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Load Pull Compensation in Massive MIMO

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Aim : Provide an algorithm or process that counteracts the antenna coupling - 'load pull' in multi user Massive MIMO system. Given that, in a massive MIMO system the antenna array(s) are configured in a non linear dynamic manner.

Introduction

Massive MIMO antenna arrays are necessary to achieve the greater data rates in 5G especially at the higher mmWave frequencies.
An antenna array requires the antenna elements to be physically close to negate grating lobes, but distant enough for MIMO uncorrelation, this causes antenna coupling.
Antenna coupling, referred to as load pull changes antenna characteristics, these being:-

- Impedance - The resonant modes are altered. Causing a change in impedance at the set rx/tx frequency.
- Reflections - The impedance mismatch causes reflections back to the power amplifier (PA).
- Radiation pattern - The antenna electromagnetic field is reshaped by adjacent antenna activity.

The load pull effects are non linear and cannot be directly calculated as massive MIMO configures the array according to the inverse of the channel matrix which is derived from uplink pilot sounding reciprocation.

Methodology

A MIMO channel is:-

$$\mathbf{Y=Hs+n}$$

$$\begin{bmatrix} y_1 \\ y_2 \\ y_N \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{1M} \\ h_{21} & h_{22} & h_{2M} \\ h_{N1} & h_{N2} & h_{NM} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \\ s_N \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_N \end{bmatrix}$$

Taking the inverse of the channel matrix h – made simpler by extracting the eigenvectors and eigenvalues and applying to the rx/tx chain, MIMO spatial diversity can be achieved.
To compensate for the PA/antenna, a digital predistortion (DPD) function is used, this example a reduced coefficient Volterra series, known as memory polynomial, given as:-

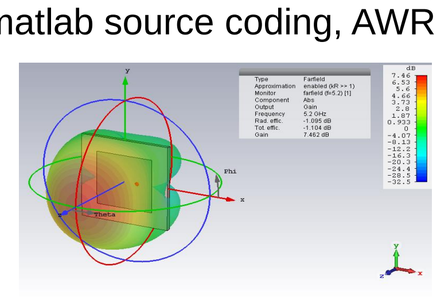
$$z(n) = \sum_{k=1}^{K} \sum_{q=1}^{Q} a_{kq} y(n-q) |(n-q)|^{k-1}$$

There are many stages to the project, these being:-

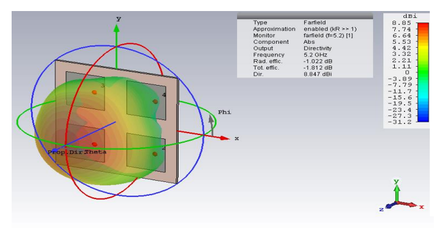
- Analysis – formulate the MIMO matrix and DPD memory model into a usable form
- Simulation – provide end to end simulation using RF tool sets, a different selection of tools are likely to be employed.
- Bench testing – design custom antenna array with PA and DPD, use vector analyser and signal generator to provide end to end testing.
- Conclusion – taking the results from the simulation, backed up with practical results from the bench testing, detail the approach required for load pull compensation in multi user massive MIMO systems.

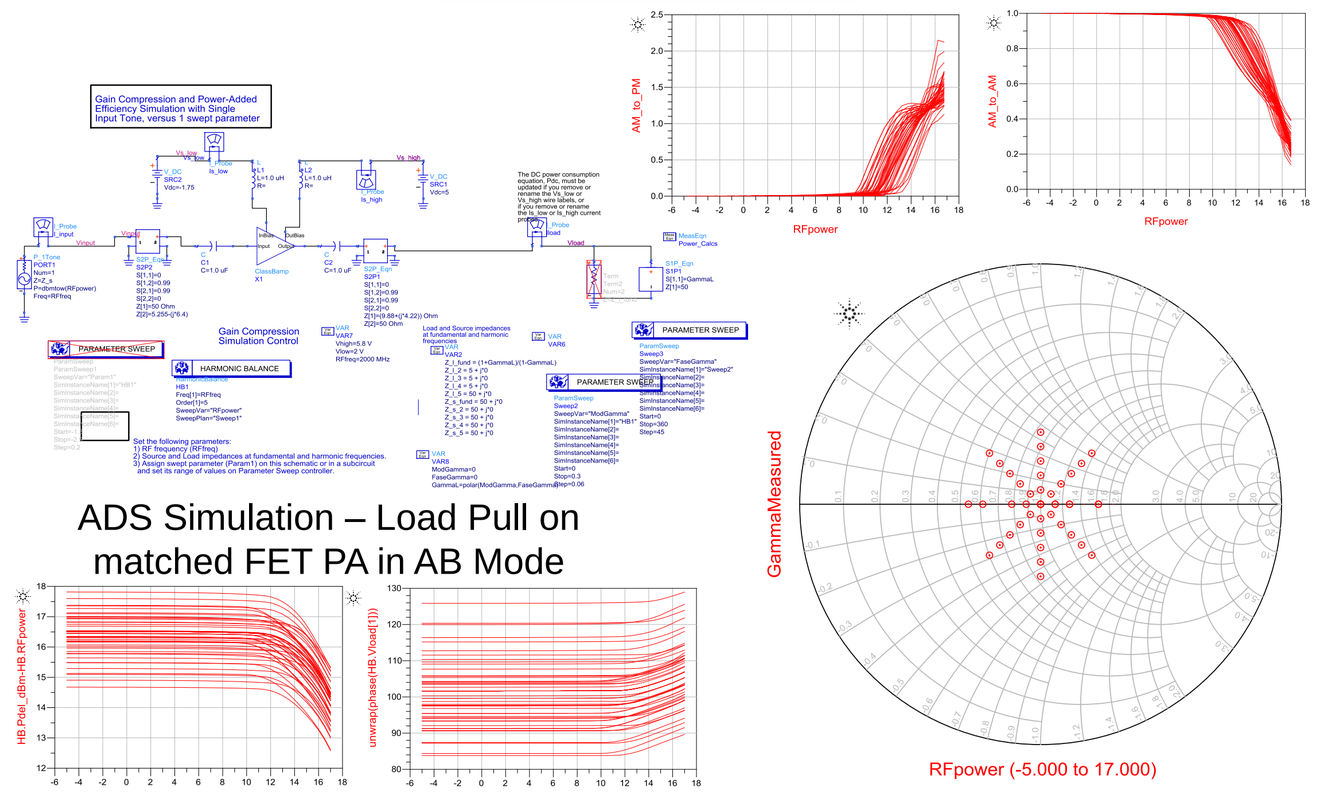
Simulation

Simulation will employ a number of tools, these being, CST for antenna design, Simulink (graphical) with matlab source coding, AWR and ADS.



CST Simulation – Single patch and 4 patch antenna, far field plots and associated S11 Parameters

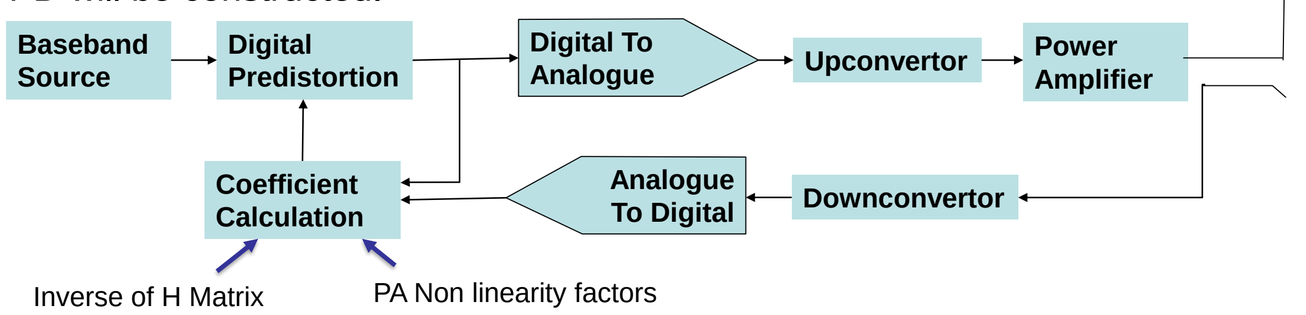




ADS Simulation – Load Pull on matched FET PA in AB Mode

Implementation

A small scale MIMO antenna array with associated PA, upscaling, downscaling, DPD will be constructed.



The DPD shall be designed as FPGA with dynamic look up table or with a fast DSP.
A PA with known characteristics shall be used with commercial ADC, DAC, scalers and custom antenna array.
A vector signal analyser measures the S parameters in and out of the PA and to display the spectrum.
A signal generator will provide complex modulation such as QAM64 or OFDM at high data rates.
Anechoic chamber testing - beamforming characteristics.

Solution and Further Work

An ideal outcome of the project would be that an algorithm or process is discovered/determined that is able to predict and compensate for load pull in a massive MIMO system in realtime. This would work efficiently for any size of MIMO system and with any (known) PA / antenna combination – without requiring RF feedback.
However, there are some issues; load pull in MIMO is non linear, it may not be a simple algorithm/process and may instead require machine learning, although this would in itself require training data which would lead to numerous simulation cases . Reciprocating the downlink channel using uplink sounding does not account for downlink transmit load pull which may make determining the H matrix non-trivial. Realtime updating the DPD for continuing channel changes may be infeasible, even with current state of the art hardware.

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