TU04D-5

Incremental DPD Linearization for Mobile Terminals with Non-Flat Frequency Response in Dynamic Bandwidth Re-Allocation Scenarios

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Outline

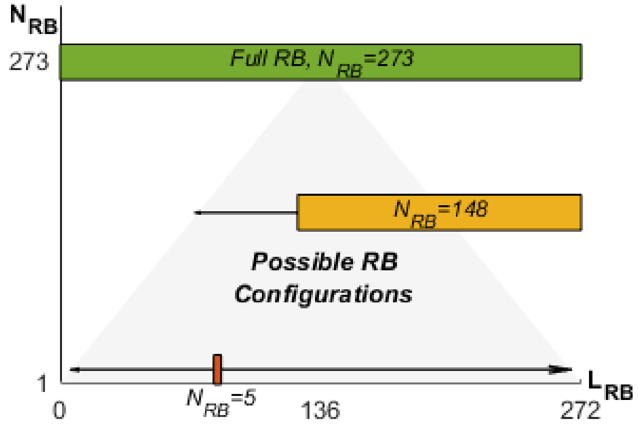
- Introduction
  - Dynamic RB Allocation in 5G NR Applications.
  - RF PA under Non-Flat Frequency Response.
- Incremental Bandwidth (IBW) Linearization
  - Incremental Bandwidth DPD Model
  - Constrained DOMP for IBW GMP Basis Selection
- Experimental Setup and Results
- Conclusion

Introduction

- 5G NR RB Reallocation Scenario: Dynamic RB location & number, assuming fixed Fc.
- For dynamic RB location (i.e., **frequency**), we propose the **FD DPD** (presented in RWW 2023).
- For dynamic RB number (i.e., **bandwidth**), we propose the **IBW DPD** (**this work**).

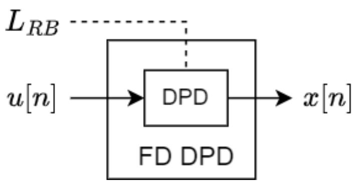
Dynamic Frequency

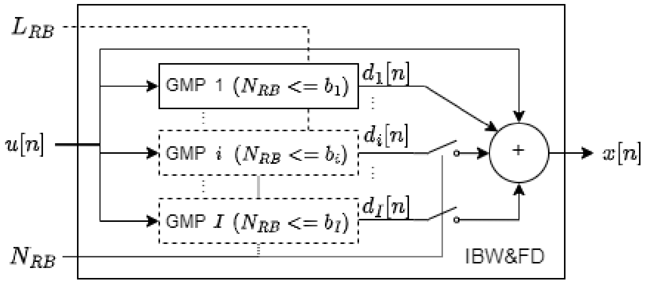
- For narrow-band signals.
- Less memory effects.
- FD nonlinearity.
- Coefficient interpolatable. (e.g., FDMP/FDP model)

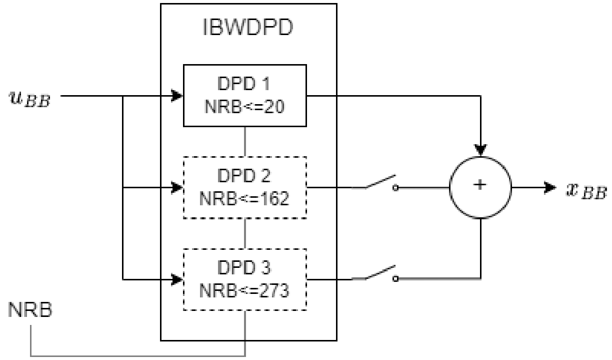


Dynamic Bandwidth

- Simple model for narrow-band.
- Introduce more basis for wide-band.
- Complexity for implementation.
- Prefer an incremental model.



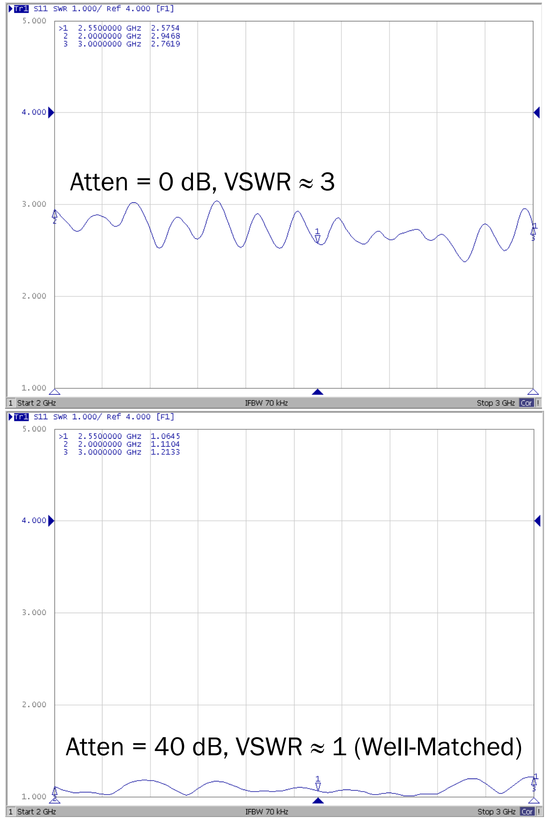


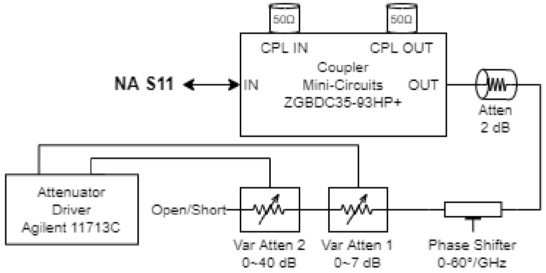


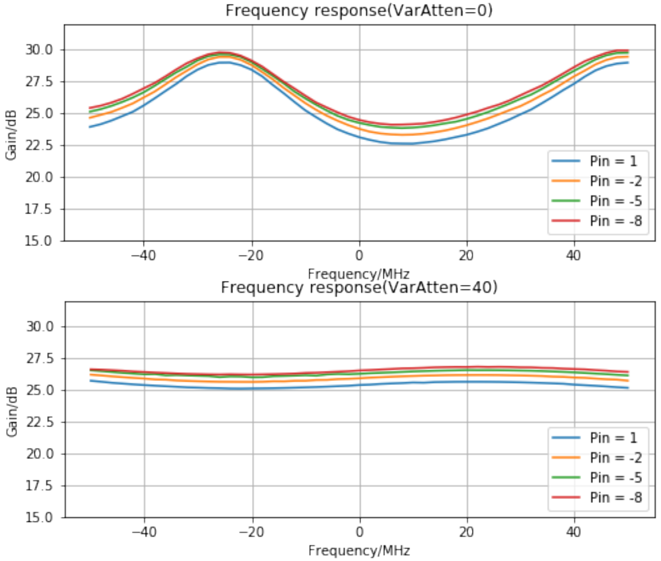
IBW & FD

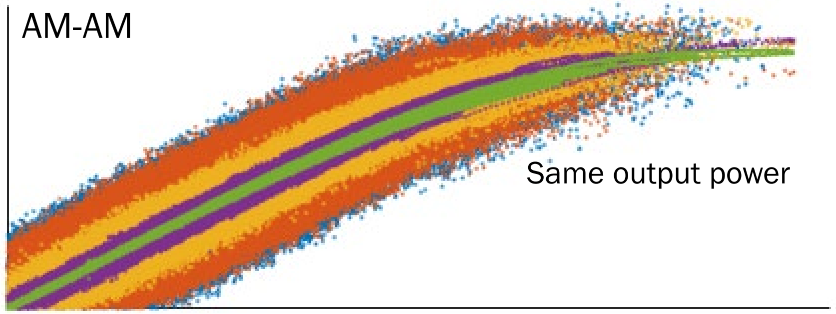
Introduction

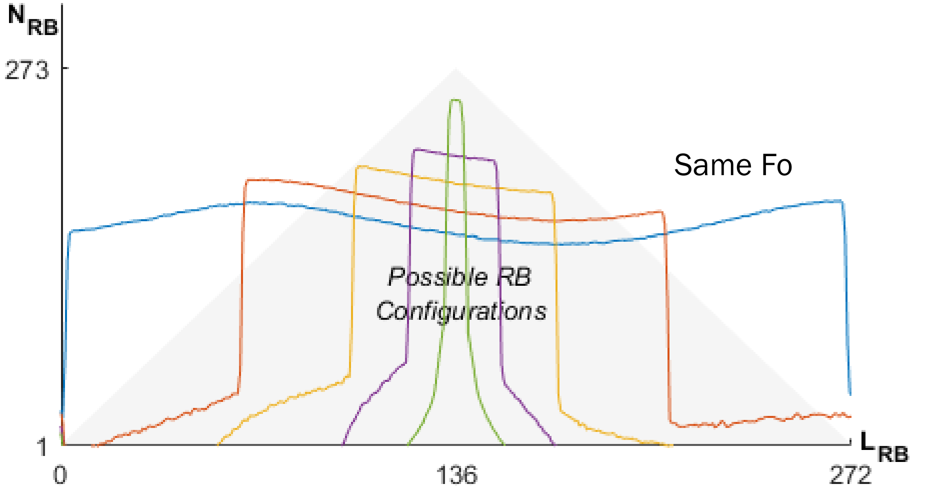
- Mobile-terminal PAs usually work under large load-mismatched conditions.











Load-mismatched Creation

Consequence of different bandwidth

Incremental Bandwidth DPD Model

Objective: Make the DPD model incremental with bandwidth,

- by appending new basis,
- with fixed coefficients.

Assuming: the additive distortion is orthogonal to the previous basis functions.

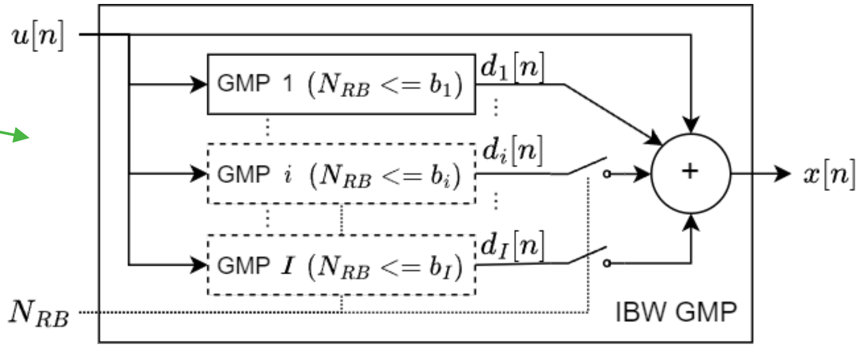
Based on GMP: $d_i[n] = \sum_{k_i=1}^{K_i} w_{k_i} u[n-\tau_{k_i}] \, |u[n-\tau_{k_i}-\sigma_{k_i}]|^{p_{k_i}}$

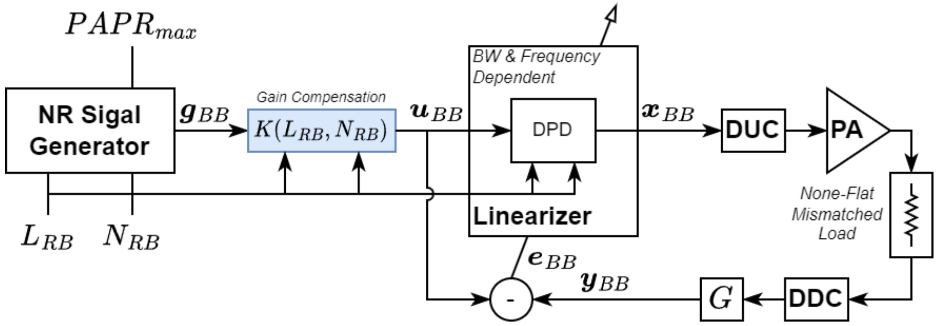
Predistortion Signal: $x[n] = u[n] - \sum_{i=1}^{I} d_i[n]$

Narrow-band error: $e_1[n] = u[n] - y[n]$

IBW error: $e_i[n] = u[n] - y[n] - \sum_{j=1}^{i-1} d_j[n]; \; (i>1)$

IBW Coefficients: $\boldsymbol{w}_i^{k+1} = \boldsymbol{w}_i^{k} + \mu(\boldsymbol{U}_i^H \boldsymbol{U}_i)^{-1} \boldsymbol{U}_i^H \boldsymbol{e}_i$





DOMP for IBW GMP Basis Selection

- Define I bandwidth configurations and the boundaries. (e.g., {10, 40, 80, 162, 273})
- Selects basis incrementally with BW by DOMP.
- Allowing reselection to retrain significant basis.

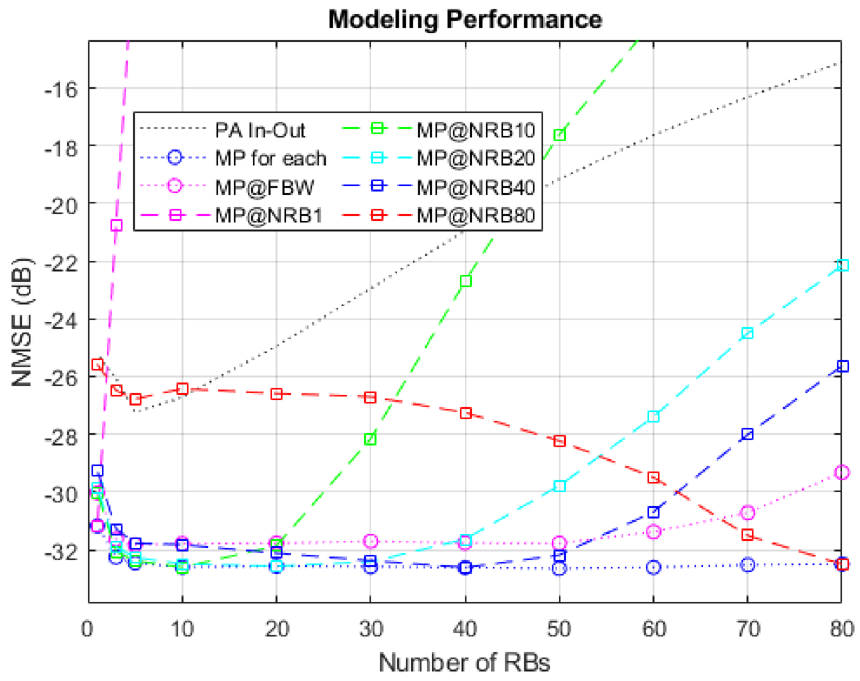
Algorithm 1 IBW Constrained DOMP

procedure IBWDOMP(M, U, y)
  $M^* \leftarrow \{\}, i \leftarrow 1, e \leftarrow y, w \leftarrow ()$
  while $i \le I$ **do**
    $M_i \leftarrow \{\}, e_i \leftarrow e_{\{i\}}, Z_i \leftarrow U_{\{i\}}$
    repeat
      $\varphi^{\{j\}} \xleftarrow{\forall j} \left| \frac{Z_i^{\{j\}}}{\|Z_i^{\{j\}}\|_2} e_i \right|$
      $j^* \leftarrow \text{pursuit}(M^*, M_i, M, \varphi)$
      $M_i \leftarrow M_i \cup M^{\{j^*\}}$
      $\sigma \leftarrow Z_i^H Z_i$
      $Z_i \leftarrow Z_i - \sigma \otimes Z_i^{\{j^*\}}$
      $U_* \leftarrow U_i[M_i]$
      $w_i \leftarrow (U_*^H U_*)^{-1} U_*^H y_i$
      $e_i \leftarrow y_i - U_* w_i$
    until stopping criterion is met
    $M^* \leftarrow M^* \cup M_i$
    $U_* \leftarrow U[M^*]$
    $w \leftarrow (w^T, w_i^T)^T$
    $e \leftarrow y - U_* w$ *<- IBW residual error*
    $M \leftarrow M_{\notin M_i}$ ▷ only if not allowing re-selection
    $i \leftarrow i + 1$
  end while
  return M^*
end procedure

* *The **i** here represents different BW*

Algorithm 2 Greedy selection with memory preference

procedure PURSUIT(M^*, M_i, M, φ)
  $P^* \leftarrow M^{*\{\tau,\sigma\}} \cup M_i^{\{\tau,\sigma\}}, P \leftarrow M^{\{\tau,\sigma\}}$
  $\varphi_n \leftarrow \frac{\varphi - \min(\varphi)}{\max(\varphi - \min(\varphi))}$
  $\varphi_s, s_{id} \xleftarrow{\forall \varphi_n > \gamma} \text{sort}_{\text{desc}}(\varphi_n)$ *<- Score threshold*
  $P_s \leftarrow P^{\{s_{id}\}}$
  if $P_s \cap P^* \neq \emptyset$ **then** *<- Memory preference*
    $j \leftarrow 0$
    repeat
      $j \leftarrow j + 1$
      $j^* \leftarrow s_{id}(j)$
    until $P_s^{\{j\}} \in P^*$
  else
    $j^* \leftarrow s_{id}(1)$
  end if
  return j^*
end procedure



↑ Clues for defining the IBW boundaries.

DOMP for IBW GMP Basis Selection

- Define I bandwidth configurations and the boundaries. (e.g., {10, 40, 80, 162, 273})
- Selects basis incrementally with BW by DOMP.
- Allowing reselection to retrain significant basis.

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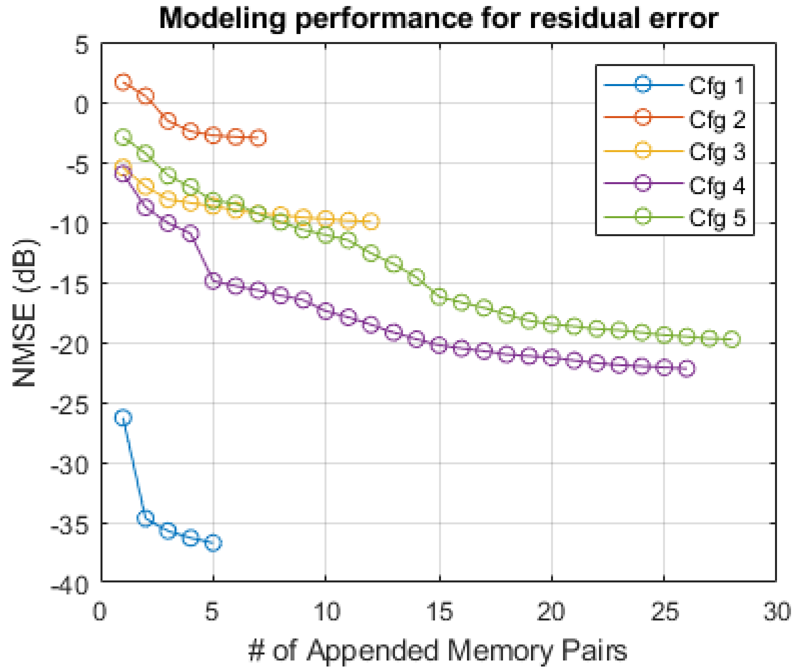
  $\boldsymbol{M}^* \leftarrow \{\}, i \leftarrow 1, \boldsymbol{e} \leftarrow \boldsymbol{y}, \boldsymbol{w} \leftarrow ()$
  while $i \leq I$ **do**
    $\boldsymbol{M}_i \leftarrow \{\}, \boldsymbol{e}_i \leftarrow \boldsymbol{e}_{\{i\}}, \boldsymbol{Z}_i \leftarrow \boldsymbol{U}_{\{i\}}$
    repeat
      $\varphi^{\{j\}} \xleftarrow{\forall j} \left| \frac{\boldsymbol{Z}_i^{\{j\}}}{\left\| \boldsymbol{Z}_i^{\{j\}} \right\|_2} \boldsymbol{e}_i \right|$
      $j^* \leftarrow$ pursuit($\boldsymbol{M}^*, \boldsymbol{M}_i, \boldsymbol{M}, \varphi$)
      $\boldsymbol{M}_i \leftarrow \boldsymbol{M}_i \cup \boldsymbol{M}^{\{j^*\}}$
      $\boldsymbol{\sigma} \leftarrow \boldsymbol{Z}_i^H \boldsymbol{Z}_i$
      $\boldsymbol{Z}_i \leftarrow \boldsymbol{Z}_i - \boldsymbol{\sigma} \otimes \boldsymbol{Z}_i^{\{j^*\}}$
      $\boldsymbol{U}_* \leftarrow \boldsymbol{U}_i [\boldsymbol{M}_i]$
      $\boldsymbol{w}_i \leftarrow (\boldsymbol{U}_*^H \boldsymbol{U}_*)^{-1} \boldsymbol{U}_*^H \boldsymbol{y}_i$
      $\boldsymbol{e}_i \leftarrow \boldsymbol{y}_i - \boldsymbol{U}_* \boldsymbol{w}_i$
    until stopping criterion is met
    $\boldsymbol{M}^* \leftarrow \boldsymbol{M}^* \cup \boldsymbol{M}_i$
    $\boldsymbol{U}_* \leftarrow \boldsymbol{U}[\boldsymbol{M}^*]$
    $\boldsymbol{w} \leftarrow (\boldsymbol{w}^T, \boldsymbol{w}_i^T)^T$
    $\boldsymbol{e} \leftarrow \boldsymbol{y} - \boldsymbol{U}_* \boldsymbol{w}$ *<- IBW residual error*
    $\boldsymbol{M} \leftarrow \boldsymbol{M}_{\notin \boldsymbol{M}_i}$ ▷ only if not allowing re-selection
    $i \leftarrow i + 1$
  end while
  return $\boldsymbol{M}^*$
end procedure

** The* ***i*** *here represents different BW*

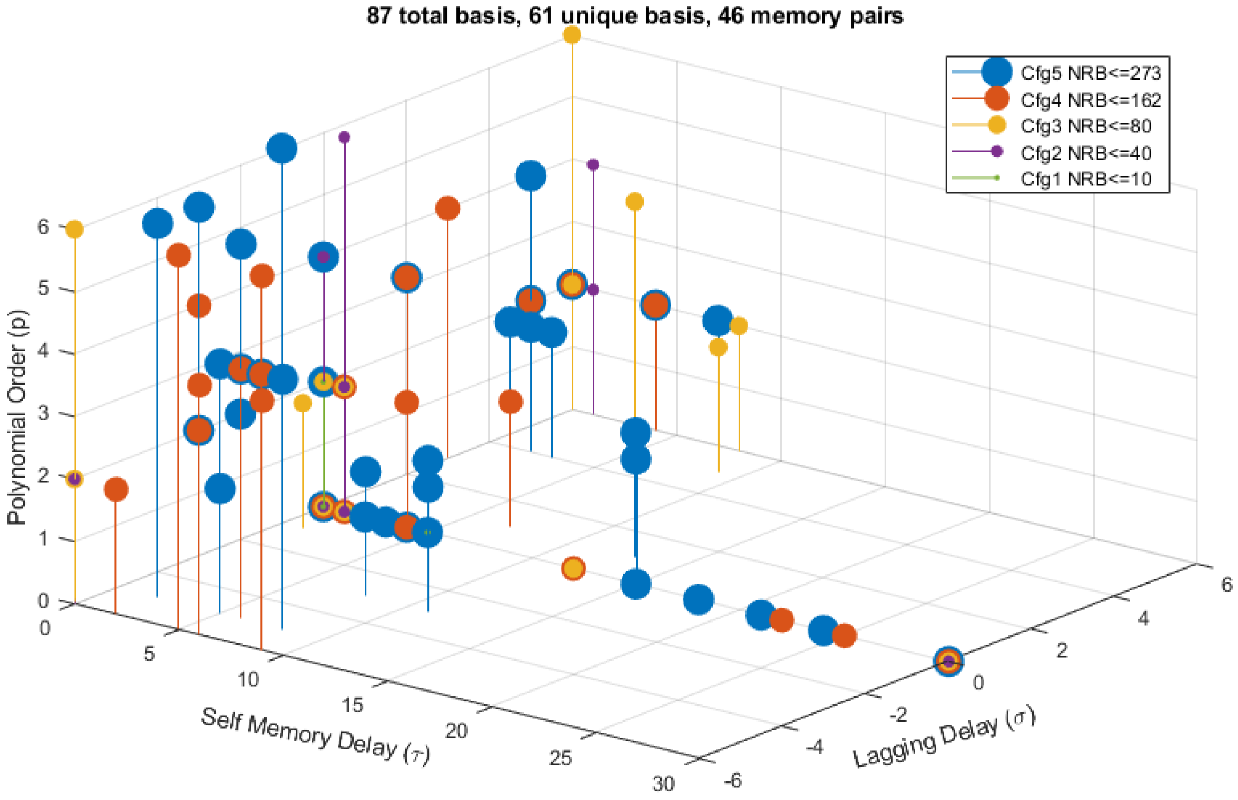
Algorithm 2 Greedy selection with memory preference

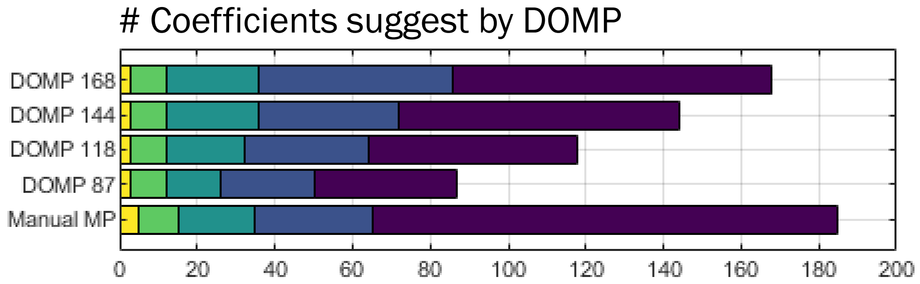
procedure PURSUIT($\boldsymbol{M}^*, \boldsymbol{M}_i, \boldsymbol{M}, \varphi$)
  $\boldsymbol{P}^* \leftarrow \boldsymbol{M}^{*\{\tau,\sigma\}} \cup \boldsymbol{M}_i^{\{\tau,\sigma\}}, \boldsymbol{P} \leftarrow \boldsymbol{M}^{\{\tau,\sigma\}}$
  $\varphi_n \leftarrow \frac{\varphi - \min(\varphi)}{\max(\varphi - \min(\varphi))}$
  $\varphi_s, s_{\mathrm{id}} \xleftarrow{\forall \varphi_n > \gamma} \mathrm{sort}_{\mathrm{desc}}(\varphi_n)$ *<- Score threshold*
  $\boldsymbol{P}_s \leftarrow \boldsymbol{P}^{\{s_{id}\}}$
  if $\boldsymbol{P}_s \cap \boldsymbol{P}^* \neq \emptyset$ **then** *<- Memory preference*
    $j \leftarrow 0$
    repeat
      $j \leftarrow j + 1$
      $j^* \leftarrow s_{id}(j)$
    until $\boldsymbol{P}_s^{\{j\}} \in \boldsymbol{P}^*$
  else
    $j^* \leftarrow s_{id}(1)$
  end if
  return j^*
end procedure

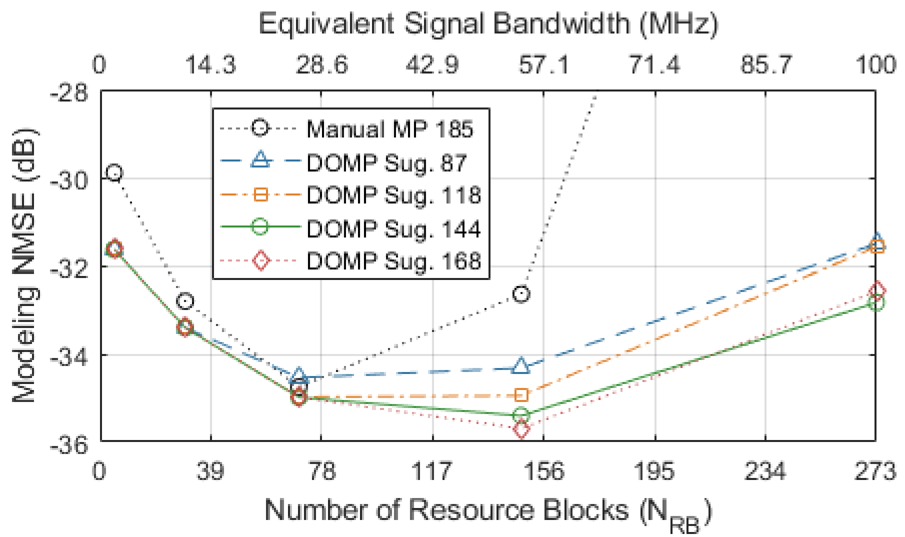


DOMP for IBW GMP Basis Selection

- Here shows the modeling results by the IBW DOMP.



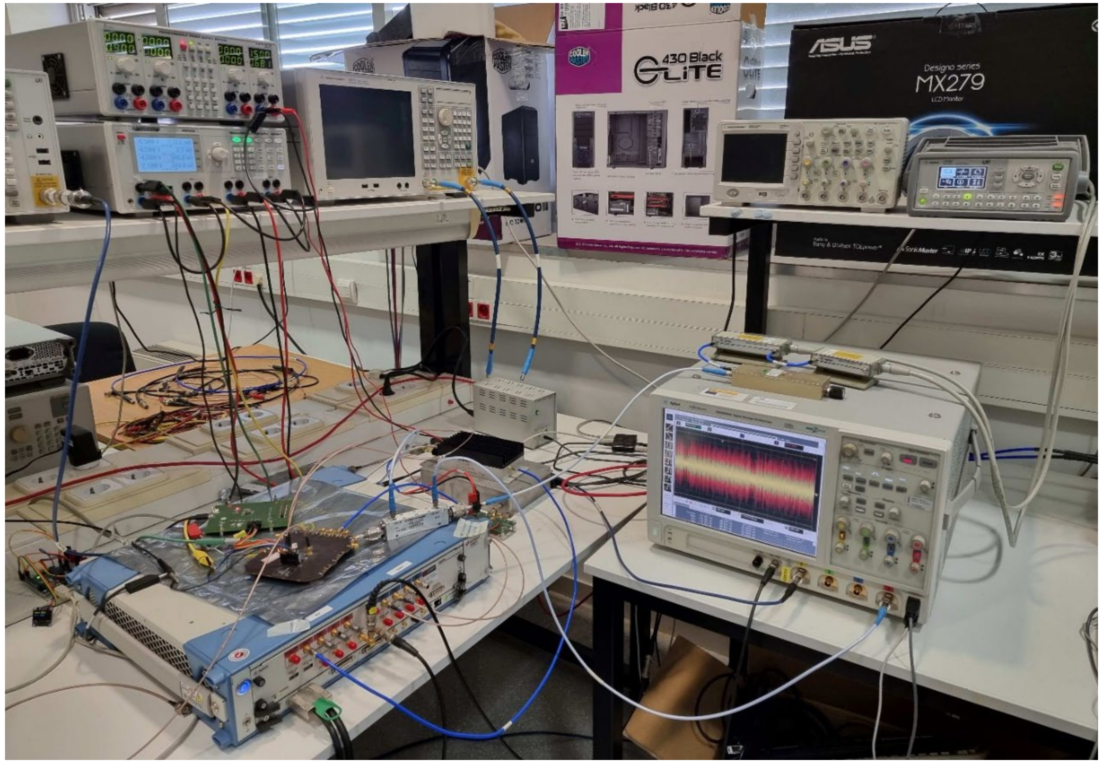


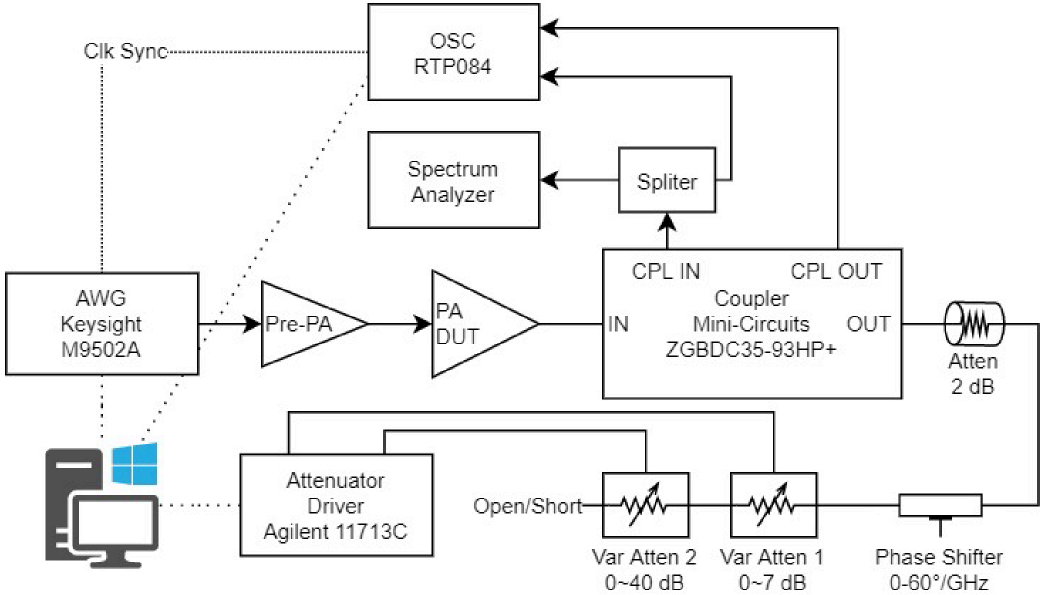


$$d_i[n] = \sum_{k_i=1}^{K_i} w_{k_i} u[n-\tau_{k_i}] \left| u[n-\tau_{k_i}-\sigma_{k_i}] \right|^{p_{k_i}}$$

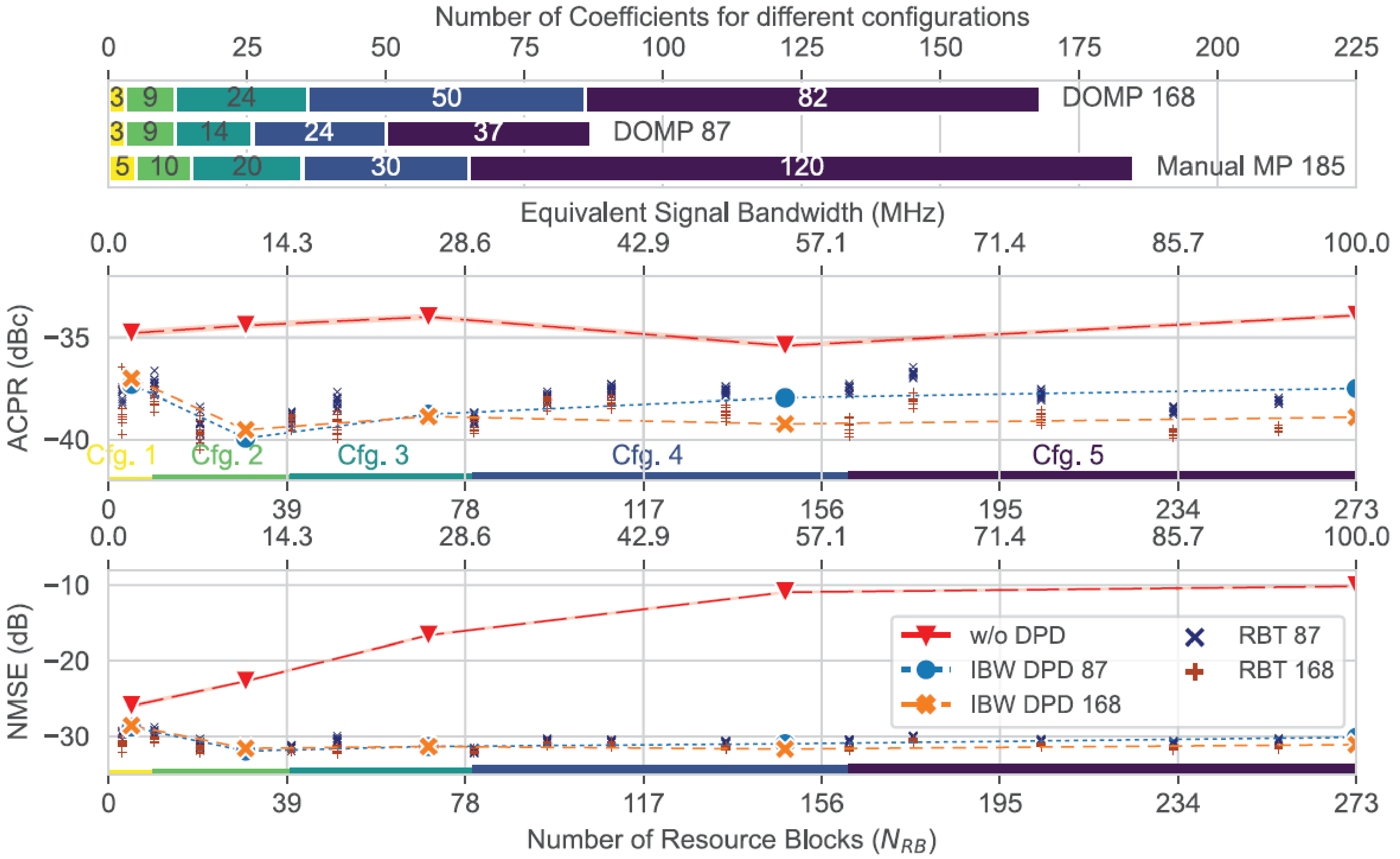
Experimental Setup

- The PA DUT is a SoC solution for handset provided by Huawei Hisilicon.
- Variable attenuator controls the power of reflected wave to have a desired VSWR.
- Phase shifter controls the phase of the reflected wave.





Experimental Results

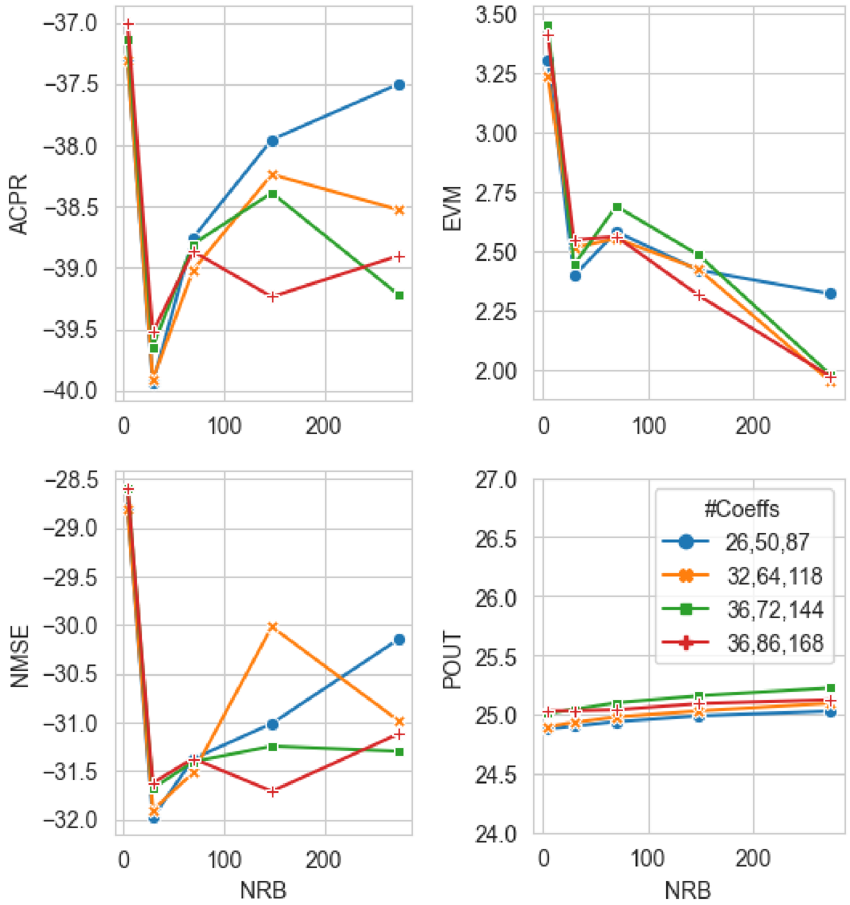


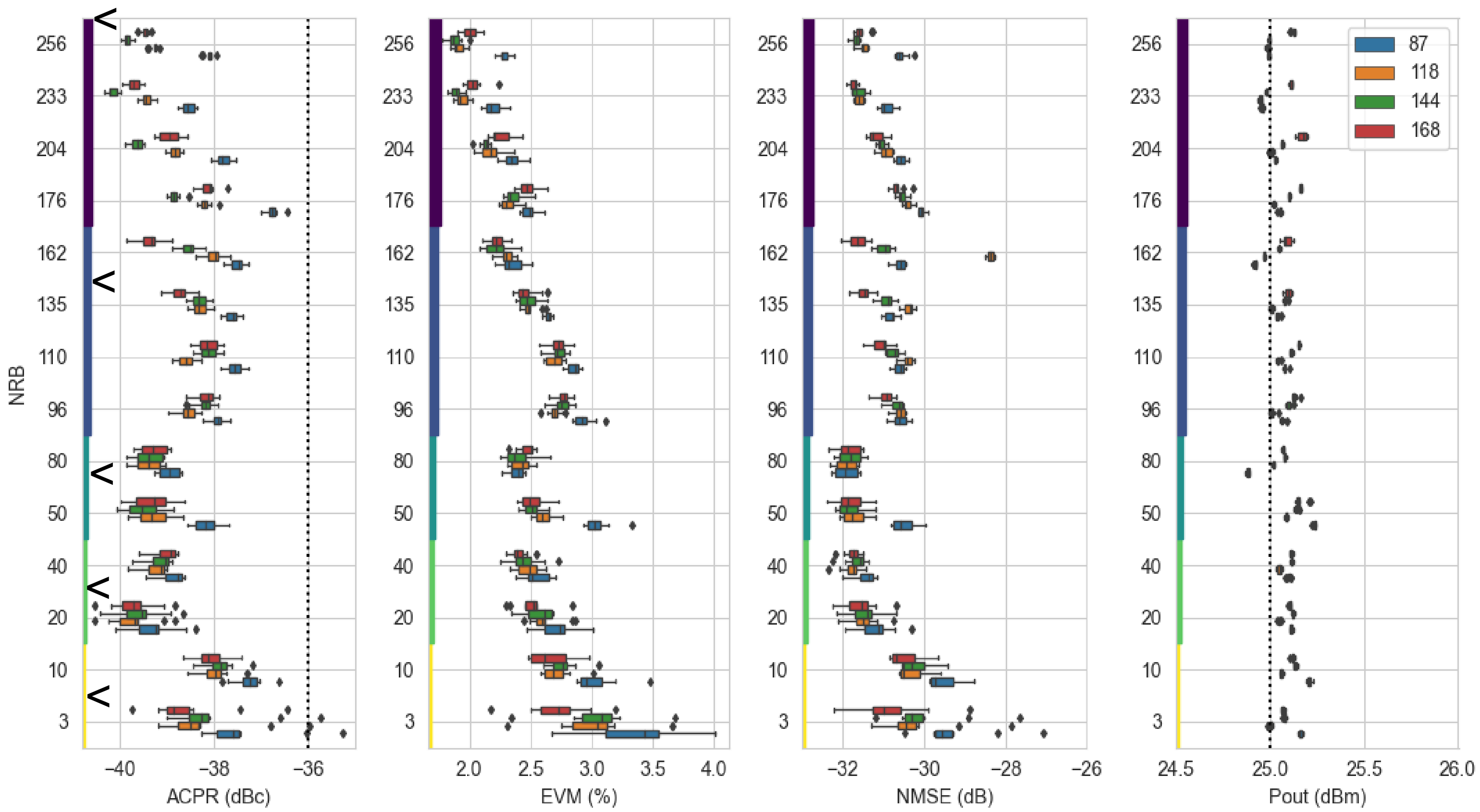
$$N_{\mathrm{RB,train}} = \{5, 30, 70, 148, 273\}$$

$$B = \{10, 40, 80, 162, 273\}$$

Experimental Results

- Performance can be improved by using more coefficients for higher bandwidth.
- In the following test, we fix the coefficients for the first 2 configurations ({3, 9} Coeffs.).
- For the 3rd, 4th and 5th configurations, we use different number of coefficients.





Summary

- We presented the IBW DPD model.
- The constrained DOMP for IBW GMP basis selection:
  - To maximize the orthogonality between the basis and the IBW residual error.
  - Flexible to trade-off the number of basis for linearization performance.
- Tested under un-matched condition and different bandwidth.
  - The IBW DPD can work for the whole 100 MHz channel.
  - It can pass the robustness test with different signals.
- **Future work:**
  - Combine FD and IBW to support both dynamic frequency and bandwidth.

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