VALUE BASED PRODUCT DEVELOPMENT

Power Bus Design Optimization Using PSPICE and Taguchi

by

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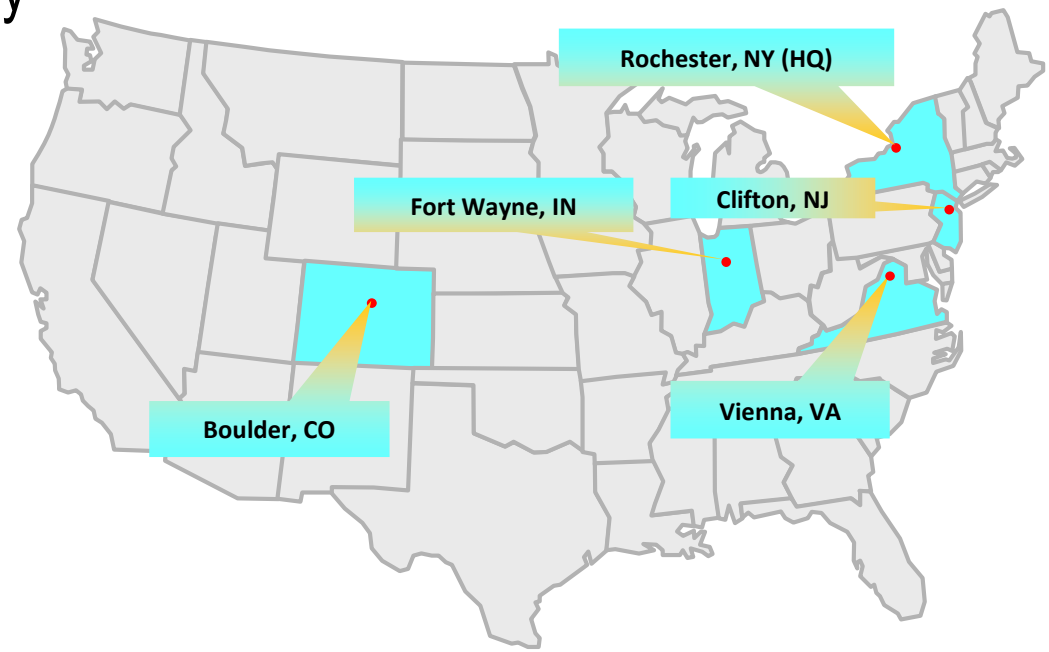
ITT Industries
Engineered for life

Introduction

- ITT Space Systems Division (SSD)
  - Rochester, New York
  - Fort Wayne, Indiana
  - Clifton, New Jersey
  - Boulder, Colorado
  - Vienna, Virginia
- 2,474 employees



Introduction

- Products
  - Intelligence, Surveillance and Reconnaissance (ISR)
  - Image Information
  - Space Science and Commercial Remote Sensing
  - Meteorological and Navigational Space Payloads

- Topic
  - Optimization process for power busses

Objectives and Benefits

Objectives

- Power Bus optimization using
  - Analysis of Means “ANOM” (Taguchi)
  - PSPICE running in a batch mode

Benefits

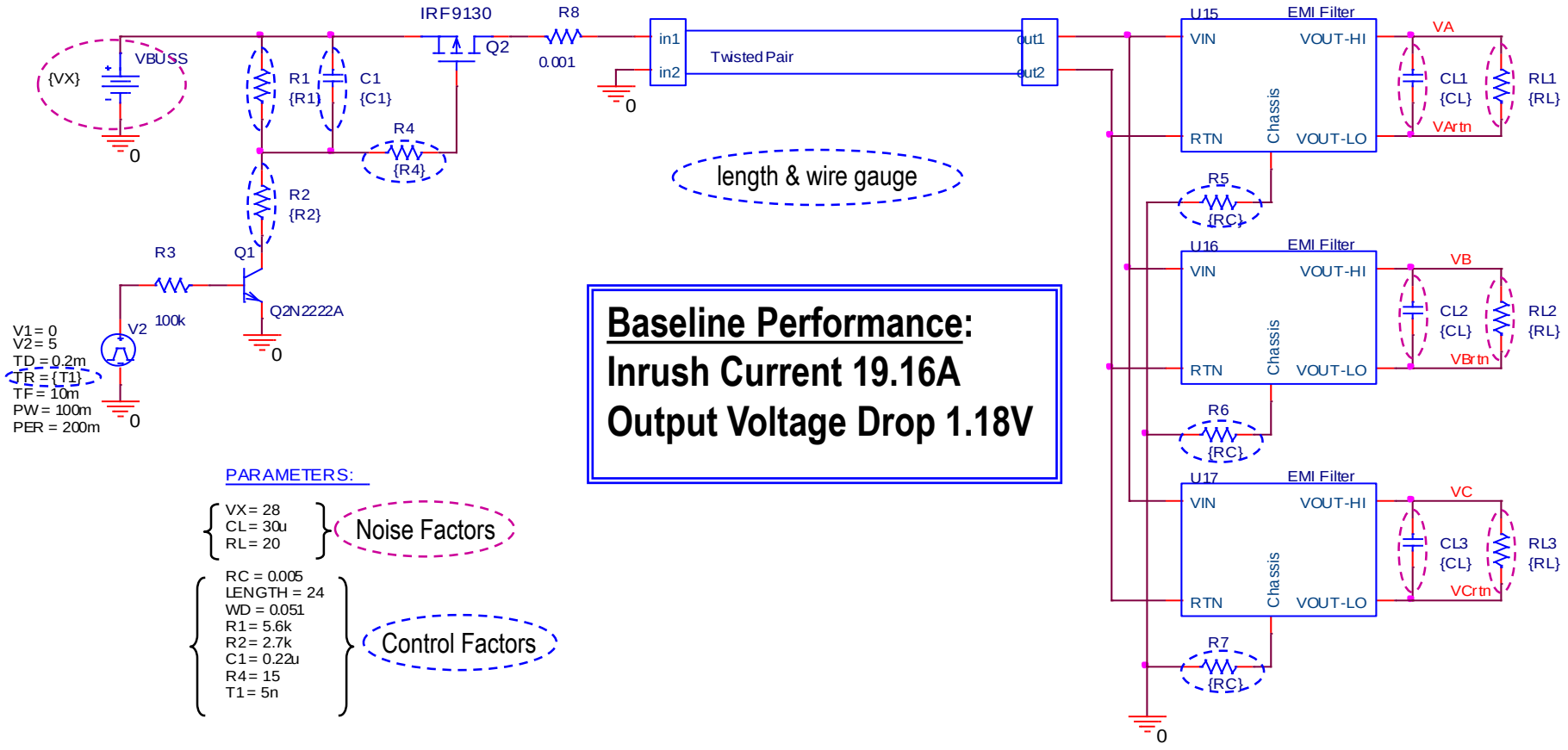
- Optimization ensures highest quality design for the customer
- Cost reduction by saving time

Approach

- Use Analysis of Means (ANOM)
  - L18 orthogonal array for eight control factors
  - L4 orthogonal array for three noise factors
  - Use the smaller-the-better signal to noise ratio
- Run simulations in a batch mode using PSPICE
- Perform confirmation runs to evaluate optimal solution

Example Power Bus

Minimize both inrush current and output voltage drop



Baseline Performance:
Inrush Current 19.16A
Output Voltage Drop 1.18V

PARAMETERS:

Noise Factors
- VX = 28
- CL = 30u
- RL = 20

Control Factors
- RC = 0.005
- LENGTH = 24
- WD = 0.051
- R1 = 5.6k
- R2 = 2.7k
- C1 = 0.22u
- R4 = 15
- T1 = 5n

Control and Noise Factors

Control Factors				
Symbol	**Description**	**Level 1**	**Level 2**	**Level 3**
A	Chassis Impedance (RC)	0.001 (ohms)	0.01 (ohms)	N/A
B	Cable Length (LENGTH)	12 (in.)	24 (in.)	36 (in.)
C	Cable Wire Diameter (WD)	0.04 (in.)	0.051 (in.)	0.064 (in.)
D	R1	4.7 K (ohms)	5.6 K (ohms)	6.8 K (ohms)
E	R2	1.8 K (ohms)	2.7 K (ohms)	3.9 K (ohms)
F	C1	0.10 μ (farads)	0.22 μ (farads)	0.056 μ (farads)
G	R4	10 (ohms)	15 (ohms)	22 (ohms)
H	T1 (Turn On Rise Time)	1 n (sec)	5 n (sec)	10 n (sec)

Noise Factors			
Symbol	**Description**	**Level 1**	**Level 2**
X	Vin (Bus Input Voltage)	22 (Volts)	34 (Volts)
Y	Load Resistance (RL)	30 (Ohms)	10 (Ohms)
Z	Load Capacitance (CL)	15 μ (farads)	47 μ (farads)

Experimental Layout

- Control Factor L18 OA
- Noise Factor L4 OA
- One experiment for inrush current
- One experiment for output voltage drop
- STB (Smaller the Better Optimization)

$$STB = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right]$$

Inrush Current

Noise Factor Array				
Z	L	H	H	L
Y	L	H	L	H
X	L	L	H	H

Control Factor Array												
Run	A	B	C	D	E	F	G	H	1	2	3	4
1	1	1	1	1	1	1	1	1				
2	1	1	2	2	2	2	2	2				
3	1	1	3	3	3	3	3	3				
4	1	2	1	1	2	2	3	3				
5	1	2	2	2	3	3	1	1				
6	1	2	3	3	1	1	2	2				
7	1	3	1	2	1	3	2	3				
8	1	3	2	3	2	1	3	1				
9	1	3	3	1	3	2	1	2				
10	2	1	1	3	3	2	2	1				
11	2	1	2	1	1	3	3	2				
12	2	1	3	2	2	1	1	3				
13	2	2	1	2	3	1	3	2				
14	2	2	2	3	1	2	1	3				
15	2	2	3	1	2	3	2	1				
16	2	3	1	3	2	3	1	2				
17	2	3	2	1	3	1	2	3				
18	2	3	3	2	1	2	3	1				

Smaller Best S/N Calculation: Inrush Current

$$STB = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right]$$

y_i = each value determined for each run
n = 4 (four groups run for each of the 18 runs)

Inrush Current									Noise Factor Array					
								Z	L	H	H	L		
								Y	L	H	L	H		
								X	L	L	H	H		
Control Factor Array														
Run	A	B	C	D	E	F	G	H	1	2	3	4	S/N	Mean
1	1	1	1	1	1	1	1	1	19.61	22.37	38.33	21.91	-28.50	25.6
2	1	1	2	2	2	2	2	2	12.36	14.33	28.30	14.94	-25.38	17.5
3	1	1	3	3	3	3	3	3	17.63	20.75	39.58	26.40	-28.76	26.1
4	1	2	1	1	2	2	3	3	11.95	13.66	27.36	14.40	-25.07	16.8
5	1	2	2	2	3	3	1	1	16.79	19.65	38.35	25.32	-28.42	25.0
6	1	2	3	3	1	1	2	2	20.38	22.92	39.84	23.04	-28.83	26.5
7	1	3	1	2	1	3	2	3	23.02	29.38	46.35	29.25	-30.41	32.0
8	1	3	2	3	2	1	3	1	16.87	20.22	38.22	21.75	-28.17	24.3
9	1	3	3	1	3	2	1	2	9.55	10.40	24.37	12.90	-23.80	14.3
10	2	1	1	3	3	2	2	1	10.27	11.60	25.81	13.65	-24.36	15.3
11	2	1	2	1	1	3	3	2	23.15	29.26	46.01	29.80	-30.41	32.1
12	2	1	3	2	2	1	1	3	16.62	20.11	38.00	21.56	-28.11	24.1
13	2	2	1	2	3	1	3	2	13.83	15.03	33.82	19.11	-26.83	20.4
14	2	2	2	3	1	2	1	3	14.81	17.31	29.38	16.02	-26.12	19.4
15	2	2	3	1	2	3	2	1	20.77	21.70	43.36	28.46	-29.53	28.6
16	2	3	1	3	2	3	1	2	21.46	23.62	45.23	28.84	-29.89	29.8
17	2	3	2	1	3	1	2	3	13.32	14.40	32.64	18.72	-26.53	19.8
18	2	3	3	2	1	2	3	1	14.61	16.95	29.03	15.66	-25.99	19.1
											Ave S/N =		-27.51	

Smaller Best S/N Calculation: Output Voltage Drop

$$STB = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right]$$

y_i = each value determined for each run
n = 4 (four groups run for each of the 18 runs)

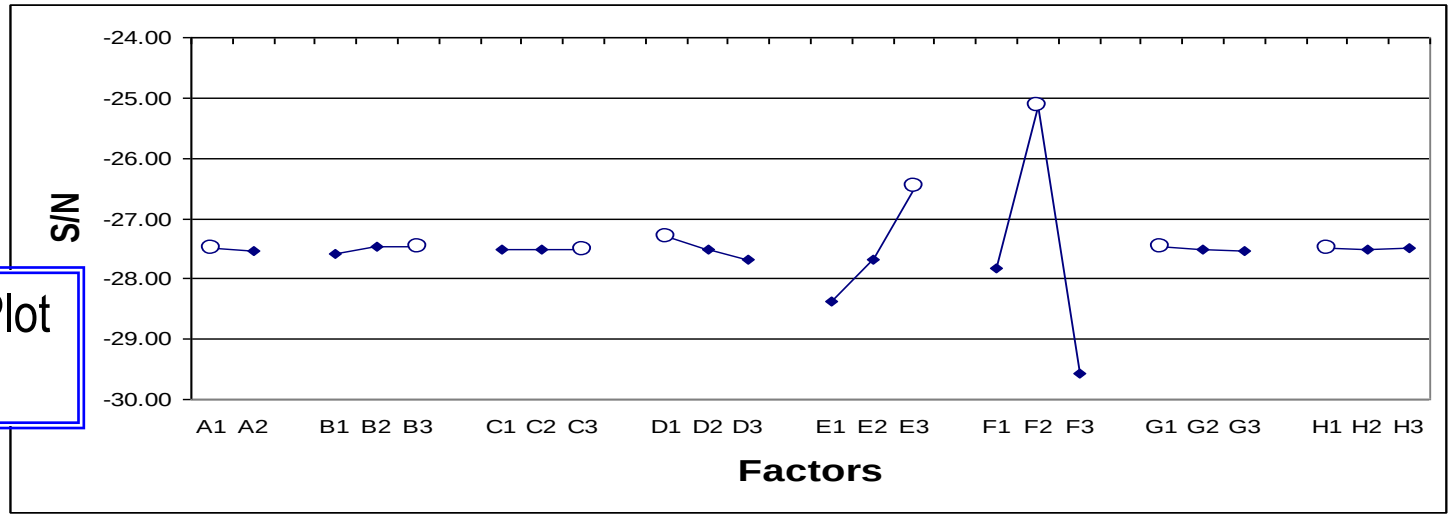
Output Voltage Drop

	Noise Factor Array			
Z	L	H	H	L
Y	L	H	L	H
X	L	L	H	H

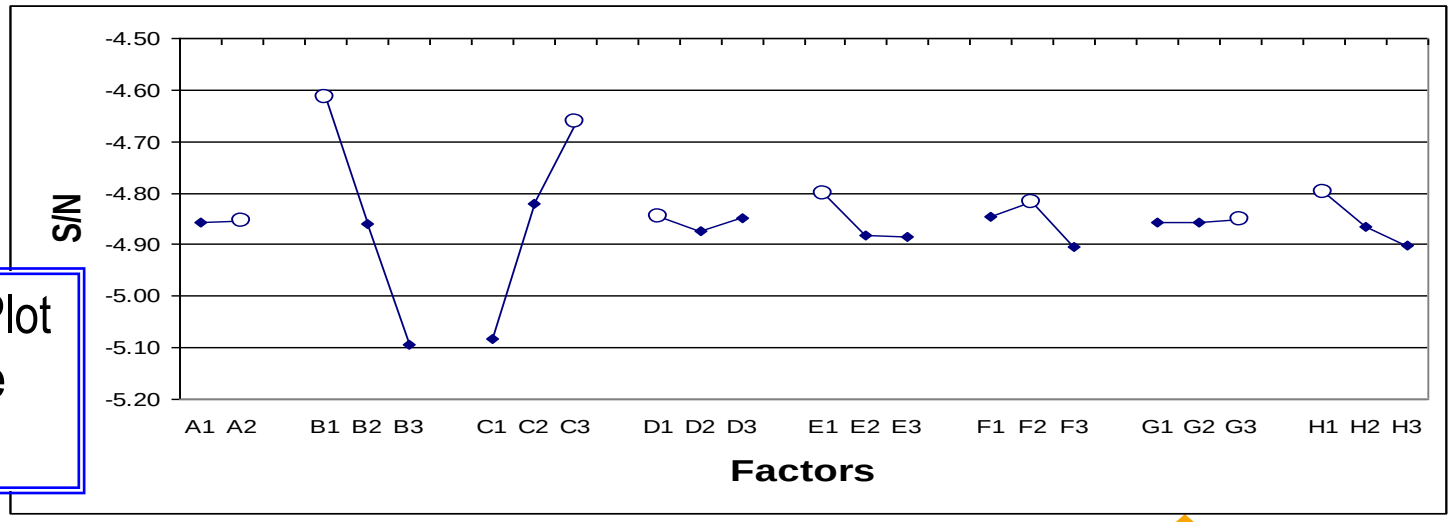
Control Factor Array														
Run	A	B	C	D	E	F	G	H	1	2	3	4	S/N	Mean
1	1	1	1	1	1	1	1	1	0.63	1.78	0.95	2.71	-4.71	1.52
2	1	1	2	2	2	2	2	2	0.62	1.76	0.94	2.68	-4.60	1.50
3	1	1	3	3	3	3	3	3	0.61	1.75	0.93	2.65	-4.53	1.49
4	1	2	1	1	2	2	3	3	0.66	1.87	1.00	2.84	-5.11	1.59
5	1	2	2	2	3	3	1	1	0.64	1.82	0.97	2.76	-4.87	1.55
6	1	2	3	3	1	1	2	2	0.62	1.76	0.94	2.68	-4.61	1.50
7	1	3	1	2	1	3	2	3	0.68	1.92	1.04	2.93	-5.38	1.64
8	1	3	2	3	2	1	3	1	0.65	1.84	0.99	2.81	-5.01	1.57
9	1	3	3	1	3	2	1	2	0.64	1.83	0.97	2.76	-4.89	1.55
10	2	1	1	3	3	2	2	1	0.63	1.80	0.96	2.73	-4.77	1.53
11	2	1	2	1	1	3	3	2	0.62	1.75	0.94	2.67	-4.57	1.49
12	2	1	3	2	2	1	1	3	0.61	1.75	0.93	2.65	-4.51	1.48
13	2	2	1	2	3	1	3	2	0.66	1.88	1.00	2.84	-5.13	1.60
14	2	2	2	3	1	2	1	3	0.63	1.79	0.96	2.73	-4.77	1.53
15	2	2	3	1	2	3	2	1	0.63	1.78	0.95	2.70	-4.68	1.51
16	2	3	1	3	2	3	1	2	0.68	1.93	1.04	2.93	-5.40	1.64
17	2	3	2	1	3	1	2	3	0.66	1.88	1.00	2.83	-5.11	1.59
18	2	3	3	2	1	2	3	1	0.63	1.79	0.96	2.73	-4.76	1.53
											Ave S/N =		-4.86	

Factor Level Average Graphs (ANOM)

Factor Effect Plot
Inrush Current



Factor Effect Plot
Output Voltage
Drop



Confirmation Trials

- Build 3 simulation schematics for each of the noise factor settings
- Do comparison of inrush current and output voltage drop for best combination STB
- Record optimization results for combination STB, Current STB and Voltage STB

Noise Factor Array				
Z	L	H	H	L
Y	L	H	L	H
X	L	L	H	H

CL		15u	47u	47u	15u							
RL		30	10	30	10							
Vin		22V	22V	34V	34V							
	A1	B1	C3	D1	E3	F2	G1	H1				
STB	RC	Length	WD	R1	R2	C1	R4	T1				
	0.001	12	0.064	4.7K	3.9K	0.22	10	1n				
	A1	B3	C3	D1	E3	F2	G1	H1				
STB-I	RC	Length	WD	R1	R2	C1	R4	T1				
	0.001	36	0.064	4.7K	3.9K	0.22	10	1n				
	A2	B1	C3	D1	E1	F2	G3	H1				
STB-V	RC	Length	WD	R1	R2	C1	R4	T1				
	0.01	12	0.064	4.7K	1.8K	0.22	22	1n				

Confirmation Trial Results

- Largest S/N ratio for inrush current (-23.8dB) is Conf-I
- Largest S/N ratio for output voltage drop (-4.49dB) is Conf-V
- Best S/N compromise for inrush current (-23.83dB) and output voltage drop (-4.61dB) is Conf-Comb

inrush current

Conf-I	1	3	3	1	3	2	1	1	-23.80
9	1	3	3	1	3	2	1	2	-23.80
Conf-Comb	1	1	3	1	3	2	1	1	-23.83
10	2	1	1	3	3	2	2	1	-24.36
4	1	2	1	1	2	2	3	3	-25.07
2	1	1	2	2	2	2	2	2	-25.38
Conf-V	2	1	3	1	1	2	3	1	-25.90
18	2	3	3	2	1	2	3	1	-25.99
14	2	2	2	3	1	2	1	3	-26.12
17	2	3	2	1	3	1	2	3	-26.53
13	2	2	1	2	3	1	3	2	-26.83
12	2	1	3	2	2	1	1	3	-28.11
8	1	3	2	3	2	1	3	1	-28.17
5	1	2	2	2	3	3	1	1	-28.42
1	1	1	1	1	1	1	1	1	-28.50
3	1	1	3	3	3	3	3	3	-28.76
6	1	2	3	3	1	1	2	2	-28.83
15	2	2	3	1	2	3	2	1	-29.53
16	2	3	1	3	2	3	1	2	-29.89
11	2	1	2	1	1	3	3	2	-30.41
7	1	3	1	2	1	3	2	3	-30.41

-23.80dB = 14.3A
-23.83dB = 14.4A
-25.90dB = 18.8A

output voltage drop

Conf-V	2	1	3	1	1	2	3	1	-4.49
12	2	1	3	2	2	1	1	3	-4.51
3	1	1	3	3	3	3	3	3	-4.53
11	2	1	2	1	1	3	3	2	-4.57
2	1	1	2	2	2	2	2	2	-4.60
6	1	2	3	3	1	1	2	2	-4.61
Conf-Comb	1	1	3	1	3	2	1	1	-4.61
15	2	2	3	1	2	3	2	1	-4.68
1	1	1	1	1	1	1	1	1	-4.71
18	2	3	3	2	1	2	3	1	-4.76
14	2	2	2	3	1	2	1	3	-4.77
10	2	1	1	3	3	2	2	1	-4.77
5	1	2	2	2	3	3	1	1	-4.87
Conf-I	1	3	3	1	3	2	1	1	-4.89
9	1	3	3	1	3	2	1	2	-4.89
8	1	3	2	3	2	1	3	1	-5.01
4	1	2	1	1	2	2	3	3	-5.11
17	2	3	2	1	3	1	2	3	-5.11
13	2	2	1	2	3	1	3	2	-5.13
7	1	3	1	2	1	3	2	3	-5.38
16	2	3	1	3	2	3	1	2	-5.40

-4.49dB = 1.48V
-4.61dB = 1.50V
-4.89dB = 1.55V

Conclusions and Benefits

- Optimal power bus design in less time and reduced cost
- PSPICE in batch mode reduces simulation time and reduces cost
- ANOM determines optimal control factor settings for best design

Acknowledgements

- Thanks to
  - Eric Smith
  - George Adamczyk