Modeling of the Power Distribution for the CMS Tracker

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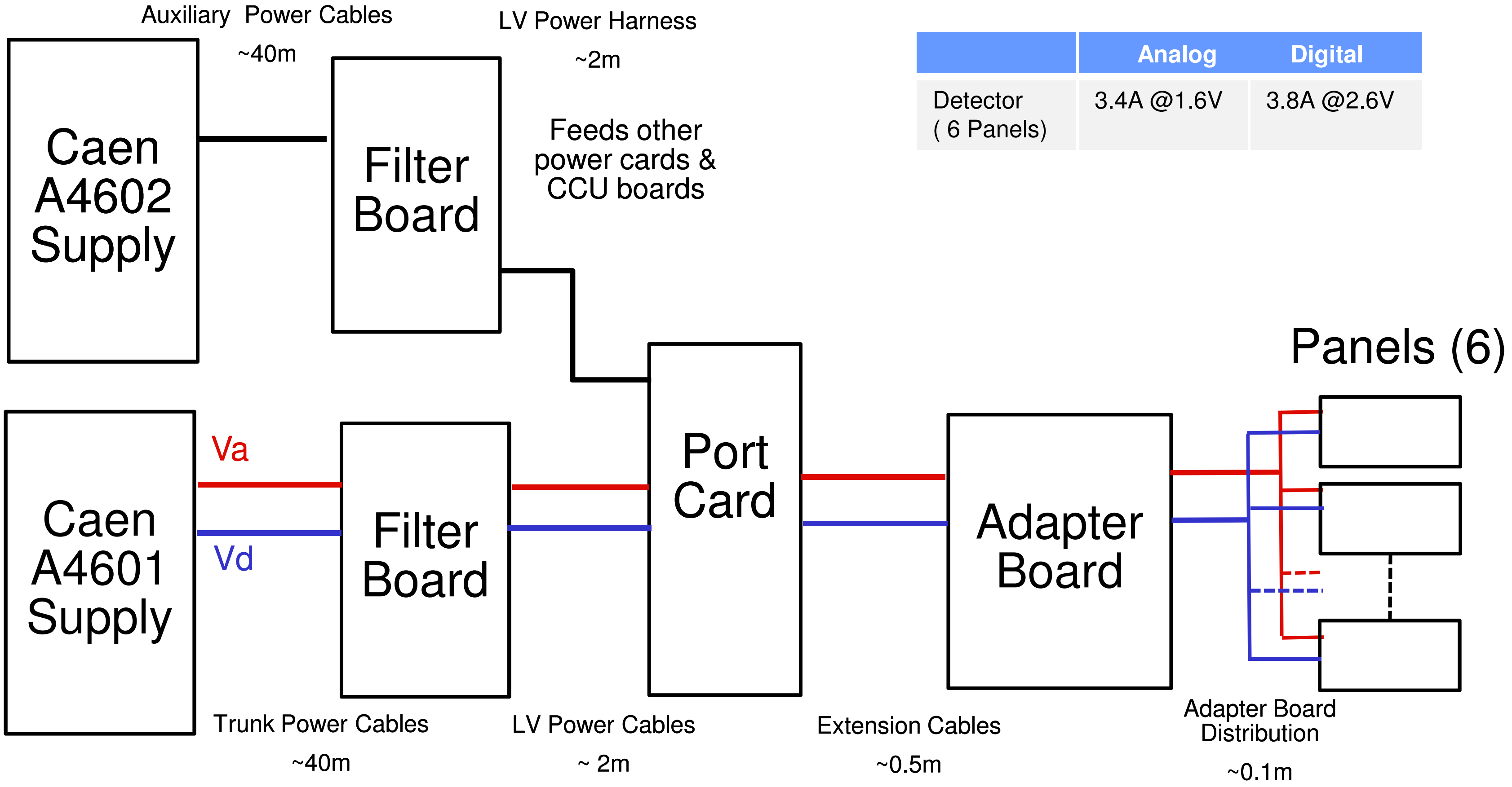
Outline

- Introduction & Motivation
- Global Power Distribution on Forward Pixel Tracker
  - Analysis of existing power network
  - DC-DC needs and requirements
- Simulation Platform for Power Network Analysis
  - Mathematical modeling aspects
  - Model based power network analysis
- Conclusions

Introduction

- Current Global Power Distribution for CMS FPIX Tracker

	Analog	Digital
Detector (6 Panels)	3.4A @1.6V	3.8A @2.6V



Auxiliary Power Cables
~40m

LV Power Harness
~2m

Caen A4602 Supply

Filter Board

Feeds other power cards & CCU boards

Caen A4601 Supply

Va

Vd

Filter Board

Port Card

Adapter Board

Panels (6)

Trunk Power Cables
~40m

LV Power Cables
~ 2m

Extension Cables
~0.5m

Adapter Board Distribution
~0.1m

Motivation

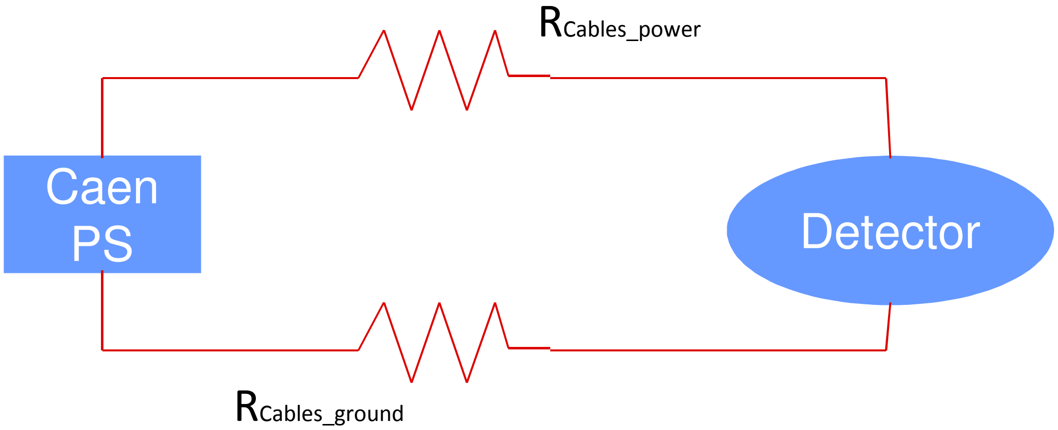
- Proposed Upgrades for CMS Tracker
- Constraints:
  - Use existing cables and power network
- Considerations:
  - Reduce the voltage drop on cables
  - Analog current is close to the limit current CAEN can supply
- DC-DC to facilitate power distribution for the upgrade
  - Reduce voltage drop on cable by supplying high *V* at low *I* from CAEN and perform step-down near the detector modules

	Analog	**Digital**
CAEN 4603 [1]		
Vconn	5.8V	7V
Imon	6A	13A
Vset	2.3V	3V
Power	125W	
Detector Module (224 ROCs)	5.6A @ 1.6V	8.6A @ 2.6V
Power Detector Module	8.96W	22.36W
Power Half Disk (4 Detector Modules)	35.84W	89.44W
	Half Disk = 125.28W	

[1] "A4603 CMS PIXEL Power Supply Module", April 2007.

Power Loss on the Network

- Power analysis with actual system's characteristics



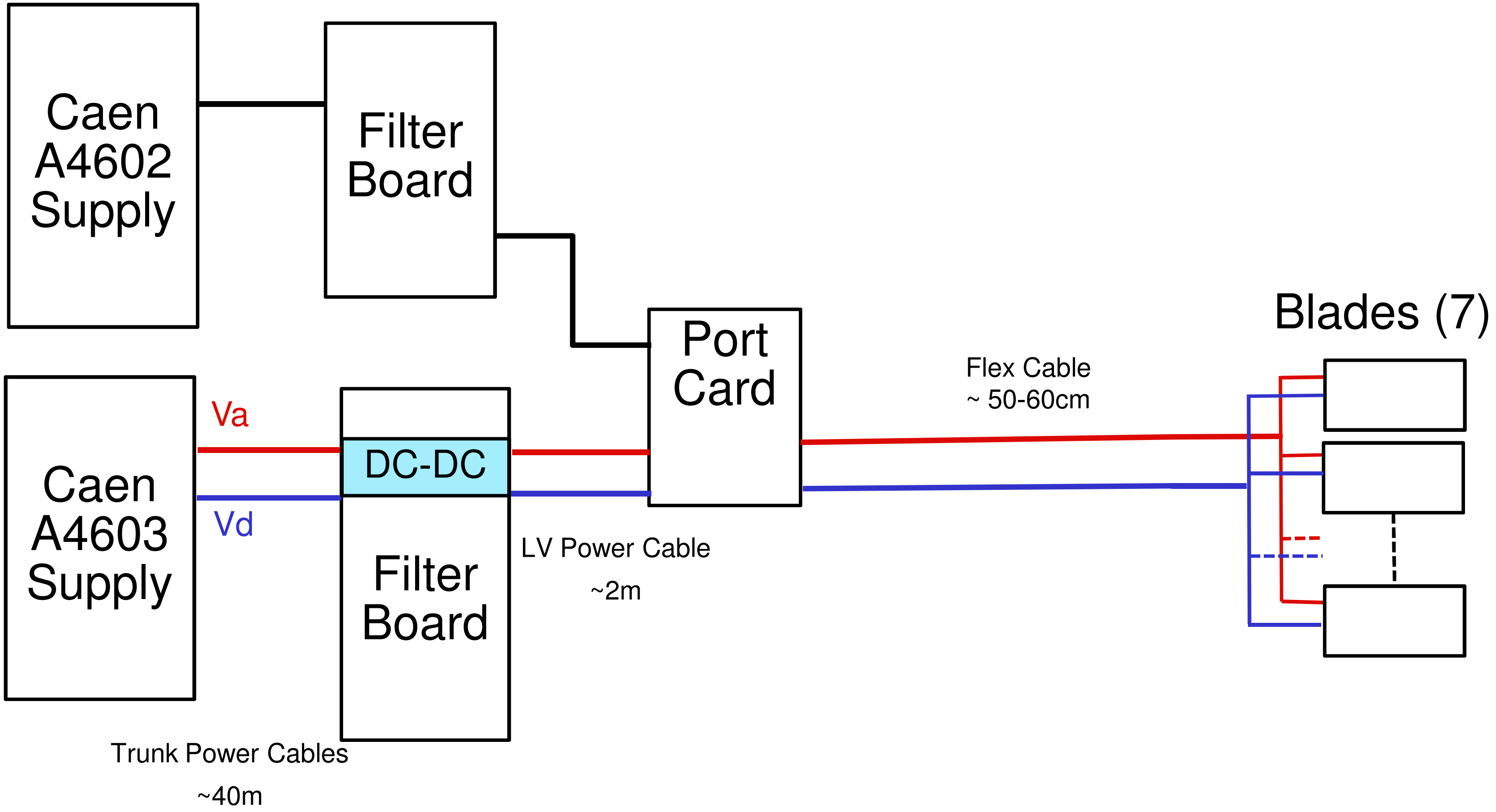
Parameters	Analog	Digital
R_{cables_power} [2]	0.301Ω	0.199Ω
R_{cables_ground} [2]	0.26Ω	0.157Ω
Detector	5.6A @1.6V	8.6A @2.6V

	Analog			Digital		
	Caen (channel)	Cables	Detector	Caen (channel)	Cables	Detector
Voltage	4.74V	3.14V drop	1.6V	5.65V	3.05V drop	2.6V
Power	26.54W	17.55W	8.96W	48.6W	26.2W	22.36W

Half Disk Power = 8.96Wx4 + 22.36Wx4 =125.28W

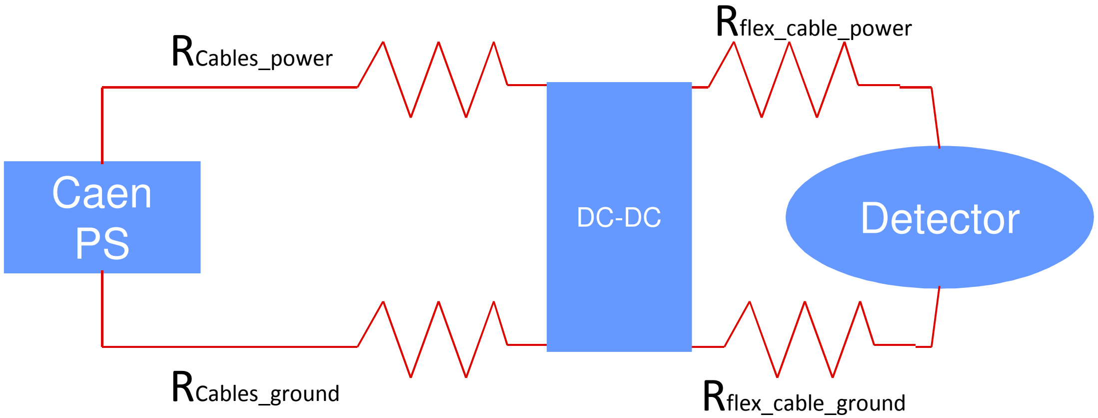
[2] S. Los, "Electrical Power Distribution", DocDB # 1022-v7

DC-DC Integration



DC-DC Integration

- Power analysis considering DC-DC integration



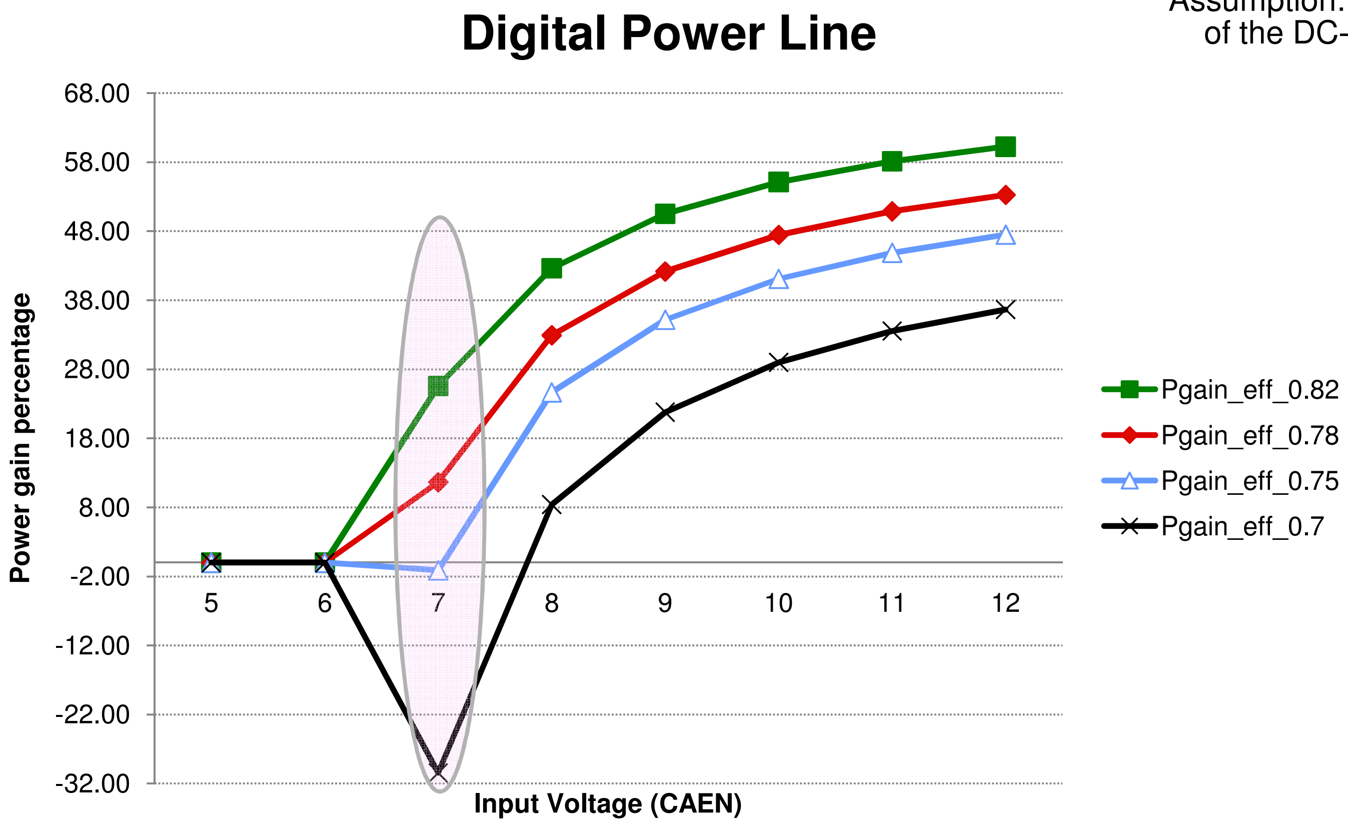
Parameters	Analog	Digital
R_{Cables_power} [2]	0.27Ω	0.168Ω
R_{Cables_ground} [2]	0.255Ω	0.153Ω
$R_{flex\_cable\_power}$ [3]	0.031Ω	0.031Ω
$R_{flex\_cable\_ground}$ [3]	0.004Ω	0.004Ω
Detector	5.6A @ 1.6V	8.6A @ 2.6V

	Analog		Digital	
	Flex Cable	Detector	Flex Cable	Detector
Voltage	0.2V drop	1.6V	0.3V drop	2.6V
Power	1.1W	8.96W	2.58W	22.36W
Pout_dc-dc	10W		24.95W	

[3] S. Los, “Pre Production Adapter Board Design Review”, CMSpix-doc-784

Power Estimations

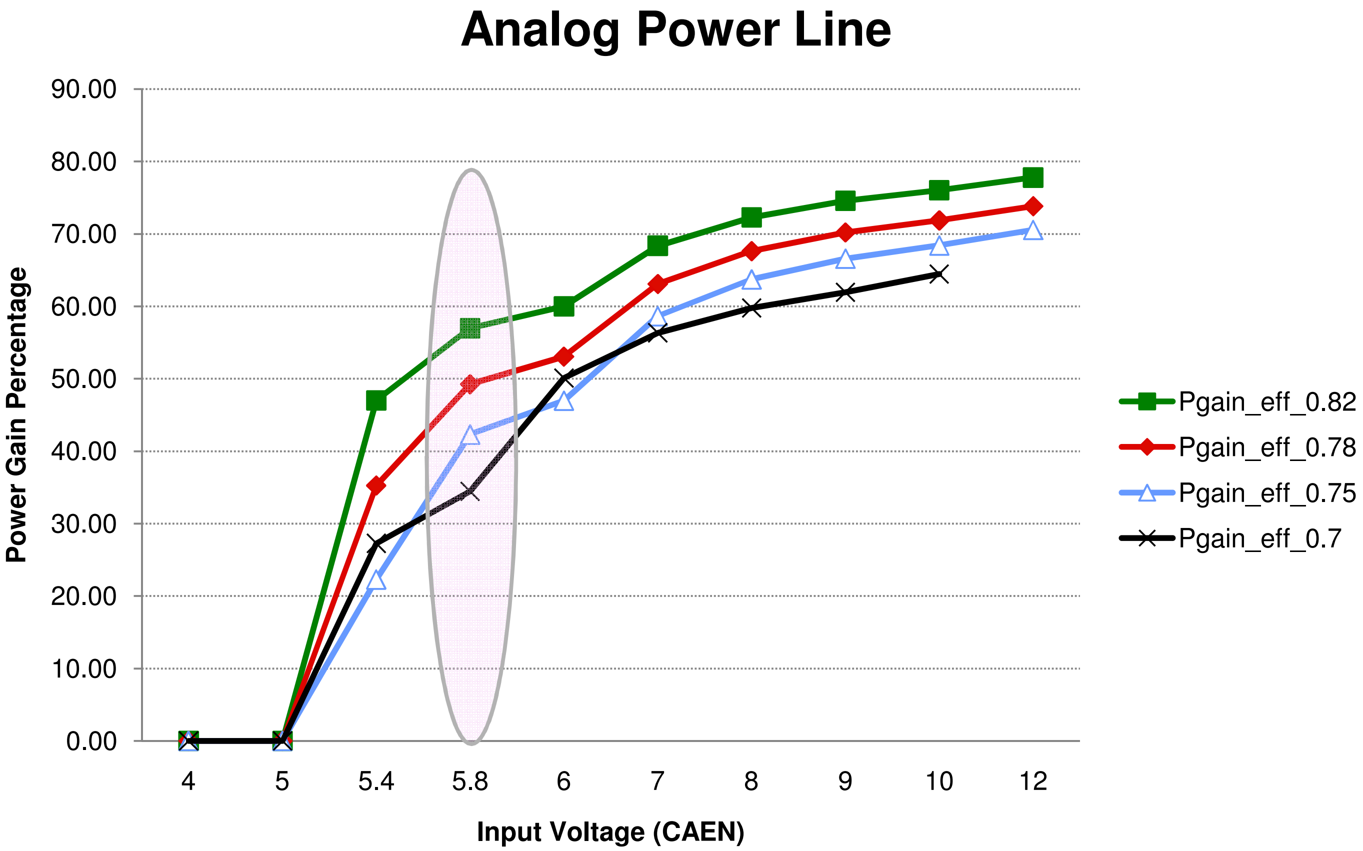
Assumption: Fixed efficiency
of the DC-DC converter



$$P_{gain}=(P_{cable\_loss\_no\_dc}-(P_{cable\_loss\_w\_dc}+P_{dc\_loss}))/P_{cable\_loss\_no\_dc}*100$$

Observation: The efficiency of the DC-DC converter should be > **0.78** for gain of **11.67%** given input voltage is **7V** (Caen digital channel).

Power Estimations

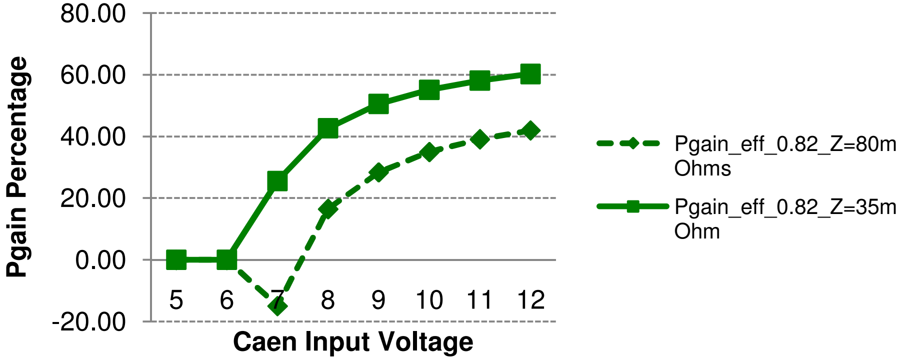


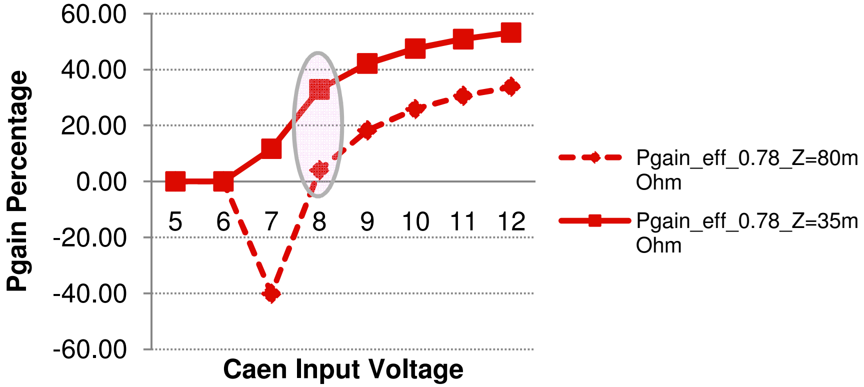
$P_{gain}=(P_{cable\_loss\_no\_dc}-(P_{cable\_loss\_w\_dc}+P_{dc\_loss}))/P_{cable\_loss\_no\_dc}*100$

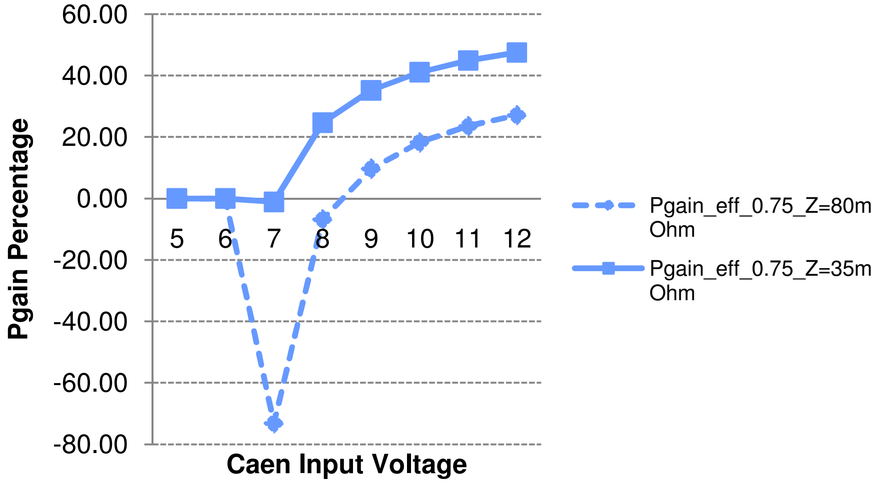
Observation: DC-DC converter of **0.78** efficiency has a gain of **49%** for input voltage of **5.8V** (Caen analog channel).

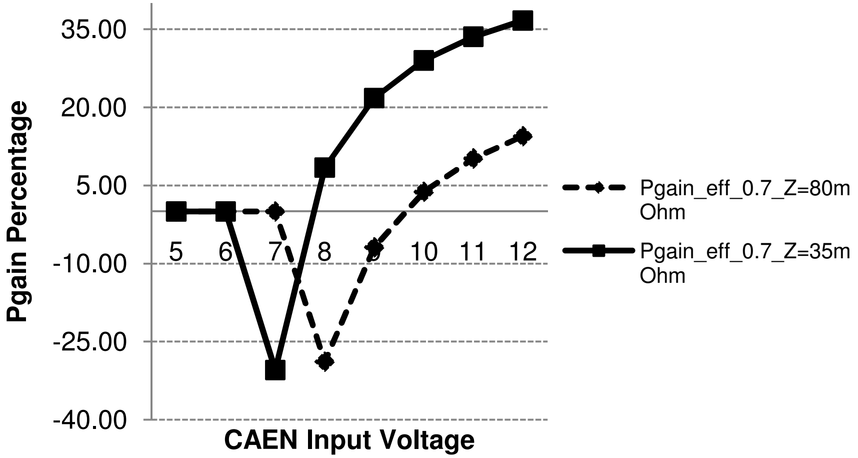
Impedance Impact

- Impact of impedance between DC-DC and detector module









Observation: Increase of Impedance between DC-DC and Detector would require a higher input voltage from CAEN channels.

Observations

- DC-DC integration requirements
  - Given that CAEN 4603 can supply (13A@7V & 6A@5.8V)
    - at least a minimum efficiency of 0.78 for DC-DC integration to be beneficial

  - Impedance between DC-DC and Detector has a significant impact on the efficiency of the DC-DC

  - If two DC-DC converters per Blade are used:
    - $I_{digital\_blade}$=32Rocs*30mA=0.96A (1 converter for digital)
    - I_{analog_blade}=32Rocs*20mA=0.64A (1 converter for analog)
    - Total of 336 Blades*2=672 DC-DC converters

  - DC-DC converter would have the following needs:
    - Input voltage range: Vin=3-6V
    - Output voltage: Va_out=1.8-2V and Vd_out=2.8-3.3V
    - Current drive: Iout=1-2A

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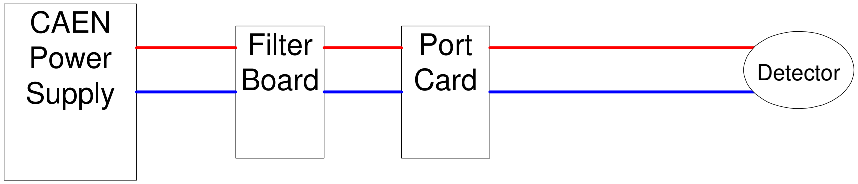
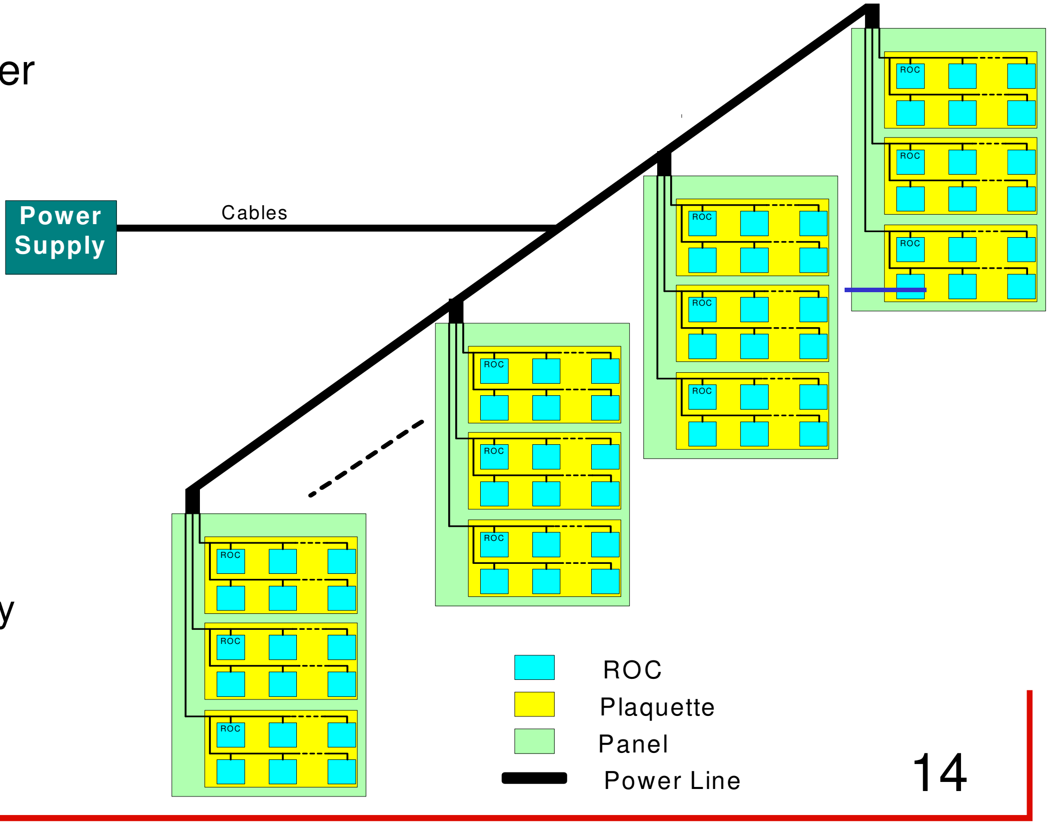
Motivation

- Develop an analysis platform to allow simulations for the CMS tracker power network distribution
- Emulate events for testing
  - Perform global level power analysis
  - Analyze implications of chip/system level changes
  - Ability to perform trade-off analysis for new design styles
- Simulate failure modes effects on the power network
  - Simulate various scenarios
- Fast and flexible simulation platform

Hierarchical Modeling

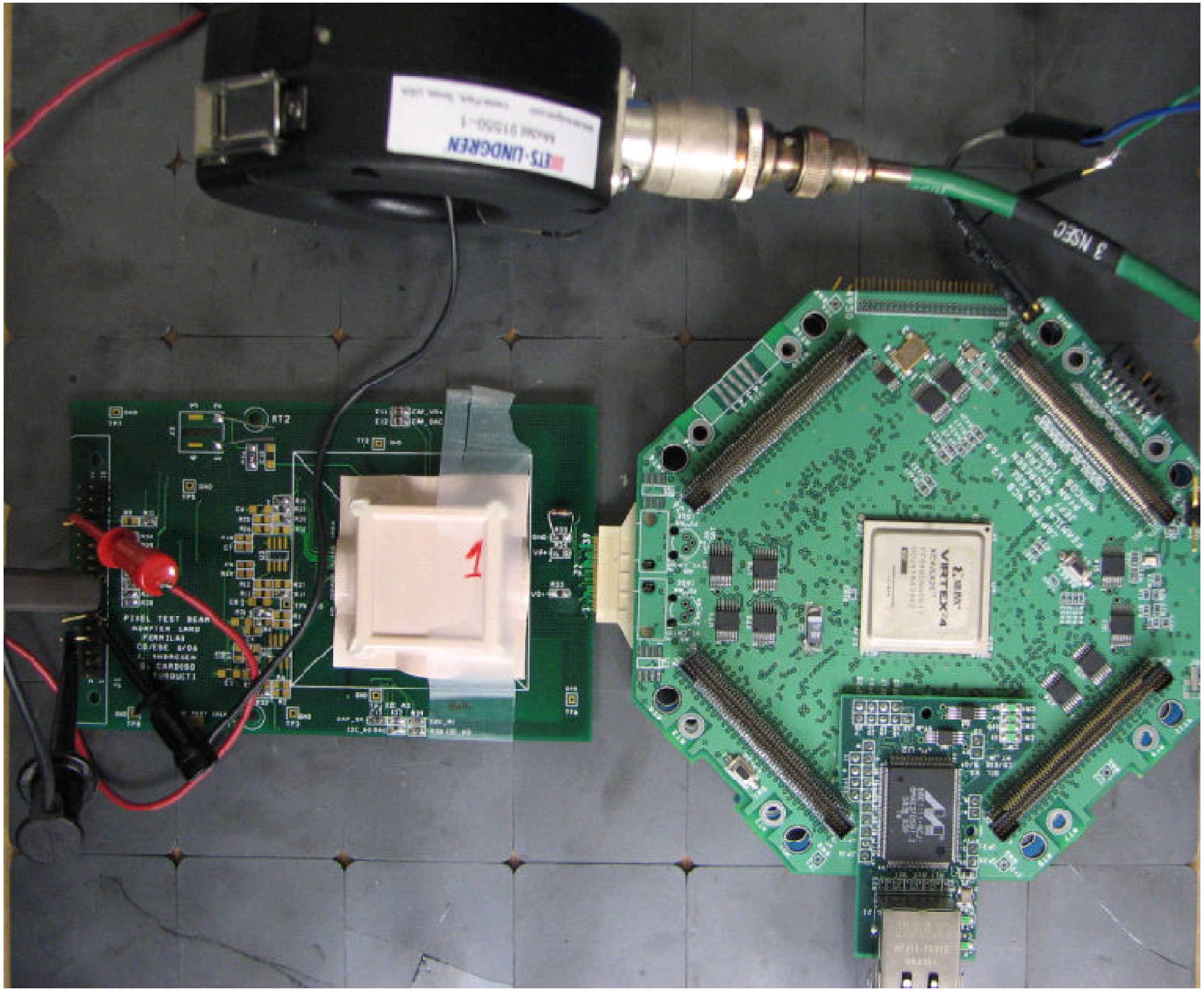
- FPIX used as an example for analysis
  - However models could be applied to other parts of the Tracker.
- Global Model
  - Capture DC characteristics and low frequency effects on the power network
  - Verify model varying parameters such as V_A, V_D, and Temp
- Local Model
  - Capture DC and transient effects on the power network
  - High frequency analysis is important part of the model
    - Obtained by varying parameters V_A, V_D and Temp and Occupancy
  - Failure modes testing at ROC, Plaquette and Blade level





Lab Setup

Power Lines



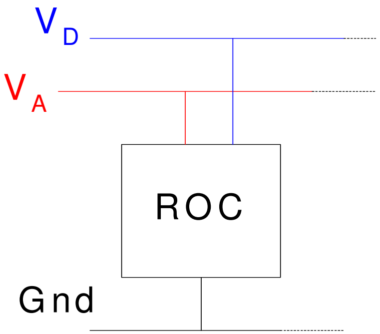
CAPTAN System

Model Characterization

- We have performed DC current measurements on a ROC for a given set of register values and DAC settings
- Objective: To build a model from experimental data

$$i_{ai} = f(V_{a_i}, V_{d_i}, Temp_i, Occ_i)$$

$$i_{di} = f(V_{a_i}, V_{d_i}, Temp_i, Occ_i)$$



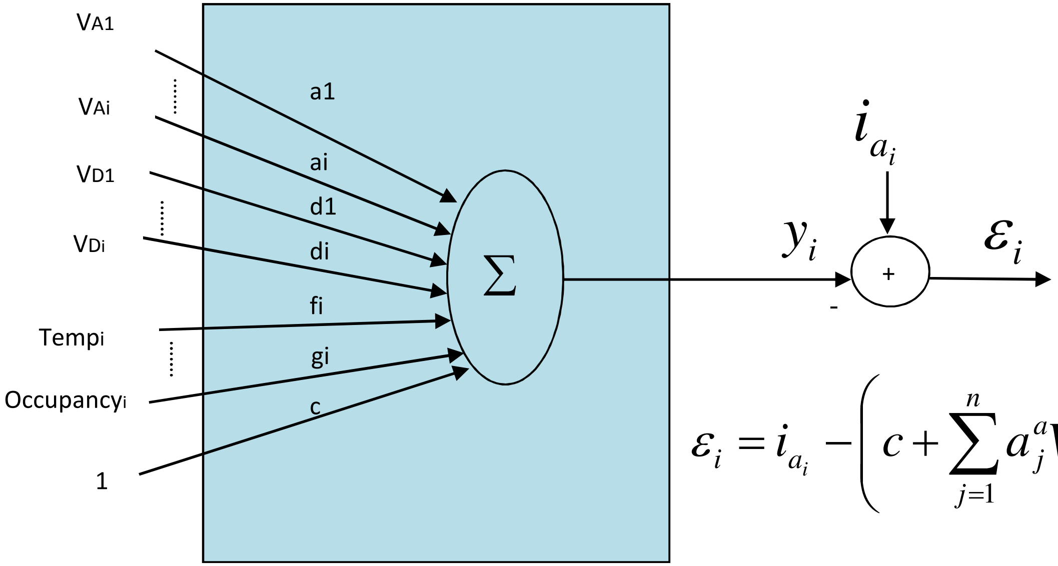
- Problem Formulation:
  - Given that currents *ia* and *id* are a function of several inputs *{VA, VD, Temp, Occupancy}*, lets find the best linear multivariate regressors of *ia* and *id* on all inputs such that mean-square error is minimized

$$i_{a_i} = a_1^a V_{a_i} + a_2^a V_{a_i}^2 + a_3^a V_{a_i}^3 + a_4^a V_{a_i}^4 + d_1^a V_{d_i} + d_2^a V_{d_i}^2 + f_1^a Temp_i + g_1^a Occ_i + c^a$$

$$i_{d_i} = a_1^d V_{a_i} + a_2^d V_{a_i}^2 + d_1^d V_{d_i} + d_2^d V_{d_i}^2 + f_1^d Temp_i + g_1^d Occ_i + c^d$$

Analytical Models

- Apply Linear Regression for Multiple Variables
  - Variables are *{V_A, V_D, Temp, Occupancy}*



$$\varepsilon_i = i_{a_i} - \left(c + \sum_{j=1}^{n} a_j^a V_{a_i}^j + \sum_{j=1}^{m} d_j^a V_{d_i}^j + \sum_{j=1}^{r} f_j^a T_i^j + \sum_{j=1}^{k} g_j^a Occ_i^j \right)$$

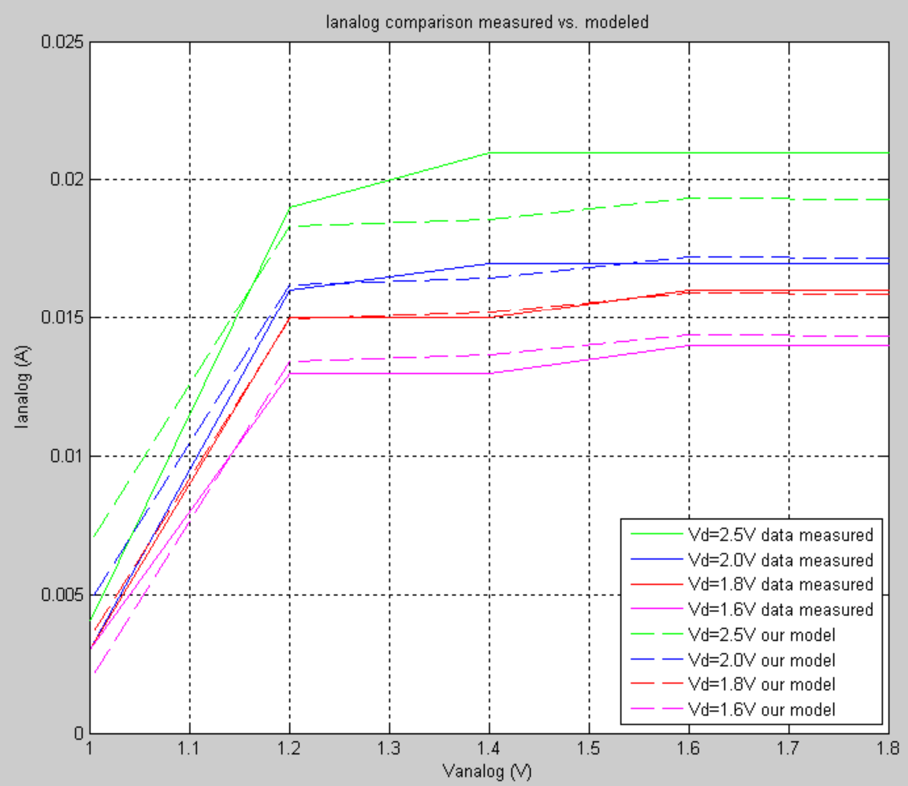
- Goal of the regression problem is to find coefficients:

$\{a_1^a, a_2^a \ldots a_n^a, d_1^a \ldots d_m^a, f_1^a \ldots f_r^a, g_1^a \ldots g_k^a\}$ analog current coefficient

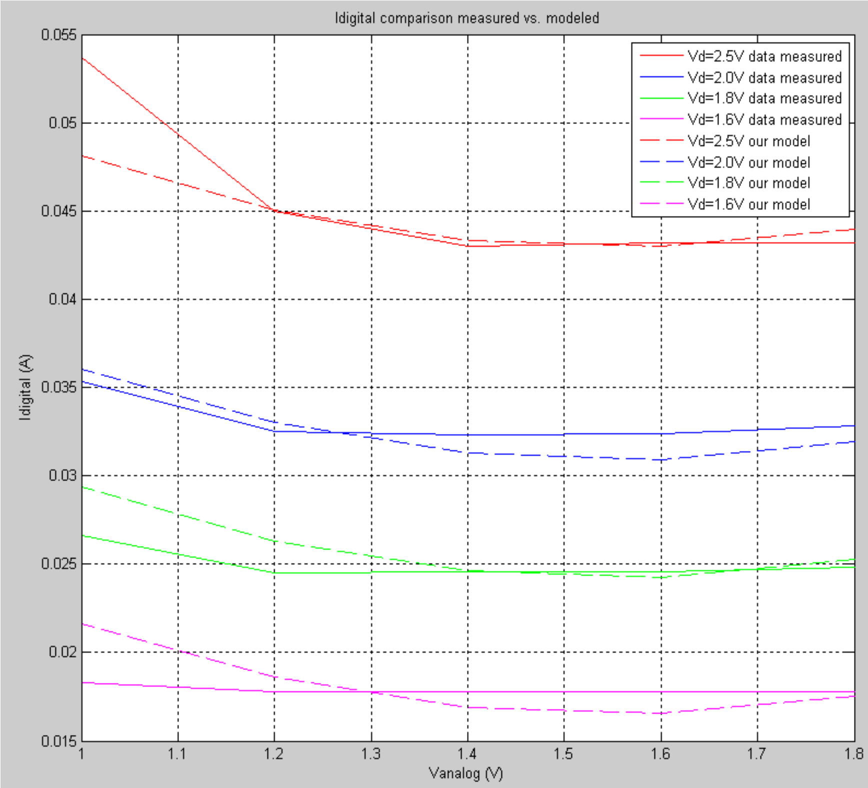
$\{a_1^d, a_2^d \ldots a_{n^*}^d, d_1^d \ldots d_{m^*}^d, f_1^d \ldots f_{r^*}^d, g_1^d \ldots g_{k^*}^d\}$ digital current coefficient

Model Comparisons

- Matlab simulation comparing the data measured versus our models



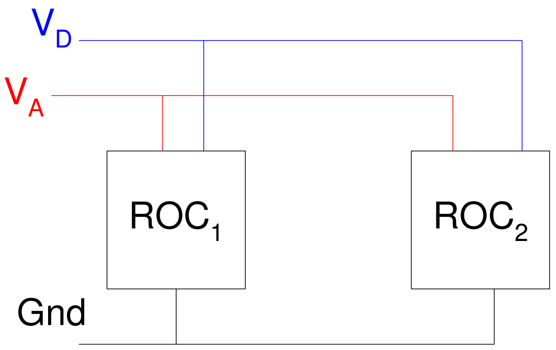
Analog current



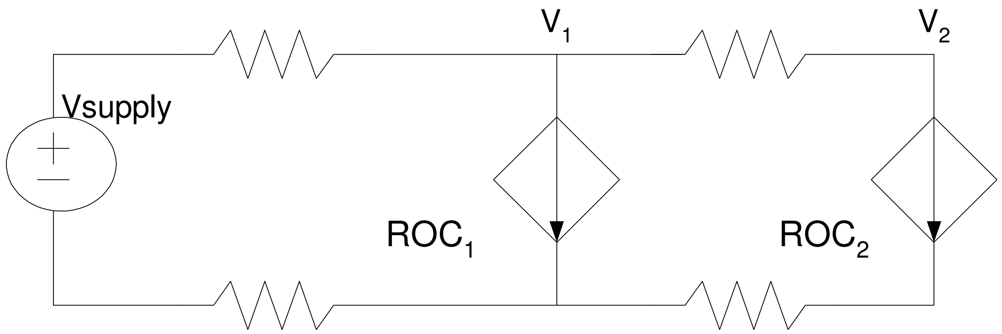
Digital current

Network Analysis

- Utilize the obtained coefficients to perform power analysis



Plaquette 1x2 ROCS



Power network (either V_A or V_D)

- Use Modified Nodal Analysis (MNA) to solve the network where circuit is represented by KCL laws.

$$G \cdot V = I$$

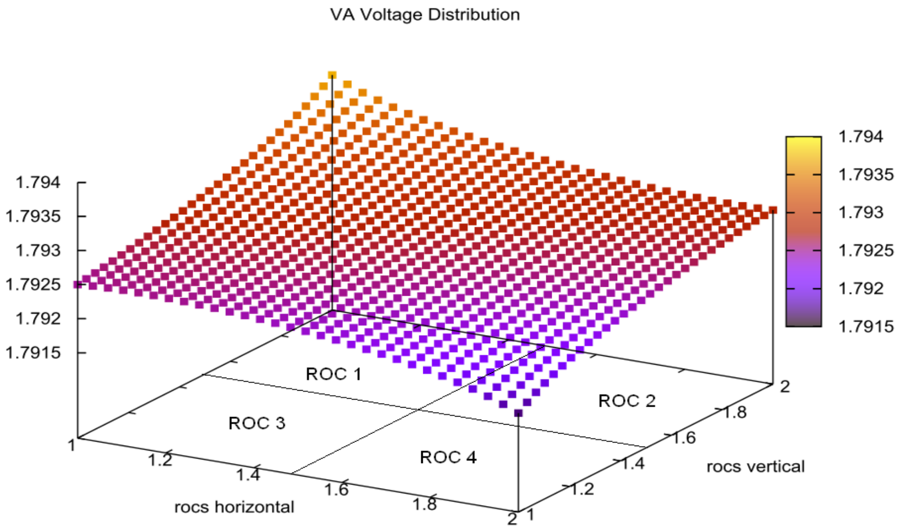
  - *G* conductance matrix, *V* node voltages vector, *I* voltage controlled current sources

Network Analysis

- Direct Method:
  - Close-form expression by replacing current vector *I* with the coefficients equations obtained from regression analysis

$$G \cdot V = A_1^a \cdot V + \cdots + A_4^a \cdot V^4 + D_1^a \cdot V + D_2^a \cdot V^2 + K$$

$$V = [V_1^a, V_2^a \ldots, V_1^d, V_2^d \ldots$$


VA Voltage Distribution

  - i.e. 2x2 Rocs,

$$V = [V_1^a, V_2^a, V_3^a, V_4^a, V_1^d, V_2^d, V_3^d, V_4^d]$$

    - max 83mV drop on Va
    - max 176mV drop on Vd

- Iterative Method:
  - 1. Set initial conditions on node voltages $\{V_0^a, V_0^d\}$
  - 2. Solve for currents $i_a = f\{V_0^a, V_0^d, T, O\}$ and $i_d = f\{V_0^a, V_0^d, T, O\}$
  - 3. Solve for node voltage based on currents obtained from step2
  - Repeat till computed current change is minimum, $\delta_a = i_a^{s-1} - i_a^s \approx 0$

Status

Ongoing:

- Continuing to make lab measurement on several chips to enhance ROC characterization
- Simulating large size Plaquettes
- Refining of algorithm

Next steps:

- Panel level network simulation utilizing the ROC and Plaquette models
- Global level network simulation
- Update models to perform transient analysis
- Develop user interface for the simulation platform

Conclusions

- Performed power distribution analysis on the current CMS FPIX Tracker
- Implications of proposed upgrades on the power network
  - DC-DC integrations needs and requirements
- Development of simulation platform for power network analysis on CMS FPIX Tracker
  - Problem formulation and approach