0.7597

Result Table for SNDR

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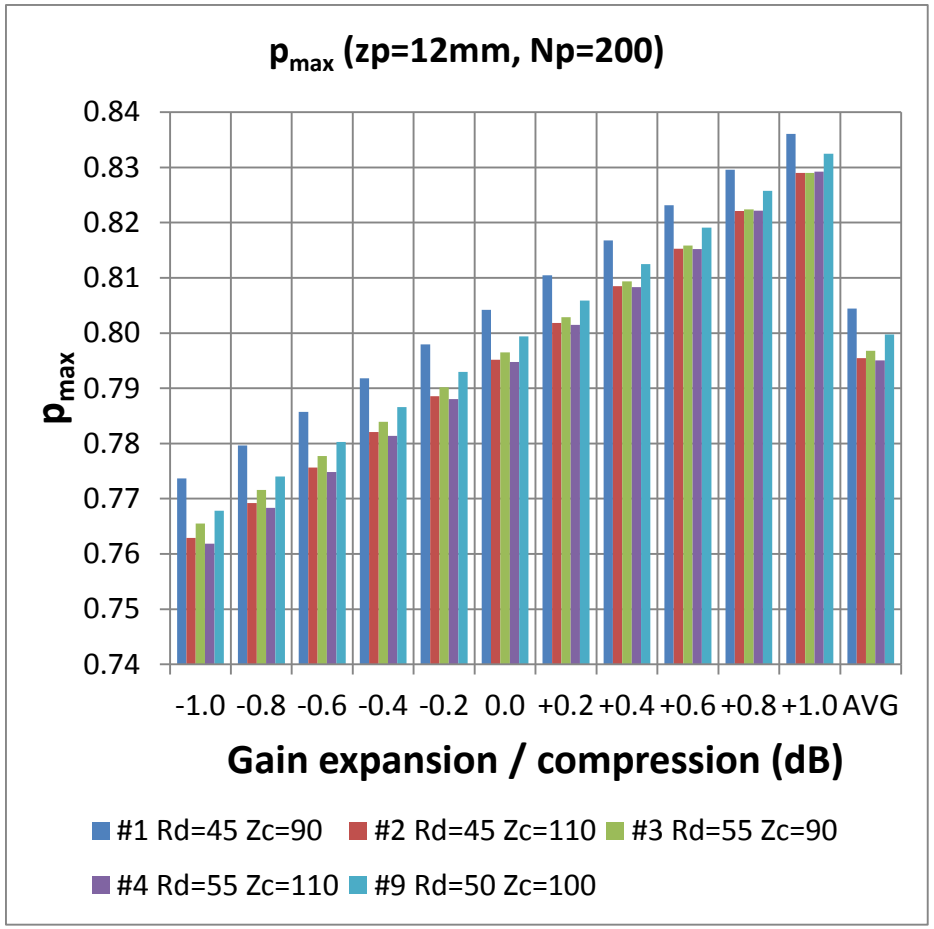
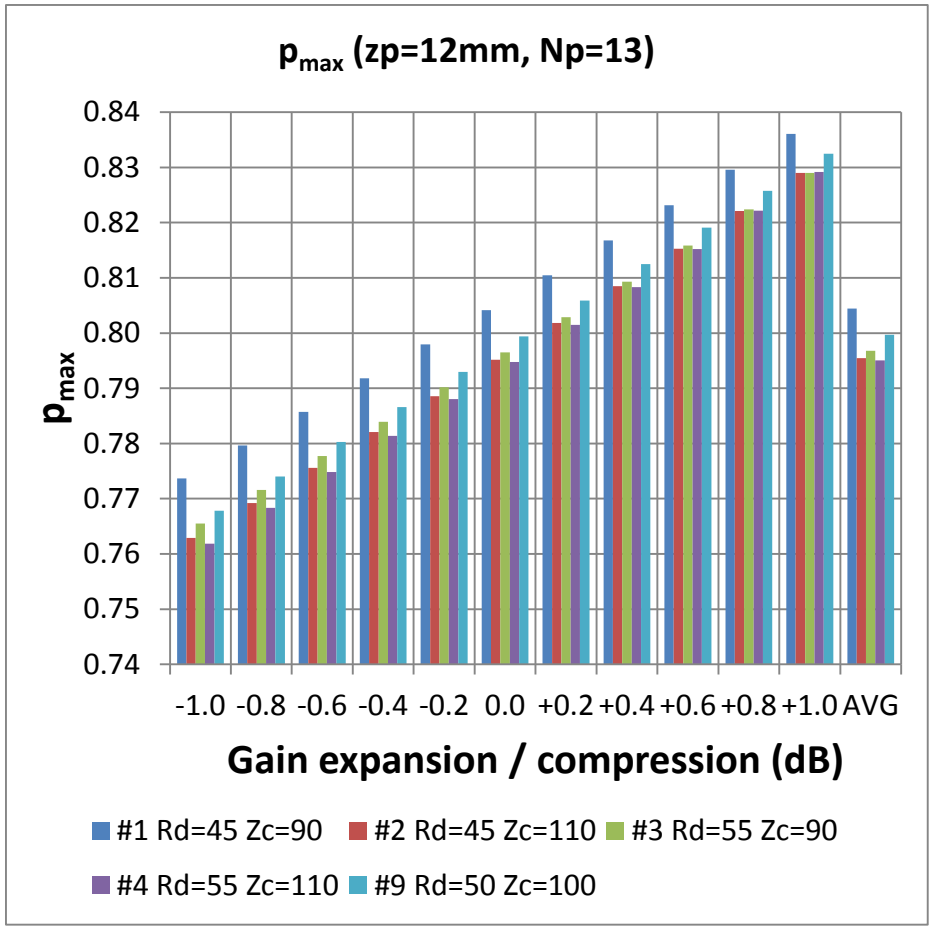
SNDR (Dp=2, Np=200)											
Case		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
zp		12				30				12	30
Rd		45		55		45		55		50	50
Zc		90	110	90	110	90	110	90	110	100	100
Gain expansion / compression (dB)	-1.0	35.91	36.01	35.90	35.95	35.44	35.43	35.44	35.33	35.93	35.37
	-0.8	37.73	37.83	37.72	37.77	37.27	37.26	37.27	37.17	37.75	37.21
	-0.6	40.01	40.10	40.00	40.05	39.58	39.57	39.58	39.48	40.02	39.52
	-0.4	42.99	43.08	42.98	43.03	42.62	42.61	42.61	42.53	43.01	42.56
	-0.2	46.96	47.02	46.96	46.99	46.72	46.72	46.72	46.67	46.98	46.69
	0.0	50.00	49.99	49.99	49.99	49.98	49.98	49.98	49.98	50.00	49.98
	0.2	46.92	46.98	46.92	46.96	46.69	46.69	46.69	46.64	46.94	46.66
	0.4	42.89	42.98	42.88	42.94	42.54	42.53	42.54	42.46	42.91	42.49
	0.6	39.83	39.94	39.83	39.90	39.46	39.45	39.46	39.37	39.86	39.40
	0.8	37.49	37.61	37.49	37.56	37.11	37.11	37.11	37.02	37.52	37.05
	1.0	35.61	35.74	35.61	35.69	35.23	35.23	35.24	35.14	35.65	35.18
Average		41.49	41.57	41.48	41.53	41.15	41.14	41.15	41.07	41.51	41.10

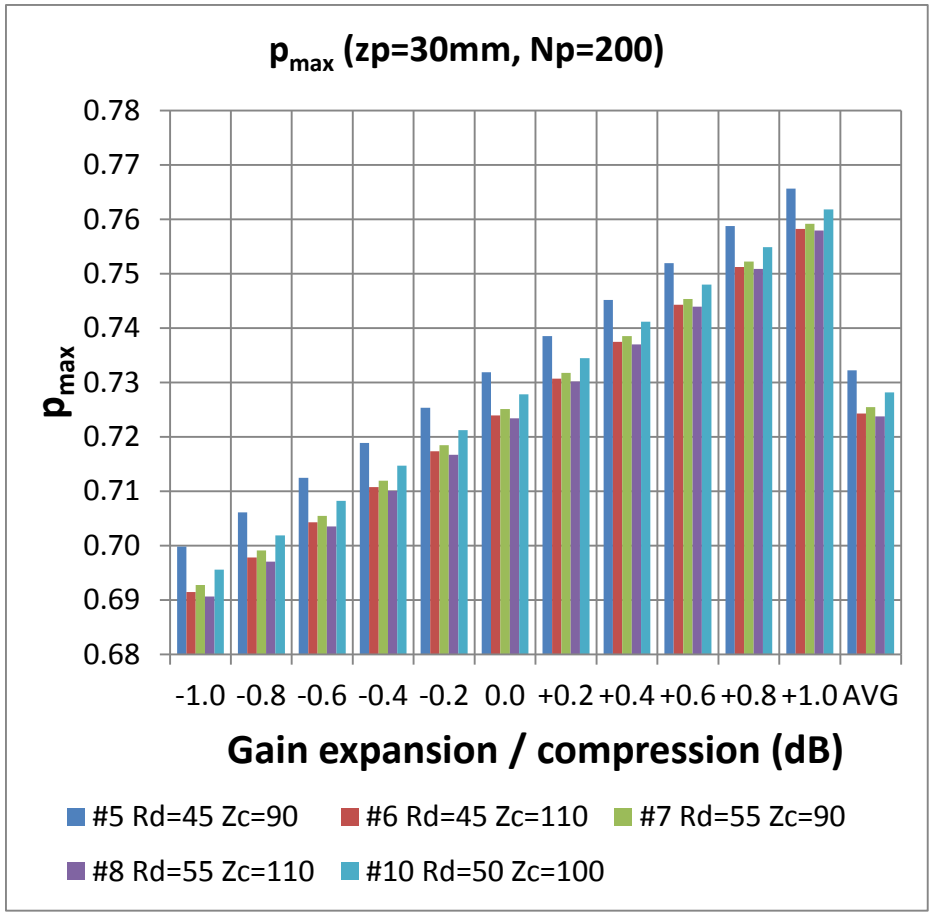
SNDR (Dp=2, Np=13)											
Case		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
zp		12				30				12	30
Rd		45		55		45		55		50	50
Zc		90	110	90	110	90	110	90	110	100	100
Gain expansion / compression (dB)	-1.0	35.82	35.91	35.80	35.86	34.49	35.01	33.65	34.80	35.83	34.66
	-0.8	37.59	37.68	37.57	37.63	35.91	36.65	34.80	36.39	37.60	36.17
	-0.6	39.77	39.86	39.75	39.81	37.48	38.57	35.98	38.24	39.79	37.88
	-0.4	42.54	42.61	42.51	42.57	39.12	40.81	37.09	40.32	42.55	39.74
	-0.2	45.92	45.94	45.86	45.92	40.54	43.08	37.94	42.35	45.92	41.44
	0.0	48.11	48.07	48.01	48.08	41.17	44.22	38.29	43.33	48.09	42.23
	0.2	45.90	45.92	45.84	45.90	40.59	43.10	38.01	42.38	45.90	41.49
	0.4	42.45	42.53	42.42	42.49	39.18	40.80	37.19	40.33	42.47	39.77
	0.6	39.62	39.71	39.60	39.67	37.50	38.52	36.07	38.21	39.64	37.87
	0.8	37.36	37.47	37.36	37.43	35.88	36.54	34.85	36.31	37.39	36.11
	1.0	35.53	35.65	35.52	35.60	34.40	34.86	33.66	34.68	35.56	34.54
Average		40.96	41.03	40.93	41.00	37.84	39.29	36.14	38.85	40.98	38.35

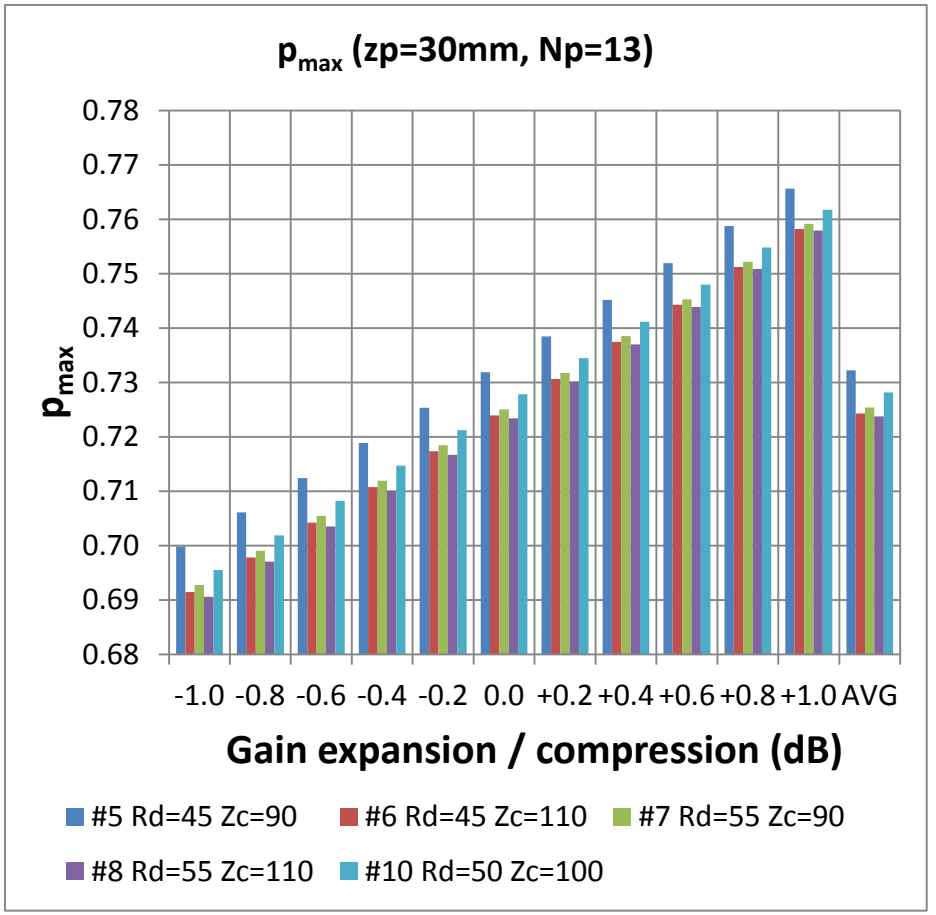
Result of p_{max} (zp=12mm)





Result of p_{max} (zp=30mm)





Result Table for p_{max}

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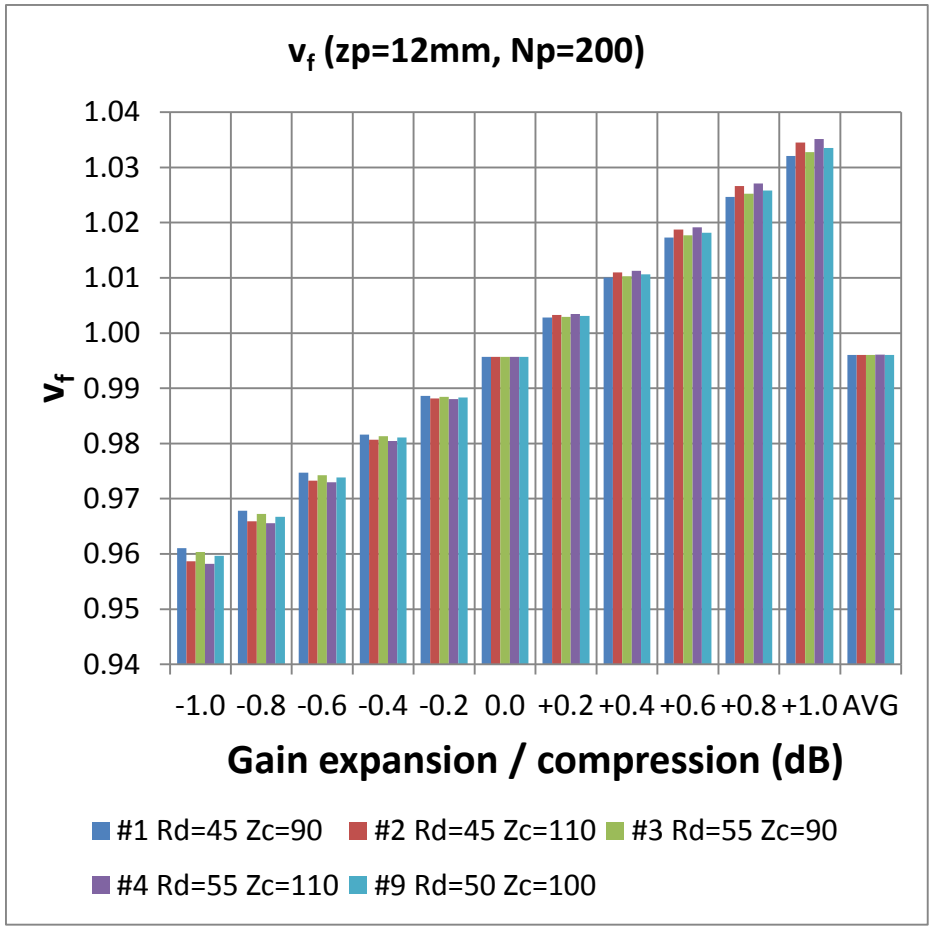
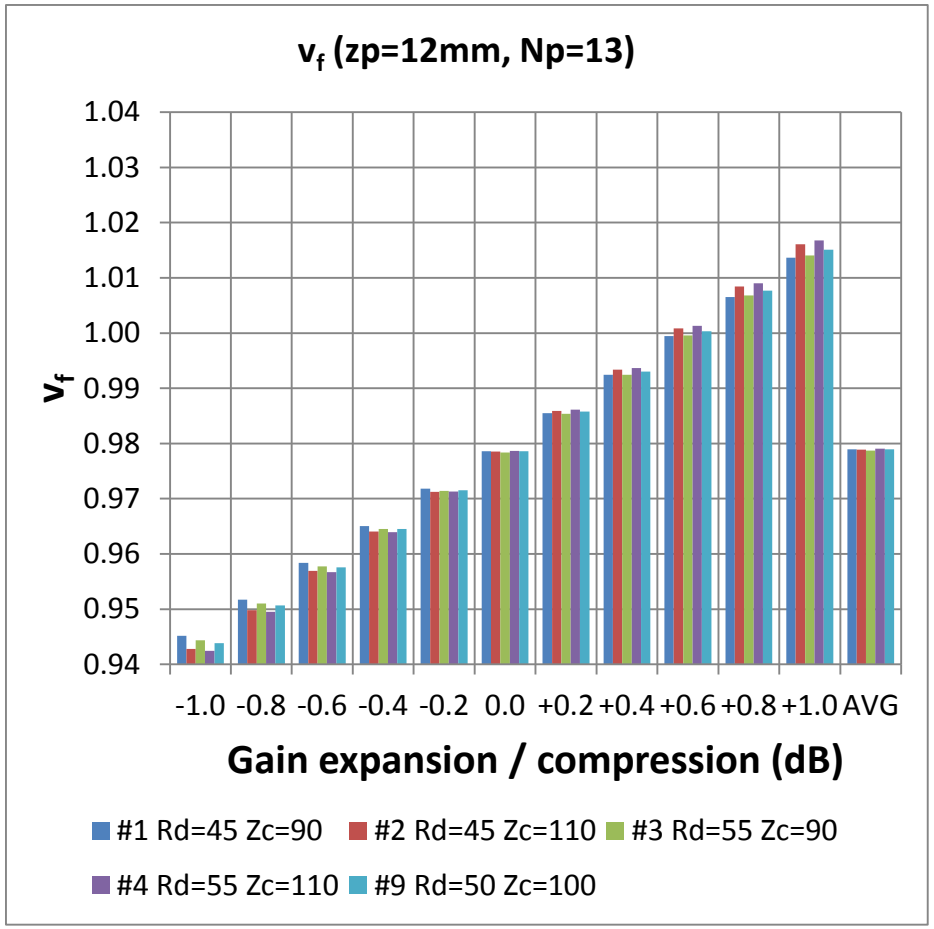
Linear Fit Pulse Peak p_{max} (Dp=2, Np=200)											
Case		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
zp		12				30				12	30
Rd		45		55		45		55		50	50
Zc		90	110	90	110	90	110	90	110	100	100
Gain expansion / compression (dB)	-1.0	0.7737	0.7629	0.7655	0.7619	0.6998	0.6915	0.6928	0.6906	0.7678	0.6956
	-0.8	0.7797	0.7692	0.7716	0.7683	0.7061	0.6978	0.6991	0.6970	0.7740	0.7019
	-0.6	0.7857	0.7756	0.7777	0.7748	0.7124	0.7043	0.7055	0.7035	0.7803	0.7083
	-0.4	0.7918	0.7821	0.7839	0.7814	0.7189	0.7108	0.7120	0.7101	0.7866	0.7147
	-0.2	0.7980	0.7886	0.7902	0.7880	0.7253	0.7173	0.7185	0.7167	0.7930	0.7212
	0.0	0.8042	0.7952	0.7965	0.7947	0.7319	0.7240	0.7251	0.7234	0.7994	0.7278
	0.2	0.8105	0.8018	0.8029	0.8015	0.7385	0.7307	0.7318	0.7302	0.8059	0.7345
	0.4	0.8168	0.8085	0.8093	0.8083	0.7452	0.7375	0.7385	0.7370	0.8125	0.7412
	0.6	0.8232	0.8153	0.8158	0.8152	0.7519	0.7443	0.7453	0.7439	0.8191	0.7480
	0.8	0.8296	0.8221	0.8224	0.8222	0.7588	0.7512	0.7522	0.7509	0.8258	0.7549
	1.0	0.8361	0.8290	0.8290	0.8292	0.7657	0.7582	0.7592	0.7580	0.8325	0.7618
Average		0.8045	0.7955	0.7968	0.7951	0.7322	0.7243	0.7254	0.7238	0.7997	0.7282

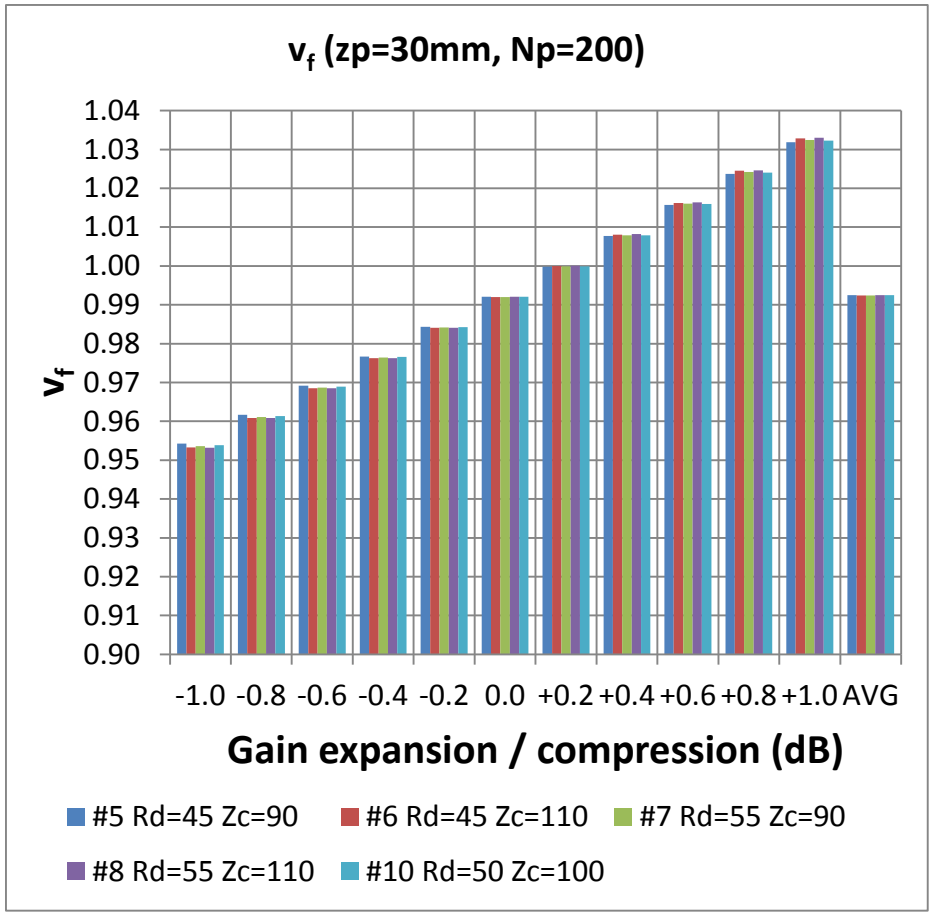
Linear Fit Pulse Peak p_{max} (Dp=2, Np=13)											
Case		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
zp		12				30				12	30
Rd		45		55		45		55		50	50
Zc		90	110	90	110	90	110	90	110	100	100
Gain expansion / compression (dB)	-1.0	0.7737	0.7629	0.7655	0.7619	0.6998	0.6915	0.6927	0.6906	0.7678	0.6955
	-0.8	0.7797	0.7692	0.7716	0.7683	0.7061	0.6978	0.6991	0.6970	0.7740	0.7019
	-0.6	0.7857	0.7756	0.7777	0.7748	0.7124	0.7043	0.7055	0.7035	0.7803	0.7082
	-0.4	0.7918	0.7821	0.7839	0.7814	0.7189	0.7108	0.7119	0.7101	0.7866	0.7147
	-0.2	0.7980	0.7886	0.7902	0.7880	0.7253	0.7173	0.7185	0.7167	0.7930	0.7212
	0.0	0.8042	0.7952	0.7965	0.7947	0.7319	0.7240	0.7251	0.7234	0.7994	0.7278
	0.2	0.8104	0.8018	0.8029	0.8015	0.7385	0.7307	0.7318	0.7302	0.8059	0.7345
	0.4	0.8168	0.8085	0.8093	0.8083	0.7452	0.7375	0.7385	0.7370	0.8125	0.7412
	0.6	0.8232	0.8153	0.8158	0.8152	0.7519	0.7443	0.7453	0.7439	0.8191	0.7480
	0.8	0.8296	0.8221	0.8224	0.8222	0.7588	0.7512	0.7522	0.7509	0.8258	0.7549
	1.0	0.8361	0.8290	0.8290	0.8292	0.7657	0.7582	0.7592	0.7580	0.8325	0.7618
Average		0.8045	0.7955	0.7968	0.7951	0.7322	0.7243	0.7254	0.7237	0.7997	0.7281

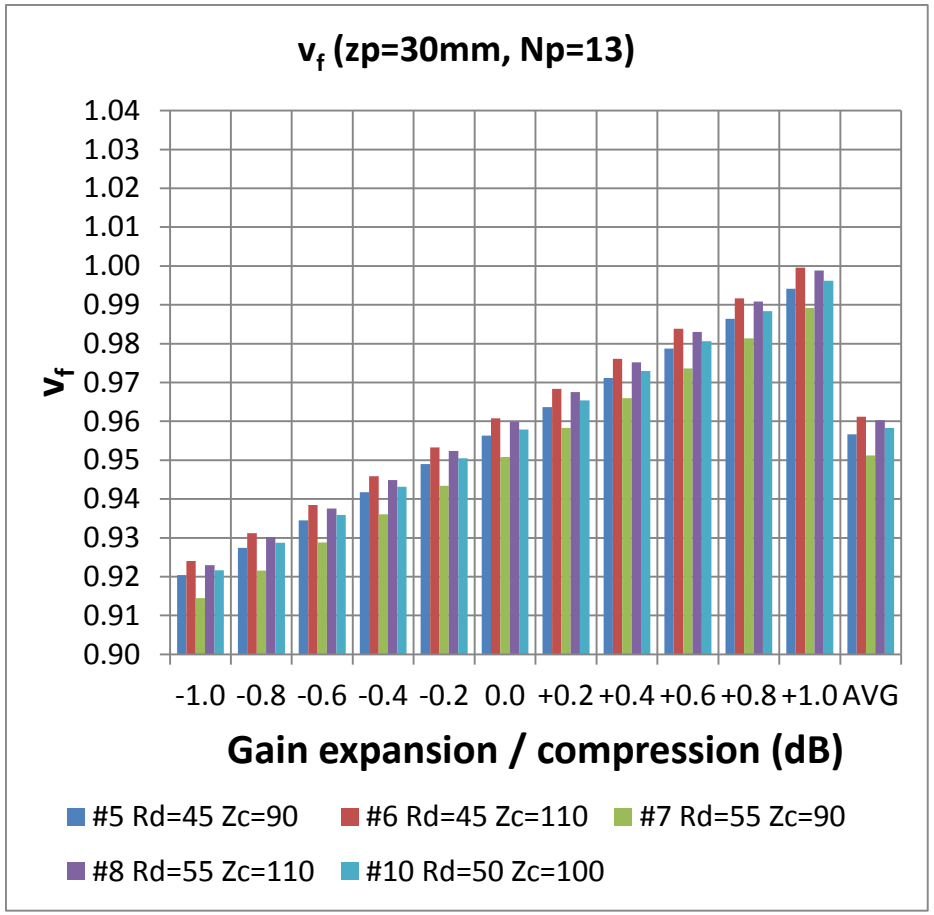
Result of v_f (zp=12mm)





Result of v_f (zp=30mm)





Result Table for v_f

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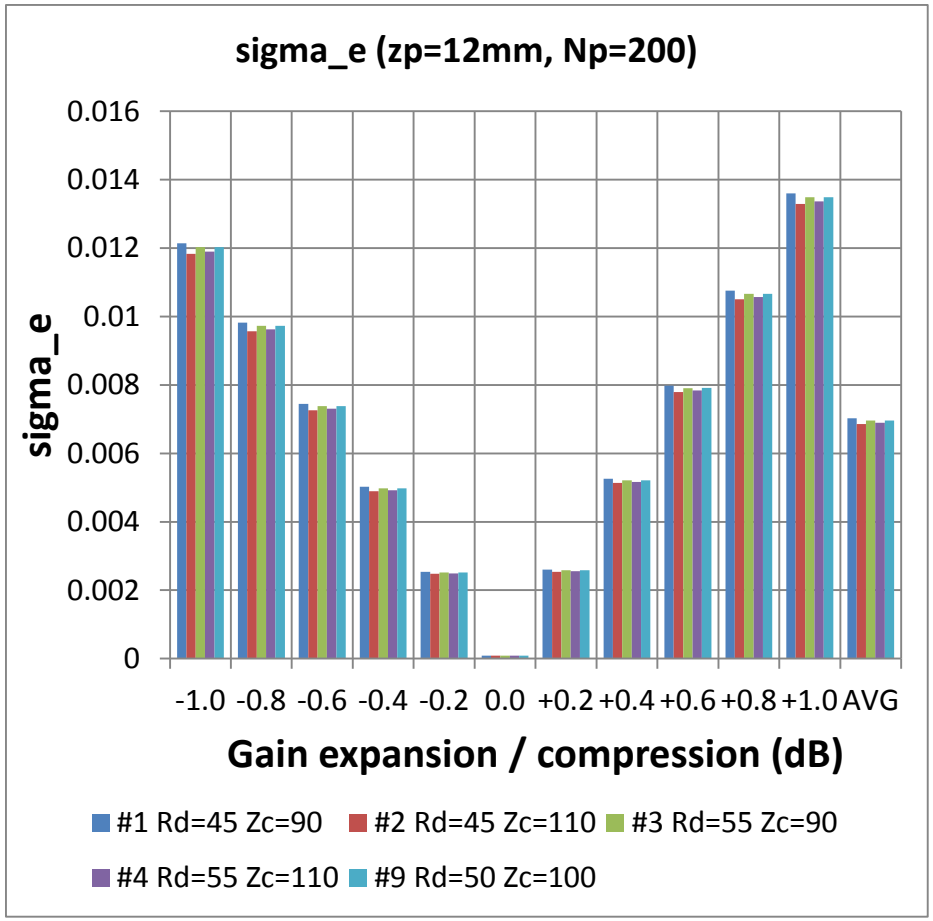
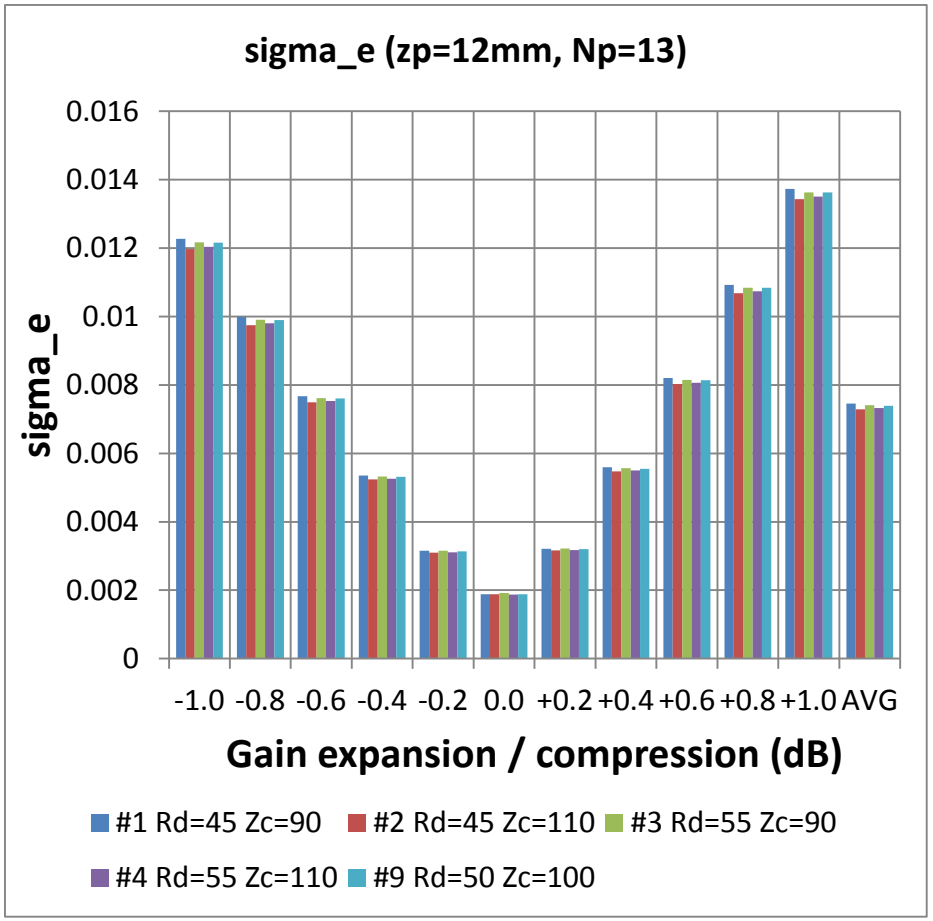
Steady-State Voltage v_f (Dp=2, Np=200)											
Case		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
zp		12				30				12	30
Rd		45		55		45		55		50	50
Zc		90	110	90	110	90	110	90	110	100	100
Gain expansion / compression (dB)	-1.0	0.9610	0.9587	0.9603	0.9582	0.9543	0.9533	0.9536	0.9532	0.9597	0.9539
	-0.8	0.9678	0.9659	0.9673	0.9655	0.9617	0.9608	0.9611	0.9608	0.9667	0.9614
	-0.6	0.9747	0.9733	0.9743	0.9730	0.9692	0.9685	0.9687	0.9685	0.9739	0.9689
	-0.4	0.9816	0.9807	0.9813	0.9805	0.9767	0.9763	0.9764	0.9763	0.9811	0.9765
	-0.2	0.9886	0.9881	0.9885	0.9881	0.9843	0.9841	0.9841	0.9841	0.9884	0.9843
	0.0	0.9957	0.9957	0.9957	0.9957	0.9921	0.9920	0.9920	0.9921	0.9957	0.9921
	0.2	1.0028	1.0033	1.0030	1.0034	0.9999	1.0000	0.9999	1.0001	1.0031	0.9999
	0.4	1.0101	1.0110	1.0103	1.0112	1.0077	1.0081	1.0079	1.0082	1.0106	1.0079
	0.6	1.0173	1.0188	1.0177	1.0191	1.0157	1.0162	1.0160	1.0164	1.0182	1.0159
	0.8	1.0247	1.0266	1.0252	1.0271	1.0237	1.0245	1.0242	1.0246	1.0258	1.0241
	1.0	1.0321	1.0345	1.0328	1.0351	1.0318	1.0328	1.0324	1.0330	1.0335	1.0323
Average		0.9960	0.9961	0.9960	0.9961	0.9925	0.9924	0.9924	0.9925	0.9961	0.9925

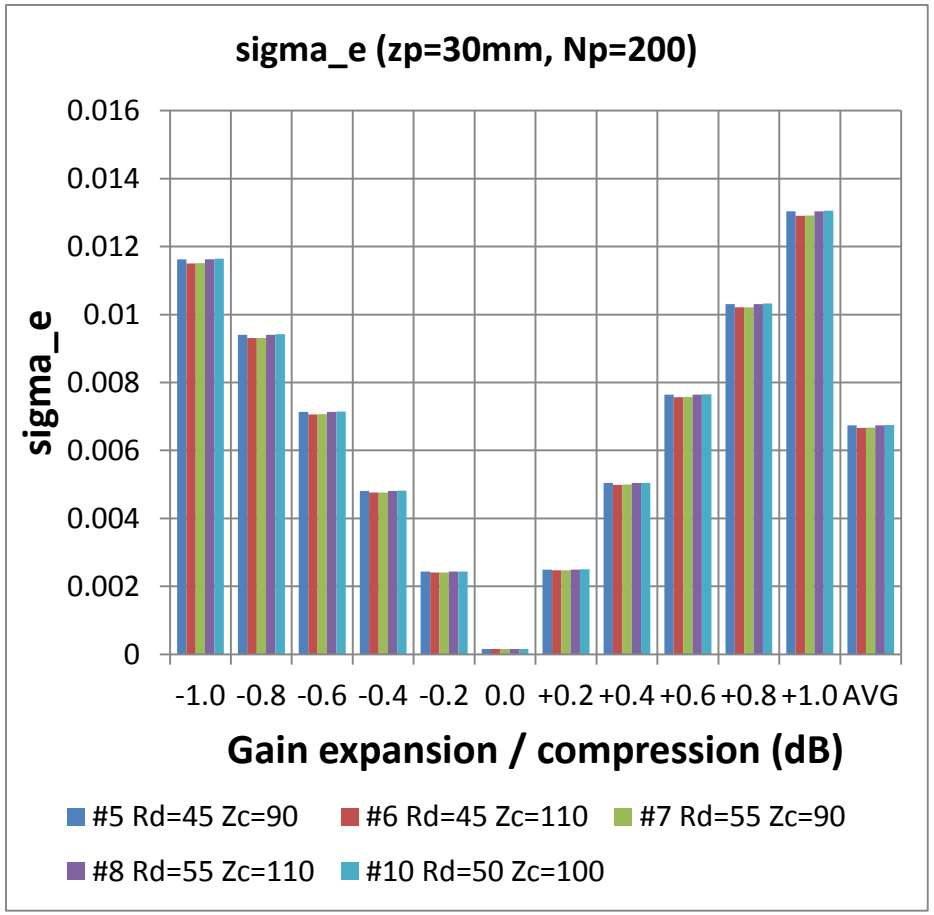
Steady-State Voltage v_f (Dp=2, Np=13)											
Case		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
zp		12				30				12	30
Rd		45		55		45		55		50	50
Zc		90	110	90	110	90	110	90	110	100	100
Gain expansion / compression (dB)	-1.0	0.9452	0.9428	0.9443	0.9424	0.9204	0.9240	0.9145	0.9230	0.9439	0.9217
	-0.8	0.9517	0.9498	0.9510	0.9495	0.9274	0.9312	0.9216	0.9302	0.9507	0.9288
	-0.6	0.9584	0.9569	0.9577	0.9567	0.9345	0.9385	0.9288	0.9375	0.9576	0.9359
	-0.4	0.9650	0.9640	0.9645	0.9640	0.9417	0.9458	0.9361	0.9449	0.9645	0.9432
	-0.2	0.9718	0.9713	0.9714	0.9713	0.9490	0.9533	0.9434	0.9523	0.9715	0.9505
	0.0	0.9786	0.9786	0.9784	0.9787	0.9563	0.9608	0.9508	0.9599	0.9786	0.9579
	0.2	0.9855	0.9859	0.9854	0.9861	0.9637	0.9684	0.9583	0.9675	0.9858	0.9654
	0.4	0.9924	0.9934	0.9924	0.9937	0.9712	0.9761	0.9659	0.9752	0.9930	0.9730
	0.6	0.9994	1.0009	0.9996	1.0013	0.9788	0.9838	0.9736	0.9830	1.0003	0.9806
	0.8	1.0065	1.0084	1.0068	1.0090	0.9864	0.9917	0.9813	0.9909	1.0077	0.9883
	1.0	1.0137	1.0161	1.0141	1.0168	0.9941	0.9996	0.9892	0.9988	1.0151	0.9962
Average		0.9789	0.9789	0.9787	0.9790	0.9567	0.9612	0.9512	0.9603	0.9790	0.9583

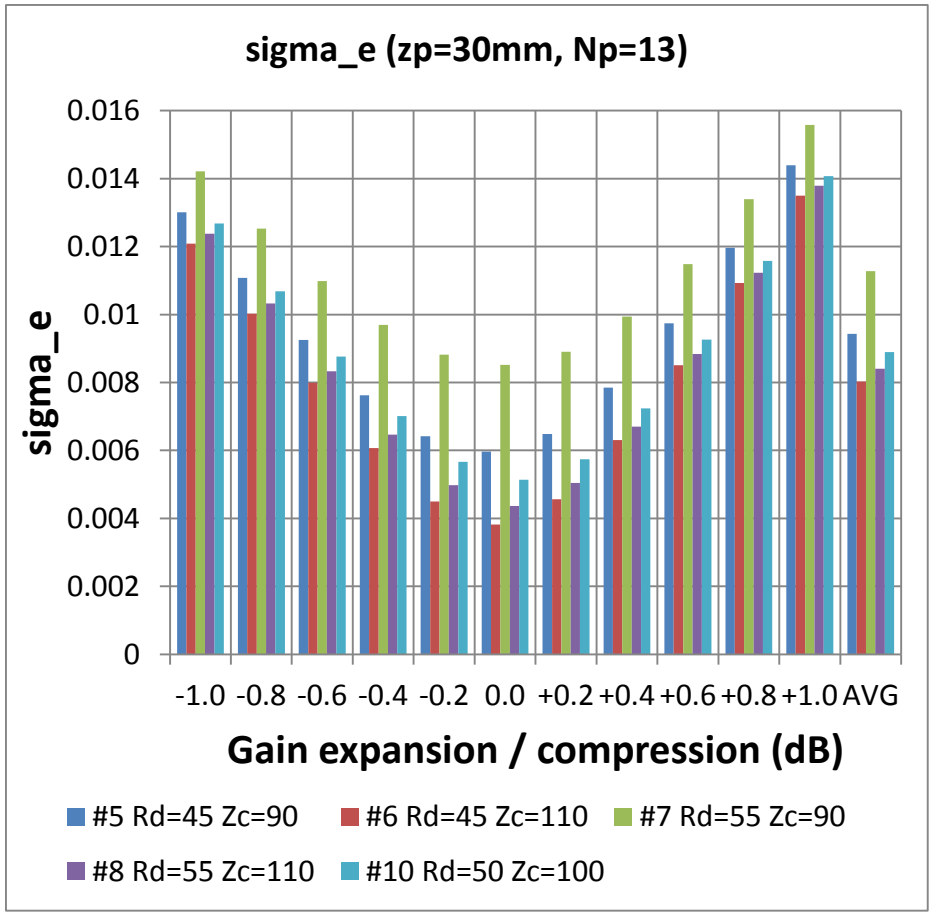
Result of σ_e (zp=12mm)





Result of σ_e (zp=30mm)





Result Table for σ_e

FUJITSU

sigma_e (Dp=2, Np=200)											
Case		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
zp		12				30				12	30
Rd		45		55		45		55		50	50
Zc		90	110	90	110	90	110	90	110	100	100
Gain expansion / compression (dB)	-1.0	1.21E-02	1.18E-02	1.20E-02	1.19E-02	1.16E-02	1.15E-02	1.15E-02	1.16E-02	1.20E-02	1.16E-02
	-0.8	9.82E-03	9.57E-03	9.73E-03	9.63E-03	9.40E-03	9.31E-03	9.31E-03	9.40E-03	9.73E-03	9.42E-03
	-0.6	7.45E-03	7.26E-03	7.38E-03	7.30E-03	7.13E-03	7.06E-03	7.06E-03	7.13E-03	7.38E-03	7.14E-03
	-0.4	5.02E-03	4.90E-03	4.98E-03	4.93E-03	4.81E-03	4.76E-03	4.76E-03	4.81E-03	4.98E-03	4.82E-03
	-0.2	2.54E-03	2.48E-03	2.52E-03	2.49E-03	2.43E-03	2.41E-03	2.41E-03	2.43E-03	2.52E-03	2.44E-03
	0.0	8.56E-05	8.61E-05	8.62E-05	8.56E-05	1.54E-04	1.56E-04	1.56E-04	1.54E-04	8.56E-05	1.54E-04
	0.2	2.60E-03	2.54E-03	2.58E-03	2.55E-03	2.50E-03	2.47E-03	2.47E-03	2.50E-03	2.58E-03	2.50E-03
	0.4	5.26E-03	5.13E-03	5.21E-03	5.16E-03	5.04E-03	4.99E-03	4.99E-03	5.04E-03	5.21E-03	5.05E-03
	0.6	7.98E-03	7.79E-03	7.91E-03	7.84E-03	7.64E-03	7.57E-03	7.57E-03	7.65E-03	7.91E-03	7.66E-03
	0.8	1.08E-02	1.05E-02	1.07E-02	1.06E-02	1.03E-02	1.02E-02	1.02E-02	1.03E-02	1.07E-02	1.03E-02
	1.0	1.36E-02	1.33E-02	1.35E-02	1.34E-02	1.30E-02	1.29E-02	1.29E-02	1.30E-02	1.35E-02	1.31E-02
Average		7.02E-03	6.85E-03	6.96E-03	6.89E-03	6.73E-03	6.67E-03	6.67E-03	6.73E-03	6.96E-03	6.74E-03

sigma_e (Dp=2, Np=13)											
Case		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
zp		12				30				12	30
Rd		45		55		45		55		50	50
Zc		90	110	90	110	90	110	90	110	100	100
Gain expansion / compression (dB)	-1.0	1.23E-02	1.20E-02	1.22E-02	1.20E-02	1.30E-02	1.21E-02	1.42E-02	1.24E-02	1.22E-02	1.27E-02
	-0.8	9.99E-03	9.75E-03	9.91E-03	9.80E-03	1.11E-02	1.00E-02	1.25E-02	1.03E-02	9.90E-03	1.07E-02
	-0.6	7.67E-03	7.49E-03	7.62E-03	7.53E-03	9.25E-03	7.99E-03	1.10E-02	8.33E-03	7.61E-03	8.76E-03
	-0.4	5.35E-03	5.24E-03	5.32E-03	5.26E-03	7.62E-03	6.07E-03	9.70E-03	6.47E-03	5.31E-03	7.01E-03
	-0.2	3.15E-03	3.10E-03	3.16E-03	3.11E-03	6.42E-03	4.49E-03	8.82E-03	4.98E-03	3.13E-03	5.67E-03
	0.0	1.88E-03	1.88E-03	1.92E-03	1.87E-03	5.97E-03	3.82E-03	8.52E-03	4.37E-03	1.88E-03	5.14E-03
	0.2	3.21E-03	3.17E-03	3.22E-03	3.17E-03	6.49E-03	4.56E-03	8.91E-03	5.05E-03	3.20E-03	5.74E-03
	0.4	5.59E-03	5.48E-03	5.56E-03	5.50E-03	7.85E-03	6.31E-03	9.94E-03	6.70E-03	5.55E-03	7.24E-03
	0.6	8.20E-03	8.02E-03	8.14E-03	8.06E-03	9.74E-03	8.51E-03	1.15E-02	8.84E-03	8.14E-03	9.26E-03
	0.8	1.09E-02	1.07E-02	1.08E-02	1.07E-02	1.20E-02	1.09E-02	1.34E-02	1.12E-02	1.08E-02	1.16E-02
	1.0	1.37E-02	1.34E-02	1.36E-02	1.35E-02	1.44E-02	1.35E-02	1.56E-02	1.38E-02	1.36E-02	1.41E-02
Average		7.45E-03	7.29E-03	7.41E-03	7.33E-03	9.43E-03	8.03E-03	1.13E-02	8.40E-03	7.39E-03	8.89E-03

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Thank you