# RF SAMPO – NOKIA VETURI

ECOSYSTEM PROJECT

## RF and Antenna Technologies

for Industrial 5G networks and beyond

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# Base Station Model Based System Engineering

Antti Heiskanen

- Digital Twin ~ virtual up-to-date model of real-world physical counterpart
- Digital Twin simulated response ~ real-world physical counterpart response
- Model Based System Engineering is one methodology used within building up Digital Twin
- No standard modeling, simulation or analysis methods
- Many abstraction levels, modeling whole system or part of system. Which phenomena not modelled or which requirements cannot be checked via simulation ?
- Ideally, modified Digital Twin could be representation of modified existing counterpart or representation of future real world counterpart

# Contents

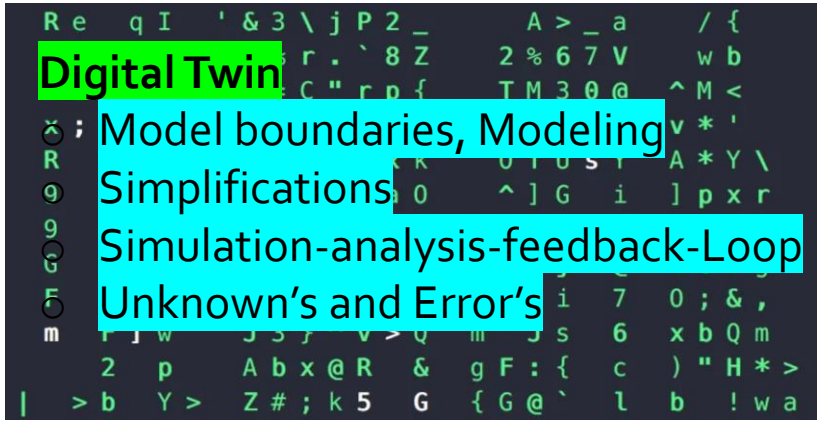
Throughout presentation: consider product lifetime/feedback loops: **build-up** and **up-date Digital Twin**

- Challenge of freezing  product and standard requirements, price and time to market
- Challenge of specifying optimal technical architecture and specify per design block requirements
- **…**
- **High Power - Base Station Project - EXAMPLE**
- Conclusions

# Challenge of freezing  product and standard requirements, price and time to market

**Product**
- Product- and requlatory requirements
- Standard's and features that shall be supported
- Co-existence requirements
- Verification
-...

(feedback to/from?
feedback accuracy?)

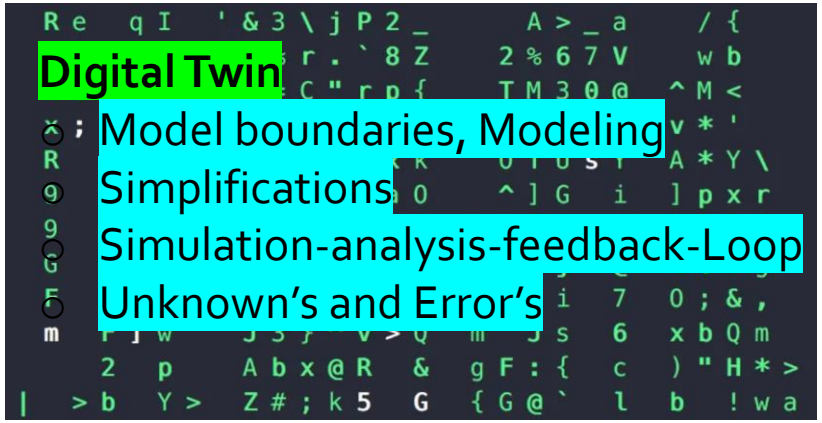



- Huge number of details to commit and guarantee that product shall be compliant
- how to stay within budget, agree and freeze requirements and still get on time into the market?

# Challenge of specifying optimal architecture and specify per design block requirements

Product
Transmission-modes
Multi-Standard
MIMO
Beamforming
Nro of TxRx antenna ports
FDD/TDD-mode
RF power level/Frequencies/iBWs
Transceiver architectures
RF PA architecture and performance
FNL stage Doherty desing &spec
Impact of algorithms
…

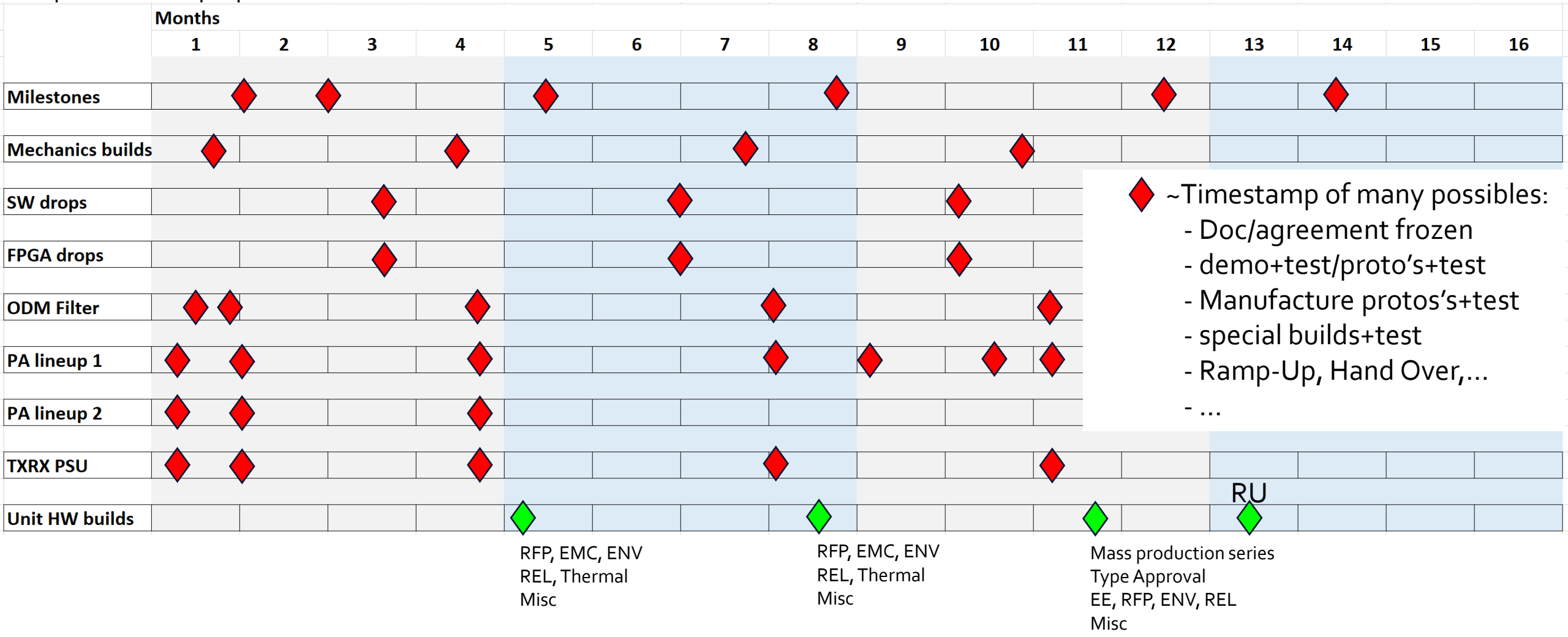
(feedback to/from?
feedback accuracy?)




- Huge number of design choice combinations→ How to select the best combination for the product?
- how to verify optimal choice through model-simulate-analyze-feedback-Loop?

# High Power - Base Station Project – EXAMPLE - schedule

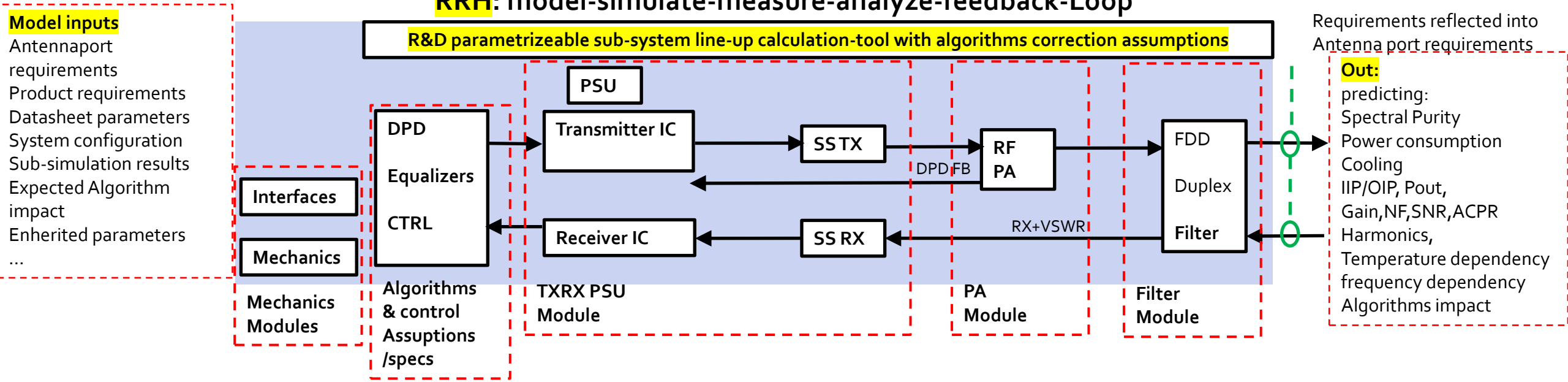
Simplified fictive project schedule.




- Parallel developments without possibility to verify as whole until at the end of project
- SW, Algorithms/parameterization, HW and mechanics are developed parallel using wide mixture of methods
- Huge number of people, different technical areas and 3rd parties inputs
- What kind of model-simulate-measure-analyze-feedback-Loop?

# High Power - Base Station Project – EXAMPLE – feedback-loops

## RRH: model-simulate-measure-analyze-feedback-Loop




- Product is modeled as sub-system (~Architecture spec) and is divided further into modules (~Module spec)
- Model and requirements are continuously updated while project goes forward
- Model is not accurate enough and some modules performance is optimized through R&D debugging methods
- Debugging methods and tuning-feedback is very complex matter, what needs to be changed and it helps?

3rd party: Project- and Product requirements ⟷ Architecture Requirements/Specifications-doc

↕

R&D &3rd party: Per module design- and test requirements/specifications-doc ⟷ per proto test+doc (**next design?**)

↕

R&D&3rd party:I&V test matrix and test requirements/specifications-doc ⟷per unit proto test+doc (**next design?**)

↑

3rd party feedback

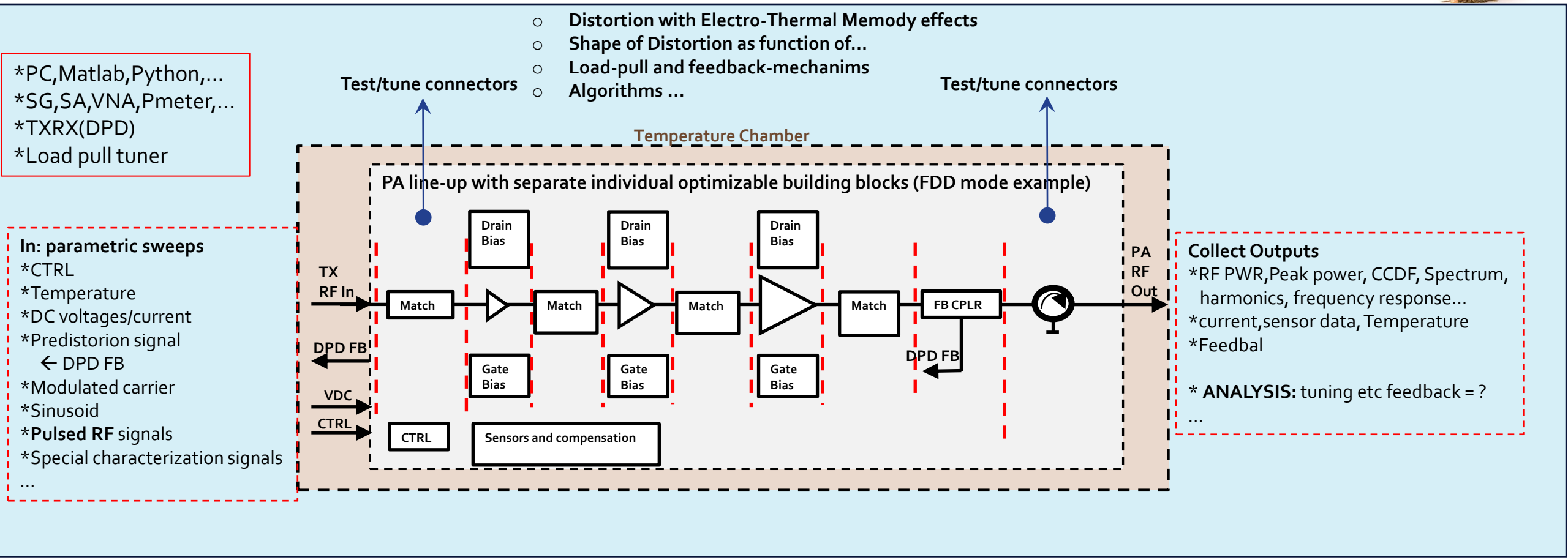
# High Power - Base Station Project – EXAMPLE – Debugging methods and tuning feedback:

## Optimization of RF PA and linearization is very complex and time consuming task

- Cannot be modelled and simulated accurately enough and often requires measurement based iterative lab-tuning
- Simulation and tuning methods are complex and difficult to perform in advance, dedicated setups and analyses are needed and used
- Often used tools: Excel, Matlab , AWR/Aplac/ADS, CST, LP-data,...many commercial and in-house tools are used, each optimal for some narrow use case

- **Distortion with Electro-Thermal Memody effects**
- **Shape of Distortion as function of...**
- **Load-pull and feedback-mechanims**
- **Algorithms ...**

*PC,Matlab,Python,...
*SG,SA,VNA,Pmeter,...
*TXRX(DPD)
*Load pull tuner




**In: parametric sweeps**
*CTRL
*Temperature
*DC voltages/current
*Predistorion signal
← DPD FB
*Modulated carrier
*Sinusoid
***Pulsed RF** signals
*Special characterization signals
...

**Collect Outputs**
*RF PWR,Peak power, CCDF, Spectrum, harmonics, frequency response...
*current,sensor data, Temperature
*Feedbal

* **ANALYSIS:** tuning etc feedback = ?
...

- AMAM AMPM (Power sweep)
- Frequency Response (frequency sweep)
- Modulated power sweep response
- (CCDF, ACP,power consumption, Harmonics, Thermal,Non-operating band emissions)
- Special characterizations/tuning tests

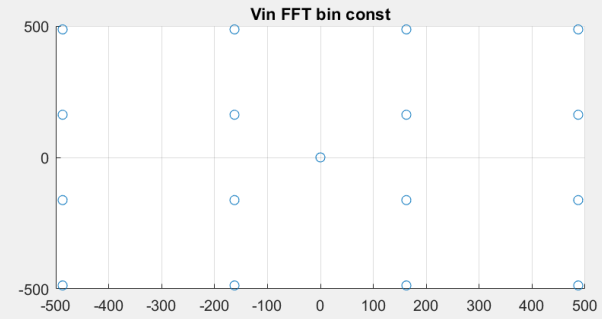
- Linearization with modulated carrier (Linearized response)
- Thermal test
- Gate and Gain rice time – test
- Ruggedness test
- Dynamic AMAM AMPM measurement and BB model Gain-model

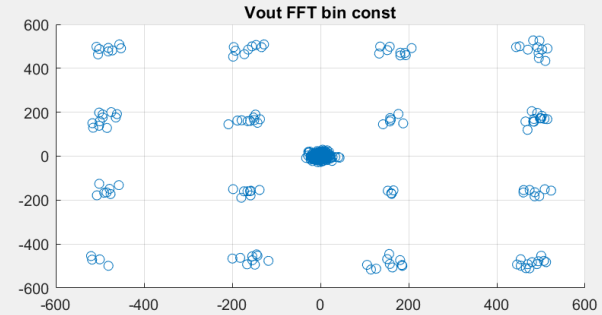
## Matlab-HW-in-the-loop-simulation/Characterization setup example (Generalized memory polynomial model):

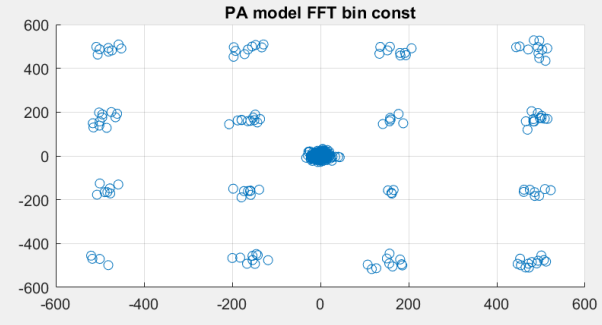
- RF PA Characterized, and model fitted using BB signal → sub 1% accuracy achieved, excellent ?
- Suppose the performance is not sufficient, for example meets module requirements but does not linearize sufficiently ? What to do, what tuning/parameterization feedbac to give? Model fit-is local and huge number of model parameters give same accuracy
- Suppose Module level Peak power and power consumption requirements are not met. What to do, what tuning/parameterization feedback to give?

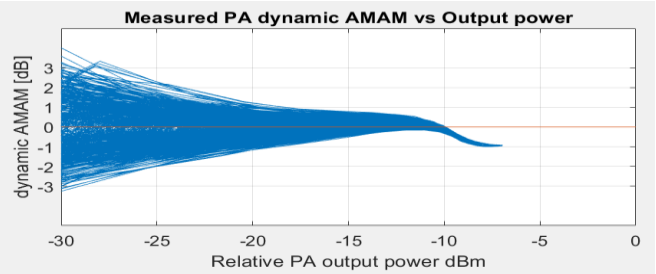
→ Even with accurate local models.. One easily ends up on doing traditional parameterized sweeps and finds optimal solution by comparing results

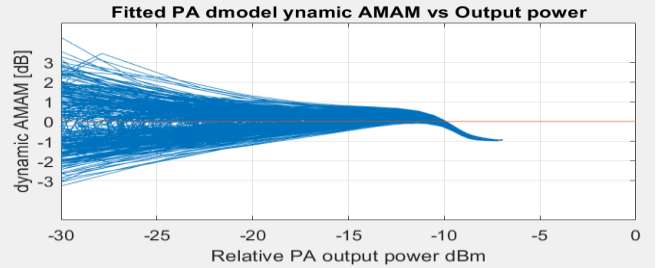

Per frequency-constellations

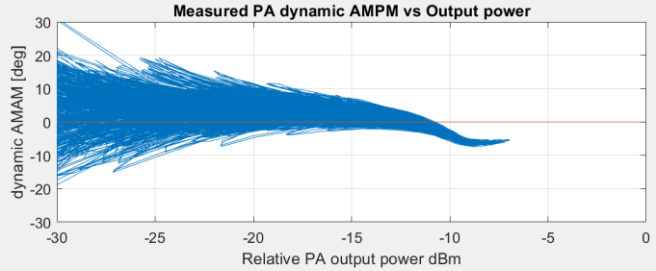


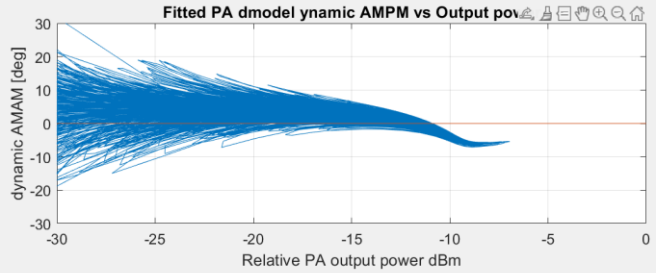



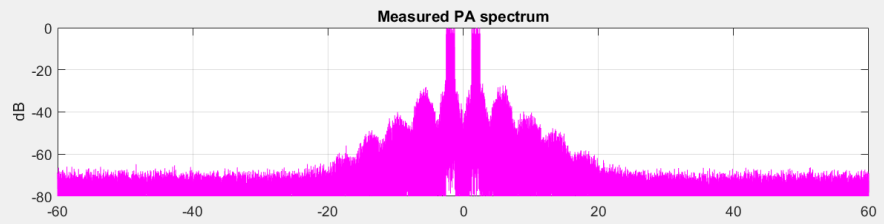



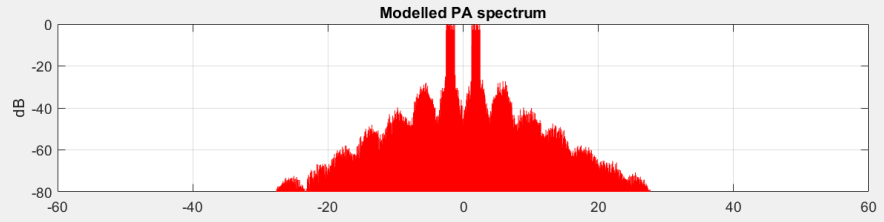



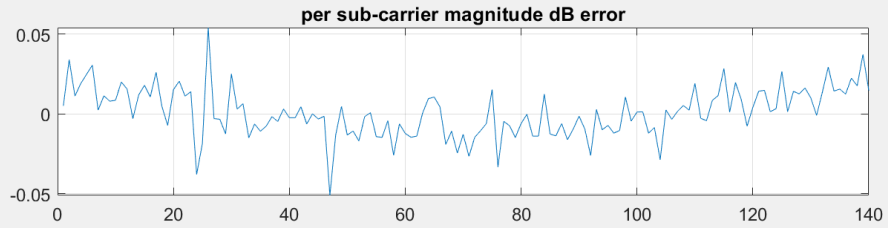



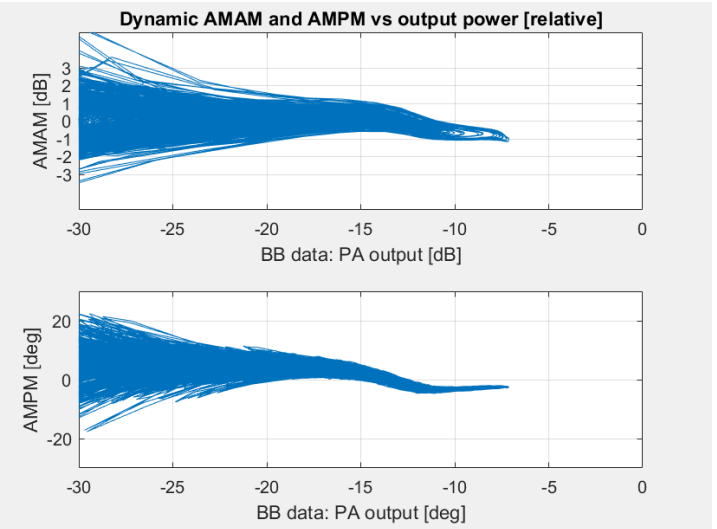
**Matlab-HW-in-the-loop-simulation/Characterization setup example:(Generalized memory polynomial pre-distortion model):**

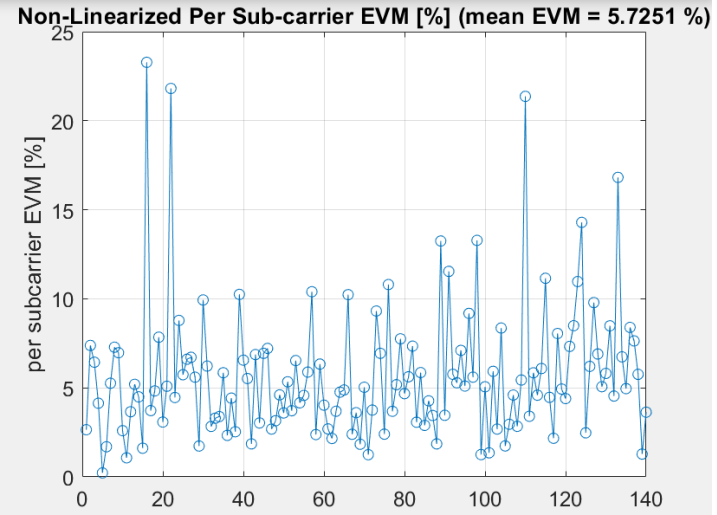
- RF PA linearized with Matlab based pre-distortion algorithm while slightly below target maximum RMS power.
- Suppose the linearized performance is not sufficient at target maximum power, while meets module requirements are met. What to do?

→ Special modeling, analysis and test methods are needed so that one does not end up on doing iterative testing…

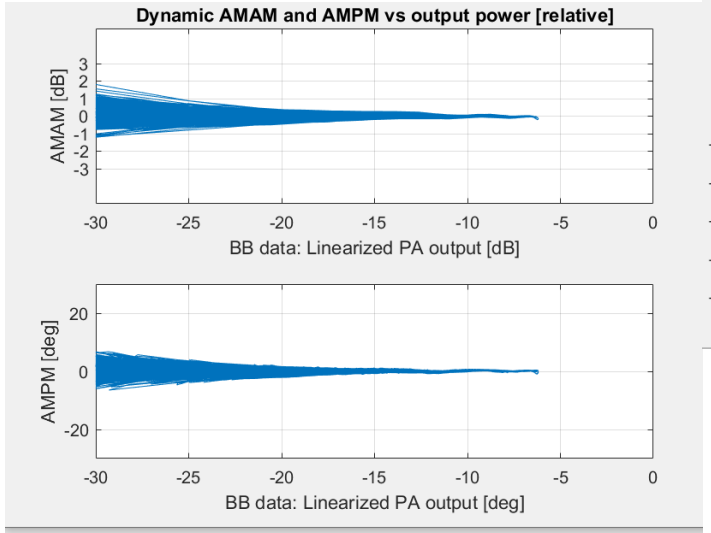
# 47.62 dBm PAR 9.8dB: Matlab spectrum vs FSW spectrum of before and after linearization

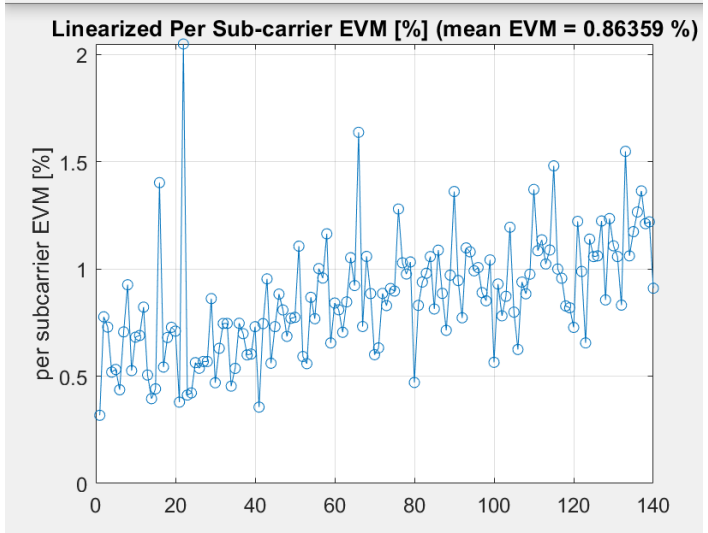
## Before Linearization

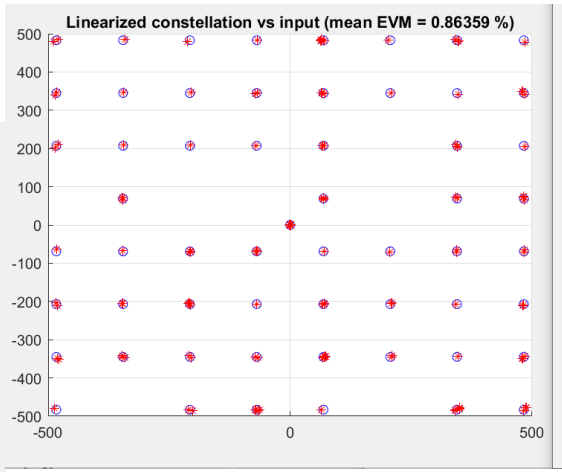


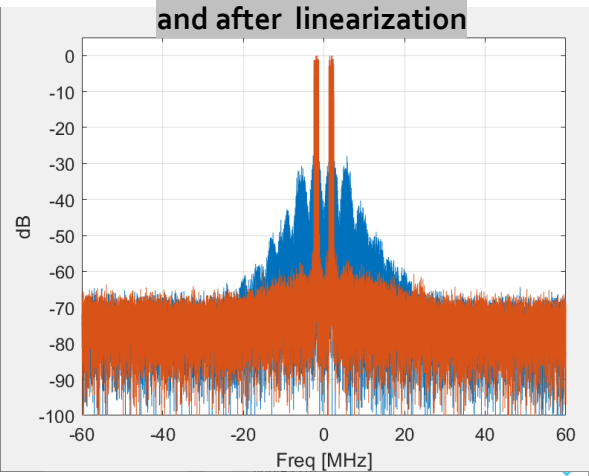

## After Linearization



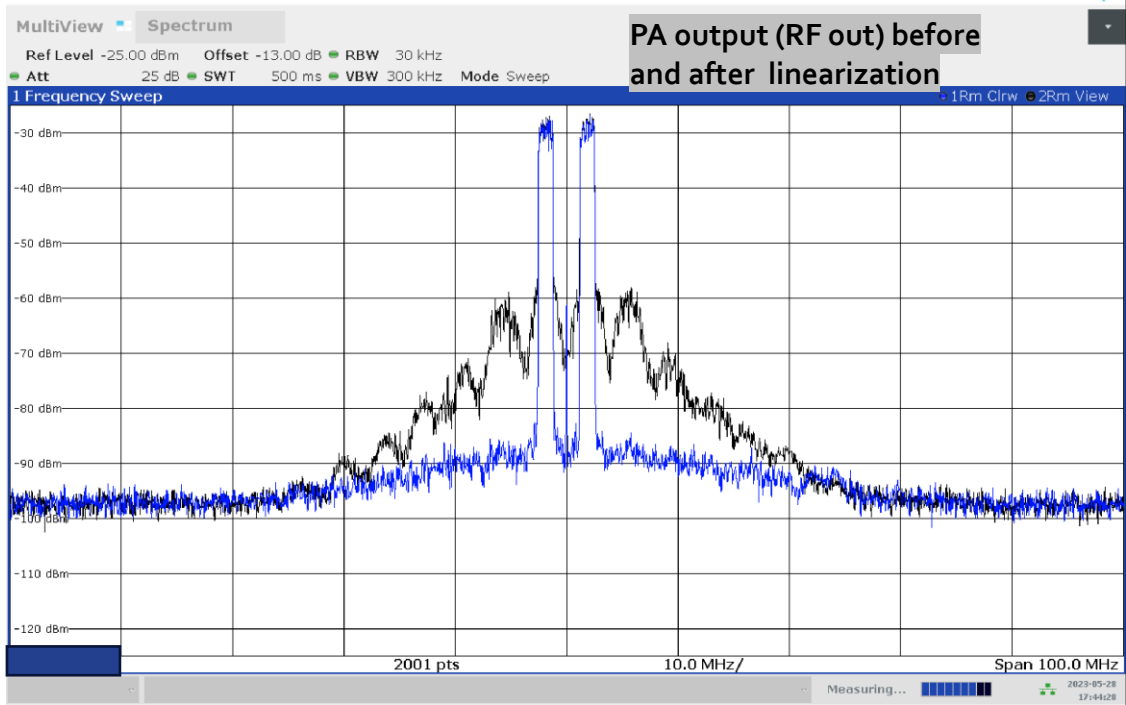




PA output (ADC input) before and after linearization




PA output (RF out) before and after linearization



## Conclusions

- MBSE methology is useful within complex base station projects. It helps to see larger picture and parallel development of sub-systems is possible.
- Usage of MBSE would be easier if simulation methods-, interface-, modeling-, data storage- and model filtting is standardized
- Some very complex phenomena are difficult to model and system performance predictions and design change predictions FAIL. Such cases needs to be made sub-model and more effort put into it
- Further development for analysis methods is needed, such that quide to correct design change without iterative parametric sweeps

# Thank you!

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# (back-up slide) High Power - Base Station Variant Project – EXAMPLE – schedule

**SW+FPGA etc. drops**

- Often times completely or partly done by 3rd party. Sometimes delays cause project challenges via delaying feedback from R&D and I&V.
- Parameterization/debug based on co-work through unit level I&V tesing
- Algorithm's performance impact into HW requirements relaxation is based on assumptions/reference (for example linearization improves RF PA performance)
- **Usually partly modelled into R&D subsystem line-up calculation-tool**

**TXRX+PSU**

- Often times frequency dependent compoents selected based on datasheets. Few build-test&tune-rounds.
- Often times special simulations not needed, per proto matching/tuning optimization done at lab
- Sometimes circuit level simulations and/or CST used for design/debug
- **Modelled into R&D subsystem line-up calculation-tool with algorithms correction assumptions**

**RF PA**

- Often times project and product botleneck via many reaons:
  - -Many builds and tuning (demo, proto's, 2nd Source build, Corner Build, mass production series),
  - -No simulation models, or modeling too innaccurate
  - -Linearization impact into performance difficult to predict in advance and in the end always needs final tuning/verification with target platfrom linearization
  - -Linearization+RFPA performance: either one can be over or under specified, or combined poor performance is mystery
  - -Performance estimation and **analysis** is insufficient
- Often circuit simulations and/or CST used for design/debug
- **Modelled into R&D subsystem line-up calculation-tool with algorithms correction assumptions**

**Filter**

- Usually simulations + build's + module testing done by 3rd party, but R&D makes also own module verification and tuning suggestions
- Long lead time within proto's
- **Modelled into R&D subsystem line-up calculation-tool with algorithms correction assumptions**

**Mechanics**

- Usually enherited from Lead-product. Minor modifications allowed, sometimes needed.
- Mechanics modeling done by editing model received from Lead procut, Filter vendor and other possible 3rd parties

**Unit**

- Builds done with existing Mechanics+SW+FPHA-drops+HW
- Time consuming testing, Not all filed operation use cases testerd and all unit contents may not be mature yet

**Should be simulated as whole system but…**

## Huge number of 3rd parties and per module parallel development

## → how to design and verify modules? What kind of Model-simulate-measure-analyze-feedback-Loop?