Band-limited Digital Predistortion with Band-Switching Feedback Architecture for 5G mmWave Power Amplifiers

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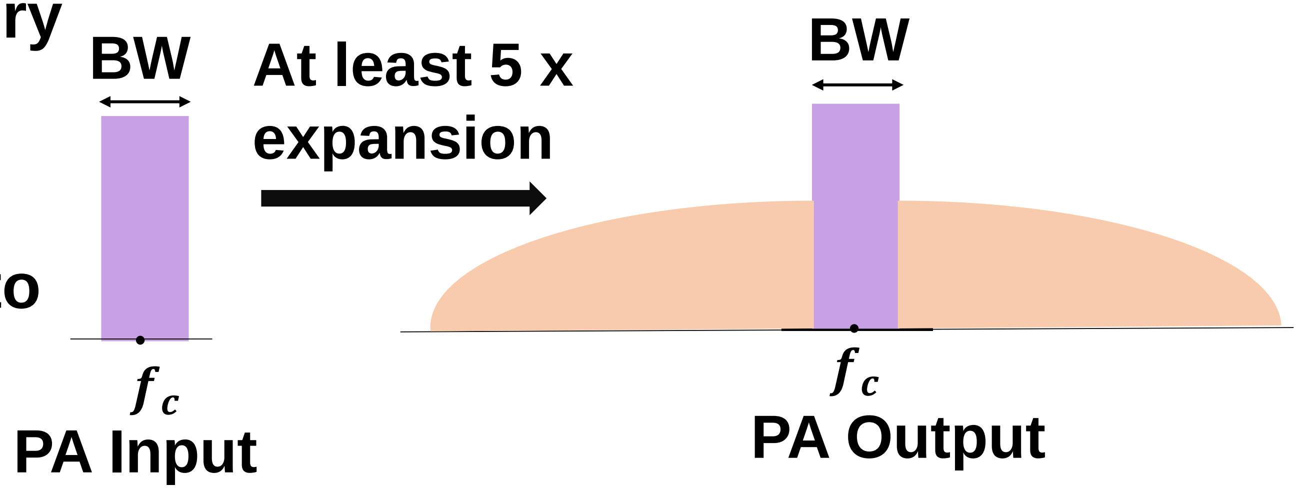
Outline

- Introduction & motivation
- Conventional band-limited digital predistortion
- Proposed band-limited digital predistortion
- Measurement results
- Conclusions

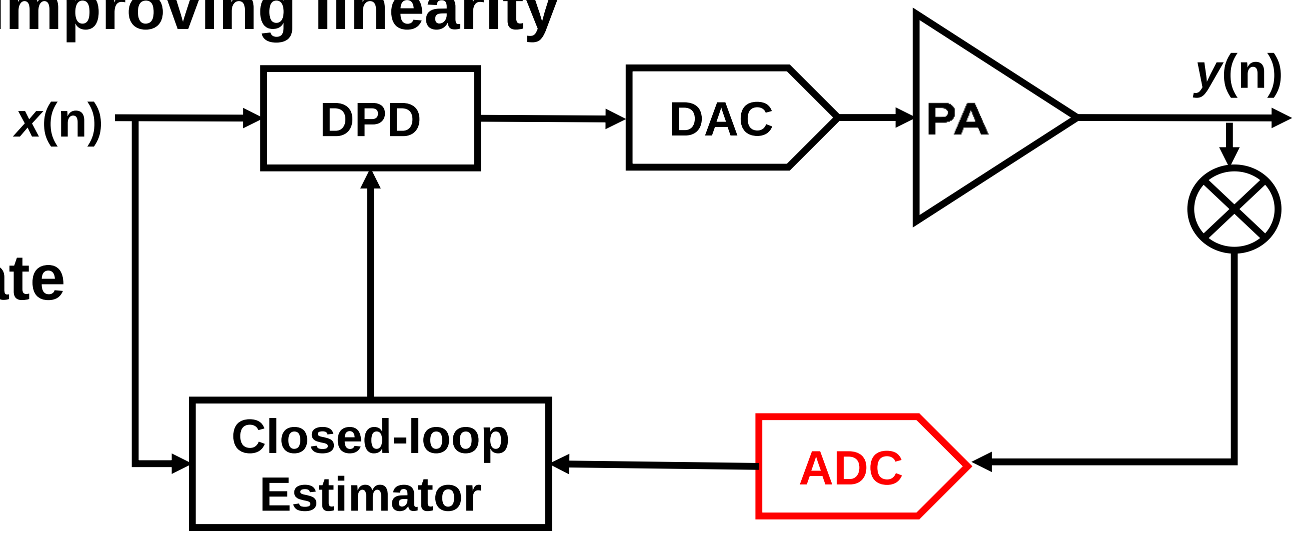
Introduction

- **PA is power-hungry**

- **Operated close to saturation leading to nonlinearity**

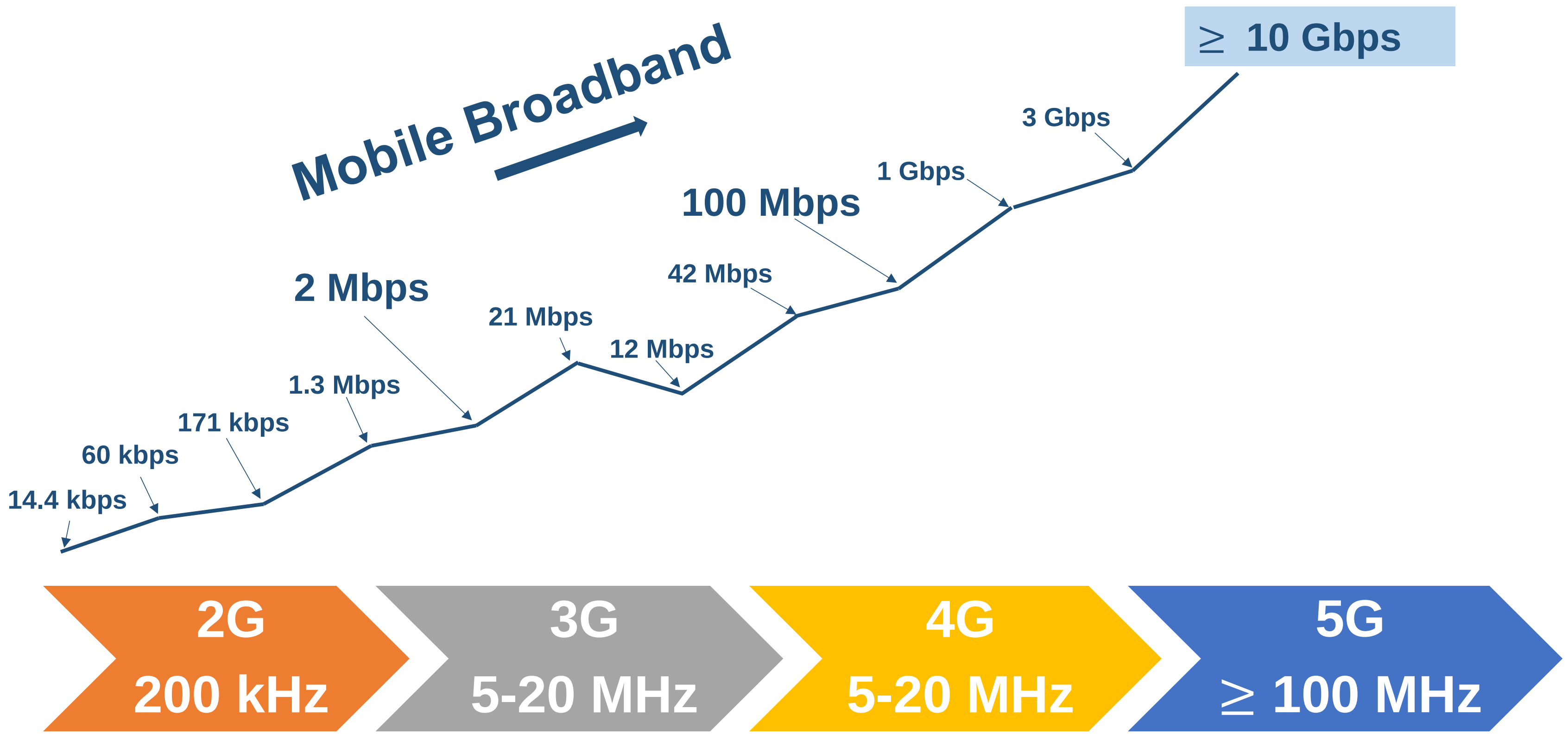


- **DPD is used for improving linearity**



- **ADC sampling rate at least 5 x BW**

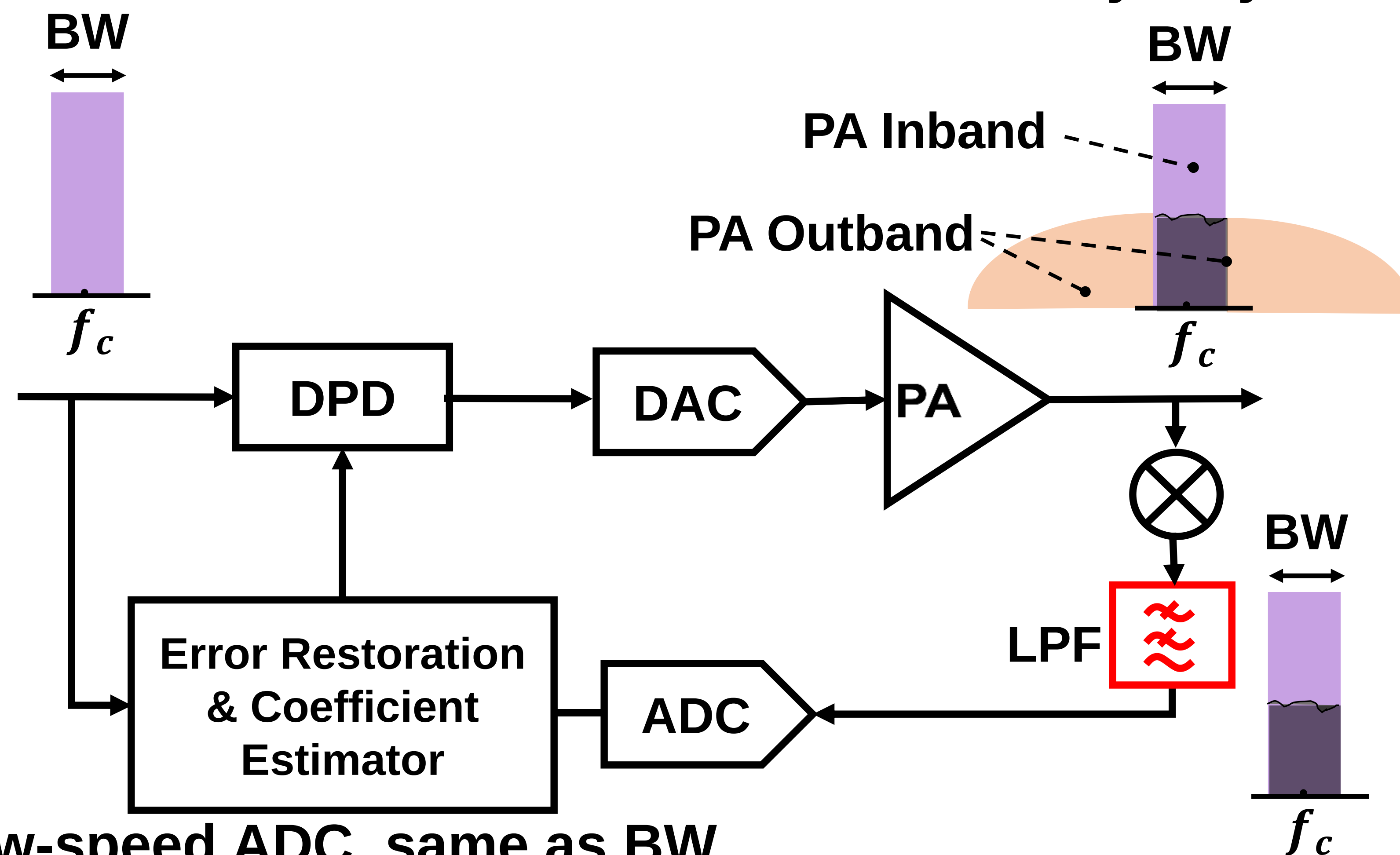
Motivation



- **Bandwidth increased**
- **BW = 800 MHz, 256 QAM, Dual polarization → 12.8 Gbps**
- **ADC sampling rate is 4 GSps – expensive, power hungry**
- **Objective is to realize wideband DPD with low-speed ADC**

Conventional Method

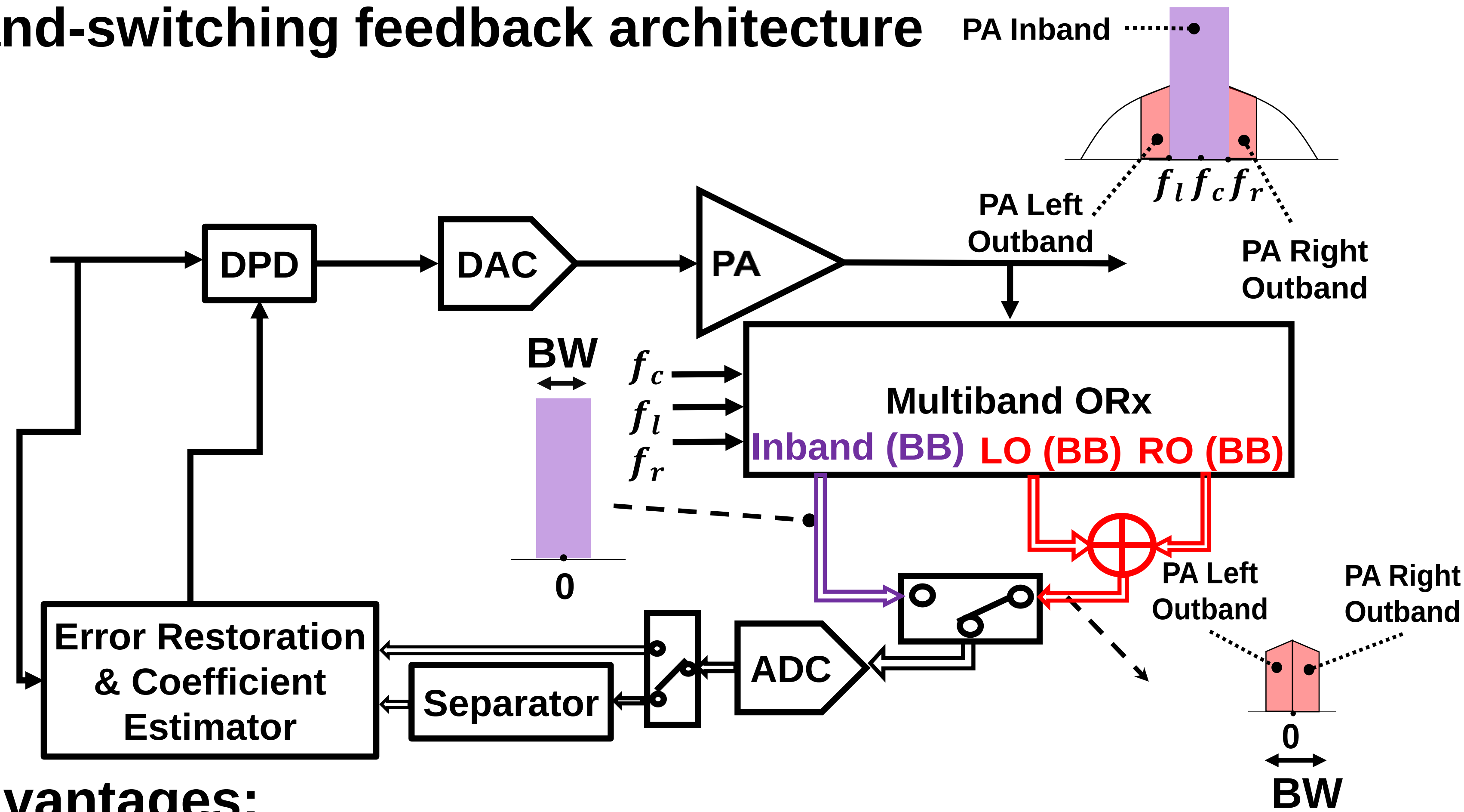
- One solution is to use PA inband nonlinearity only



- Low-speed ADC, same as BW
- Further improvement preferable for higher modulation

Proposed Band-limited Digital predistortion

- **Extraction of PA inband and outbands with low-speed ADC**
- **Band-switching feedback architecture**

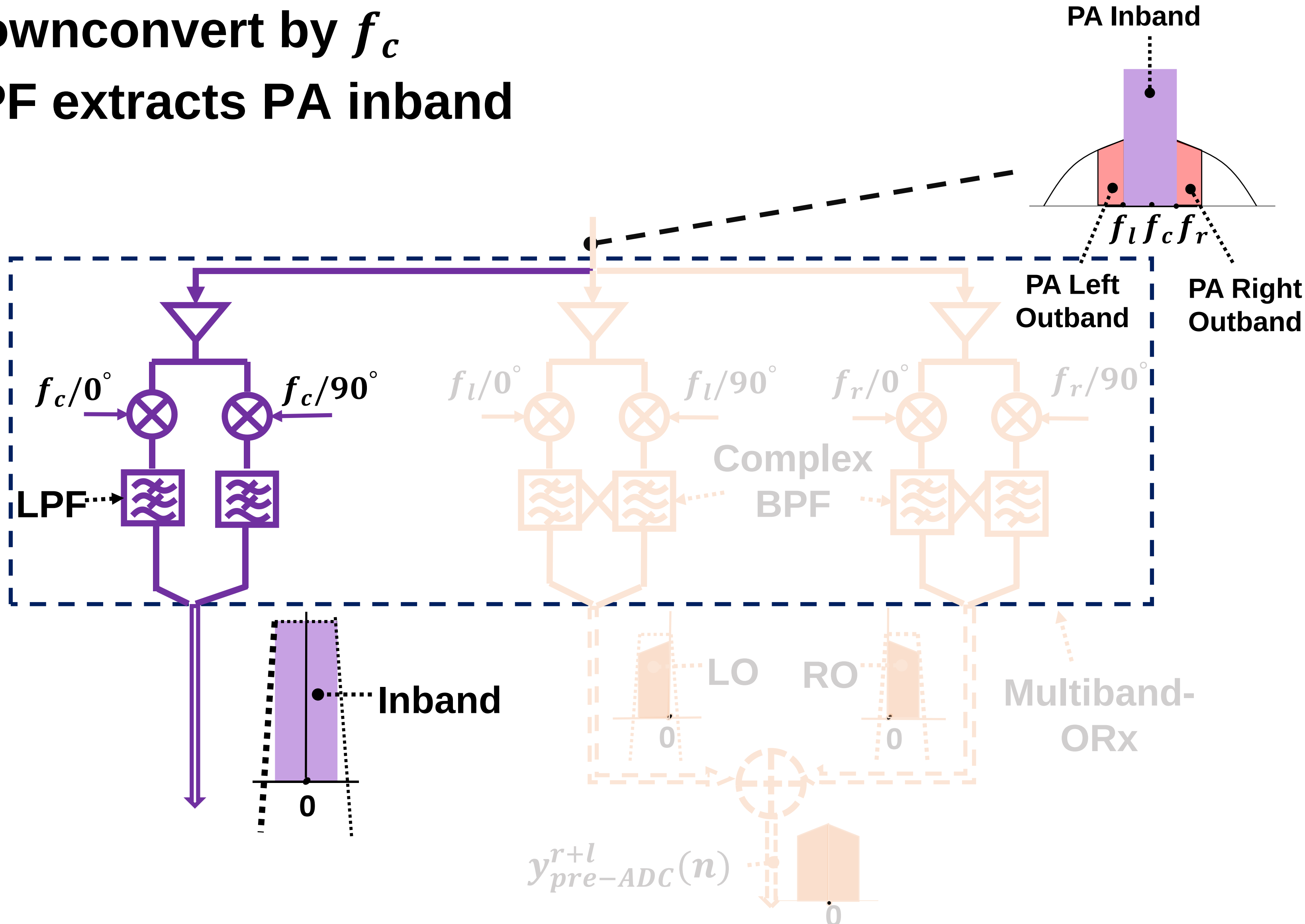


Advantages:

- ADC is low-speed, same as BW
- Further decrease in PA nonlinearity

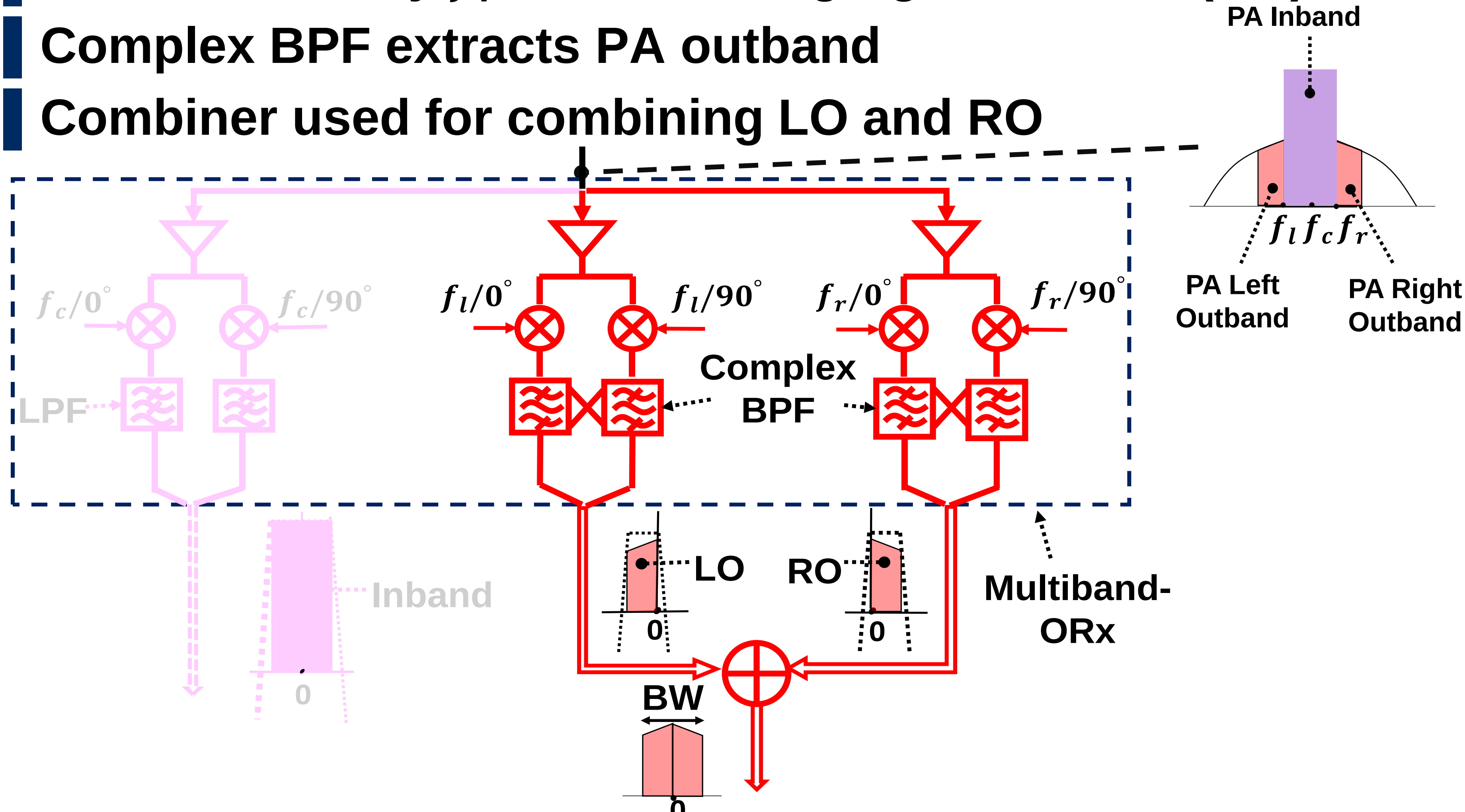
Multiband Observation Receiver (ORx) - 1

- Downconvert by f_c
- LPF extracts PA inband

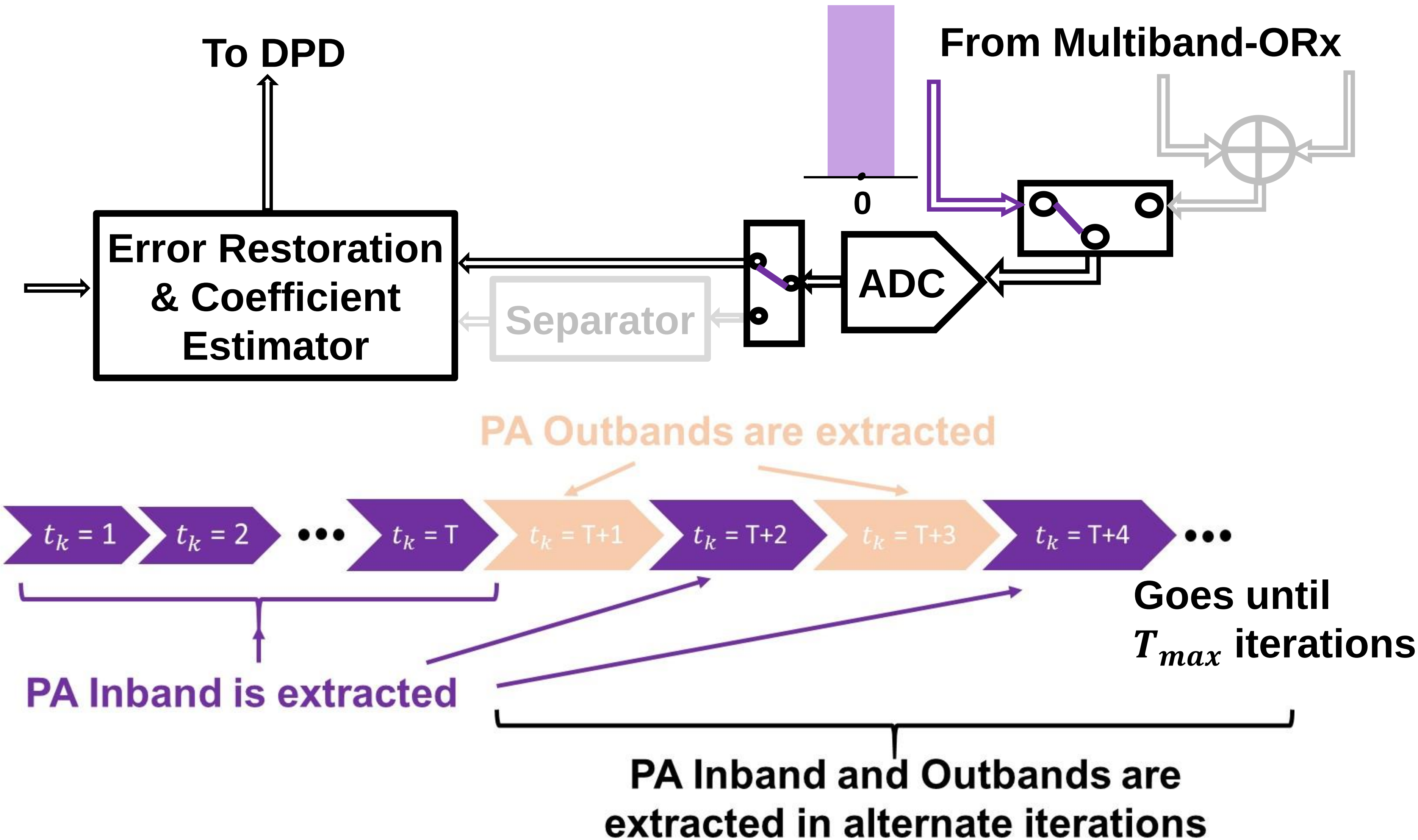


Multiband Observation Receiver (ORx) - 2

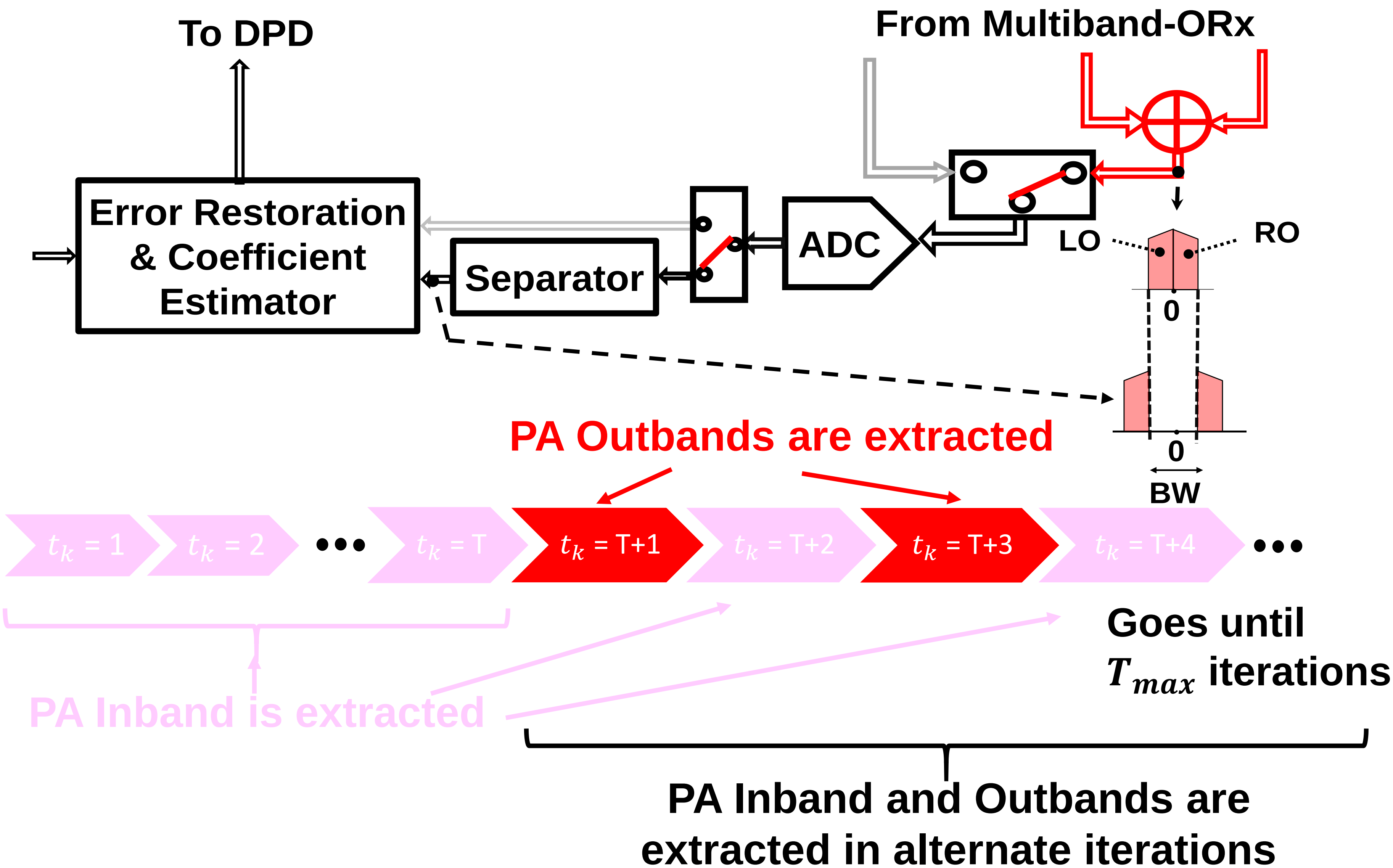
- Downconvert by f_l for extracting left outband (LO)
- Downconvert by f_r for extracting right outband (RO)
- Complex BPF extracts PA outband
- Combiner used for combining LO and RO



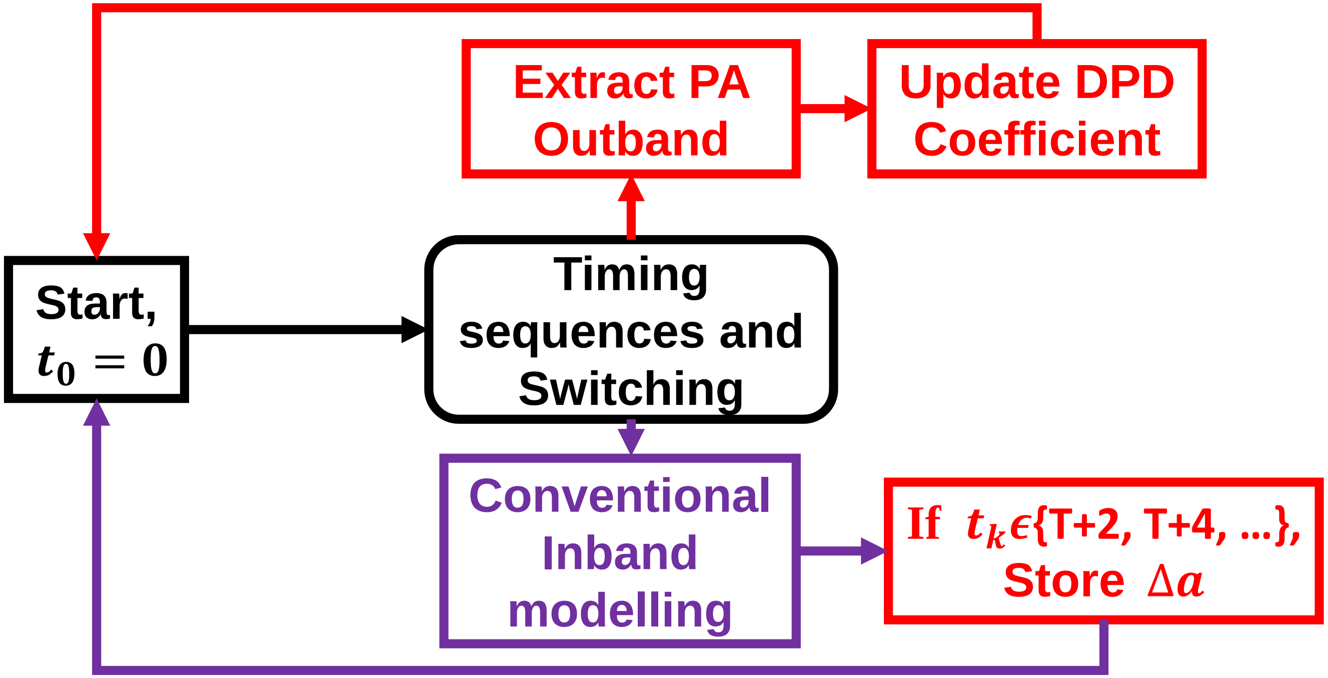
Band Switch – PA Inband



Band Switch – PA Outband



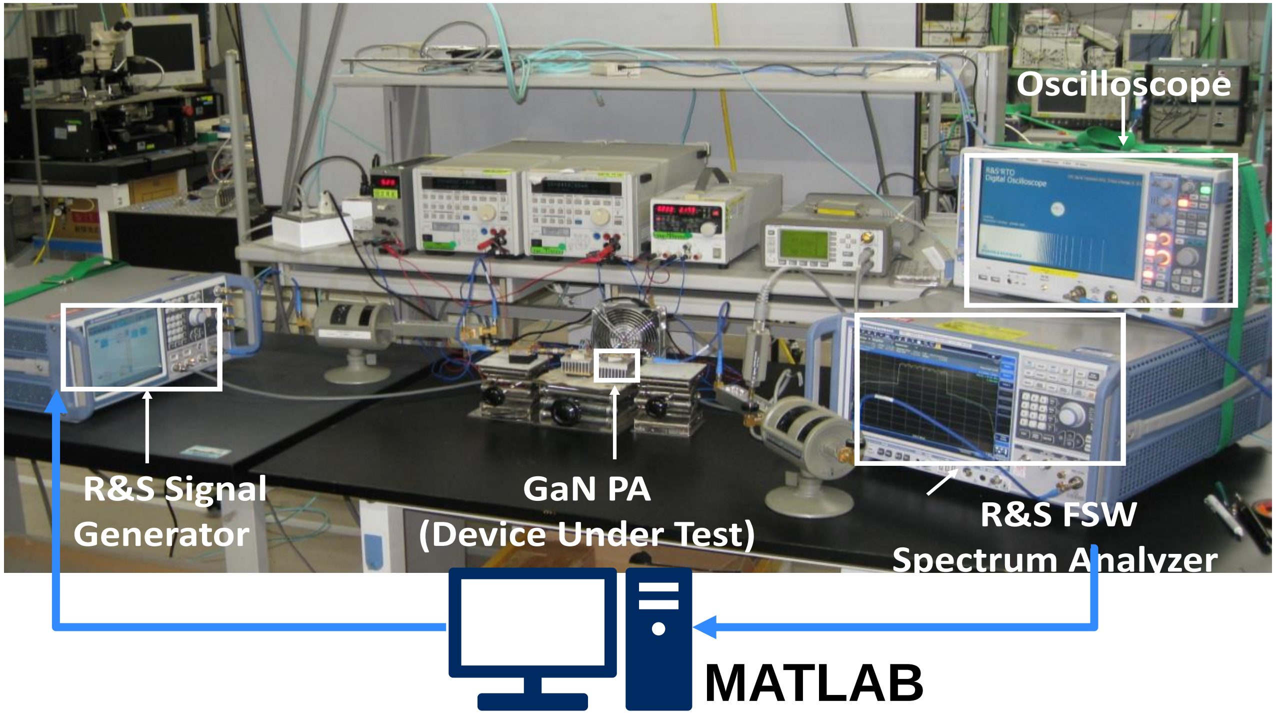
Error Restoration & Coefficient Estimator



- Reconstruct the previous error
- Reconstruct the residual nonlinearity over PA inband and PA outband
- Obtain DPD update from MMSE cost function

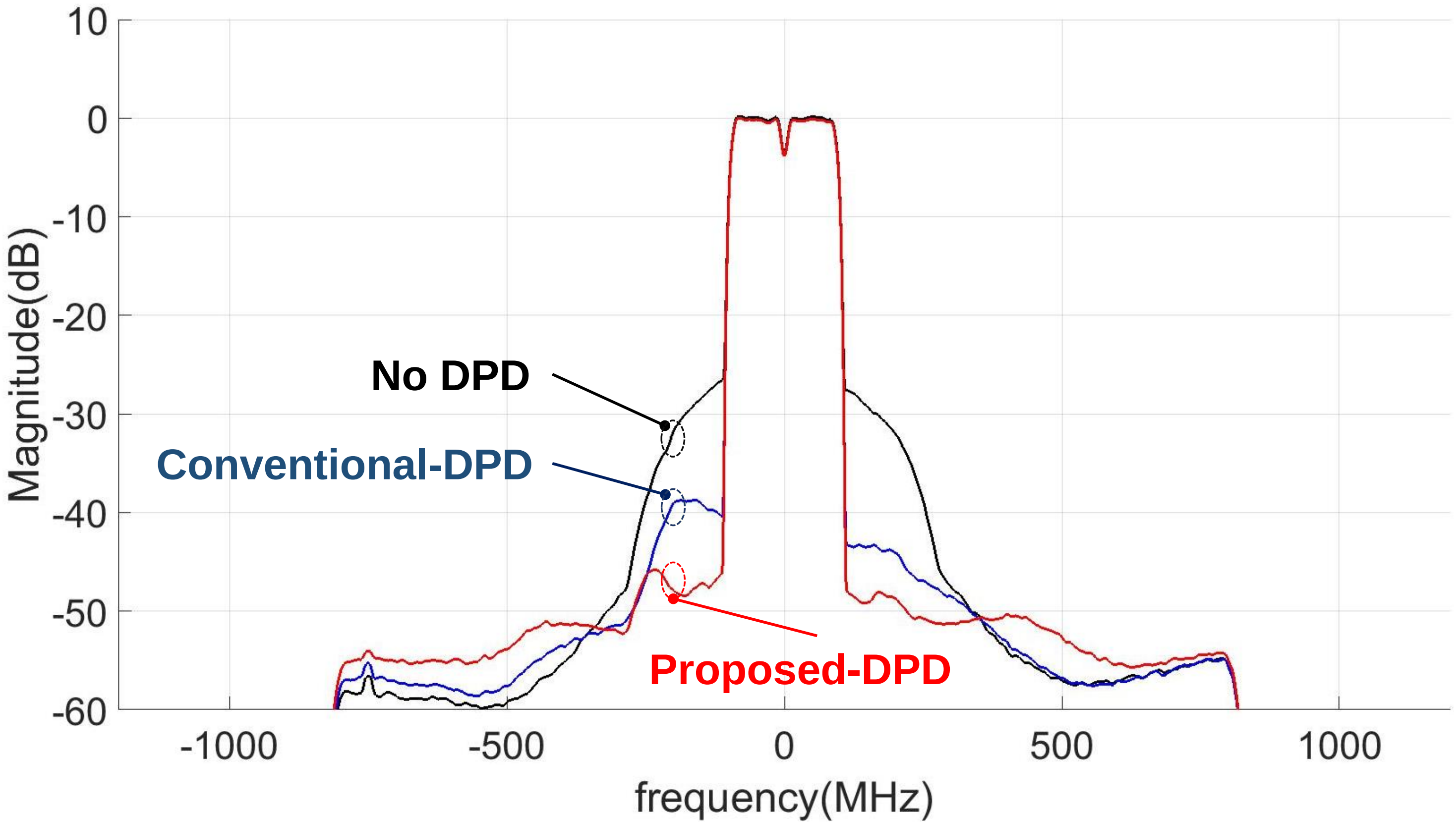
- Residual error in PA inband
- Obtain DPD update from MMSE cost function

Experimental Set-up



- GaN PA with Psat of 37 dBm
- Sampling rate of the Oscilloscope: 2.4 GHz
- Filter implemented in MATLAB has bandwidth of 800 MHz
- DPD model: a Volterra series including memory effect
- Fc = 26 GHz, Modulation: 256 QAM OFDM

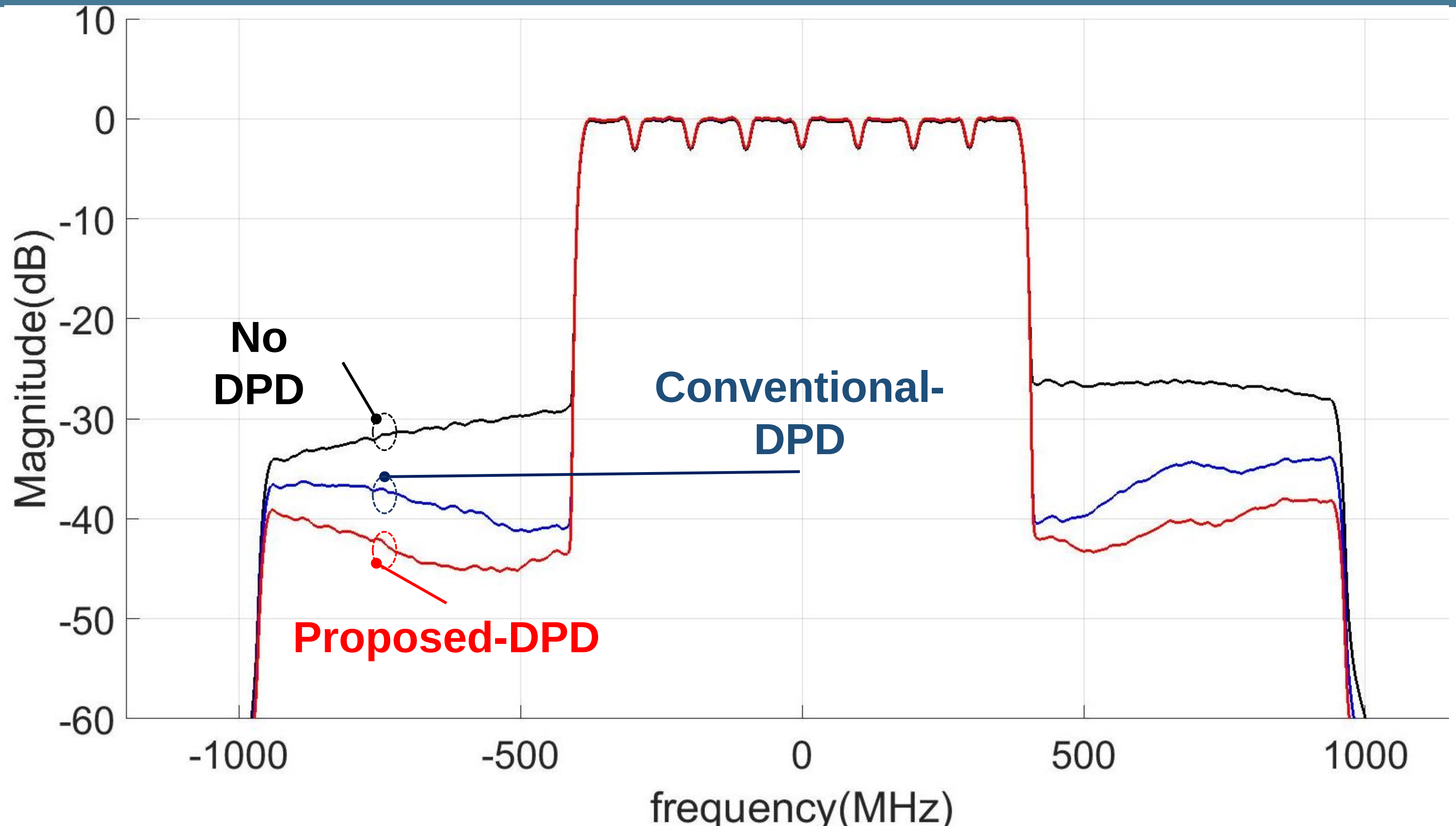
Measurement Results – 200 MHz BW



Bandwidth: 200 MHz (2 x 100 MHz)
PAPR: 7.6 dB

Proposed DPD improves the ACLR by 6~8 dB as compared to conventional DPD

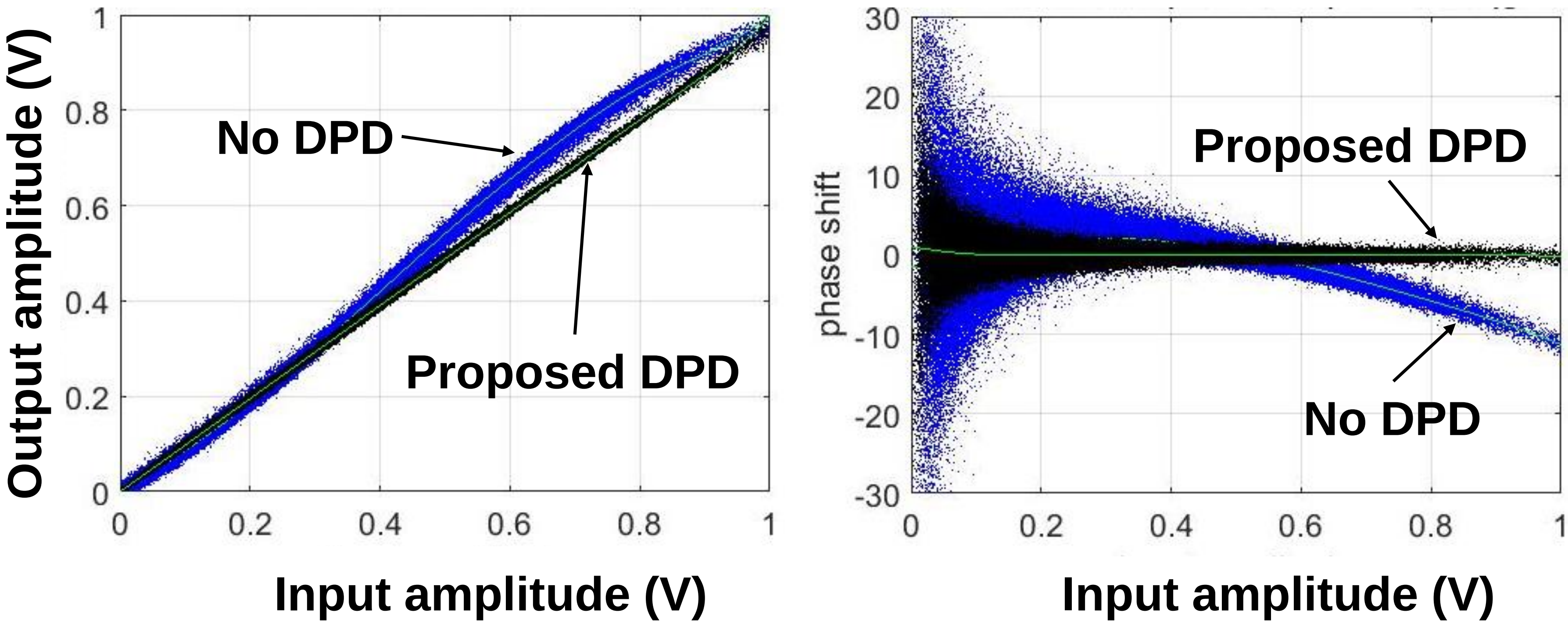
Measurement Results – 800MHz BW



Bandwidth: 800 MHz (8 x 100 MHz)
PAPR: 7.6 dB

Proposed DPD improves the ACLR by 2~3 dB as compared to conventional DPD under 256 QAM OFDM

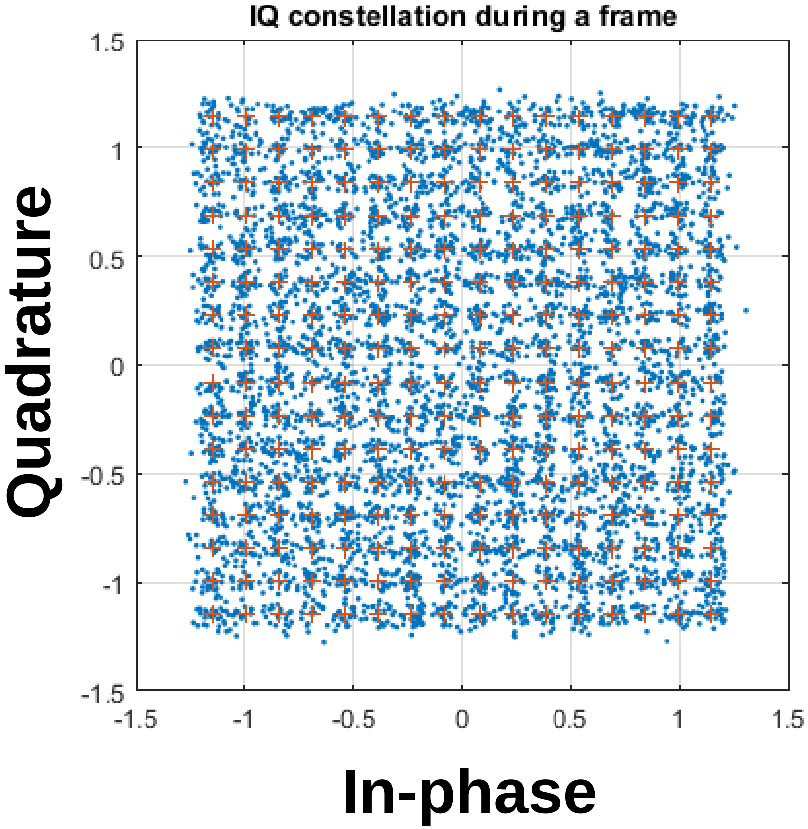
Measurement Results – AM/AM & AM/PM



Bandwidth: 800 MHz
PAPR: 9 dB

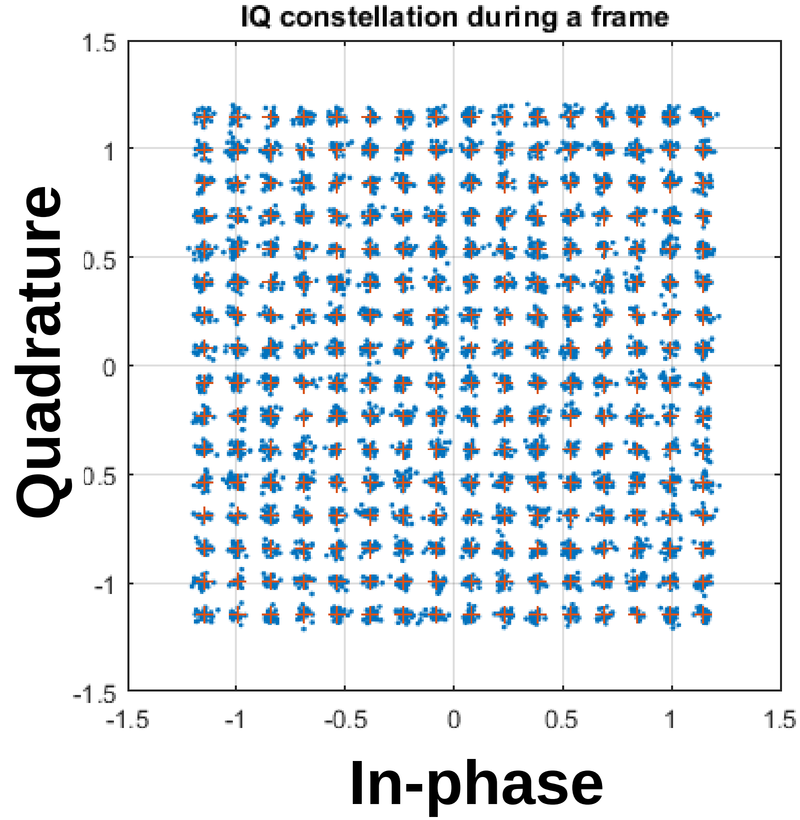
Proposed DPD achieves substantial linearity and the memory effect is also mitigated

Measurement Results – Constellations



No DPD

EVM: 5.01%



Proposed DPD

EVM: 1.33%

Bandwidth: 800 MHz

PAPR: 9 dB

Measurement Results – Summary

Bandwidth: 800 MHz (8 x 100 MHz)

Parameter	PAPR 7.6 dB			PAPR 9 dB		
	No DPD	Conventional DPD	Proposed DPD	No DPD	Conventional DPD	Proposed DPD
ACLR (dBc)	-29/-26.2	-40.7/-40.1	-43.6/-42	-29.1/-26	-43.22/-41.9	-44.4/-42.8
Pout (dBm)	30.2	30.2	30.2	28.5	28.5	28.5
EVM(%)	5.57	3.04	2.96	5.01	1.34	1.33
η_D(%)	10.17	10.09	10.08	8.4	8.26	8.26

Benchmarking

Parameters / Groups	Fc (GHz)	BW (MHz)	PAPR (dB)	ACLR (dB)	EVM (%)	Pout (dBm)	ADC BW (MHz)	η_D(%)
[1]	20	200	7	-45.5/ -45.5	-	-	98.304	-
[2]	24	320	6	-47	-	-	500	-
[3]	30	200	-	-48	1.6	15*	500 (MSa/s)	-
[3]	30	800	8.5*	< 45*	-	15*	2000* (MSa/s)	
This work (7.6 dB)	26	200	7.6	-50.1/ -51.4	3.41	30.5	200	-
This work (PAPR 7.6 dB)	26	800	7.6	-43.6/ -42	2.96	30.2	800	10.08
This work (PAPR 9 dB)	26	800	9	-44.4/ -42.8	1.33	28.5	800	8.2

[1] Q. Zhang et al., 2017 89th IEEE ARFTG Microwave Measurement Conference
[2] Y. Beltagy et al., 2017 IEEE IMS
[3] S. Boumaiza, 2017 IEEE MTT-S IMS Workshop

*** Estimated**

Conclusion

- Wideband DPD for 5G mmWave PA
- A band-switching feedback architecture for improving the linearity while keeping narrow ADC bandwidth
- Verification of the performance using 26 GHz GaN PA
  - ACLR of -51 dB and EVM of 3.41% with Pout of 30.5 dBm is achieved for 200 MHz at 256 QAM OFDM modulation
  - ACLR of -43 dB and EVM of 2.96% with Pout of 30.2 dBm is achieved for 800 MHz at 256 QAM OFDM modulation

Thank you

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DPD Model

- **Volterra Series**
- **Nonlinear**

Basis Functions

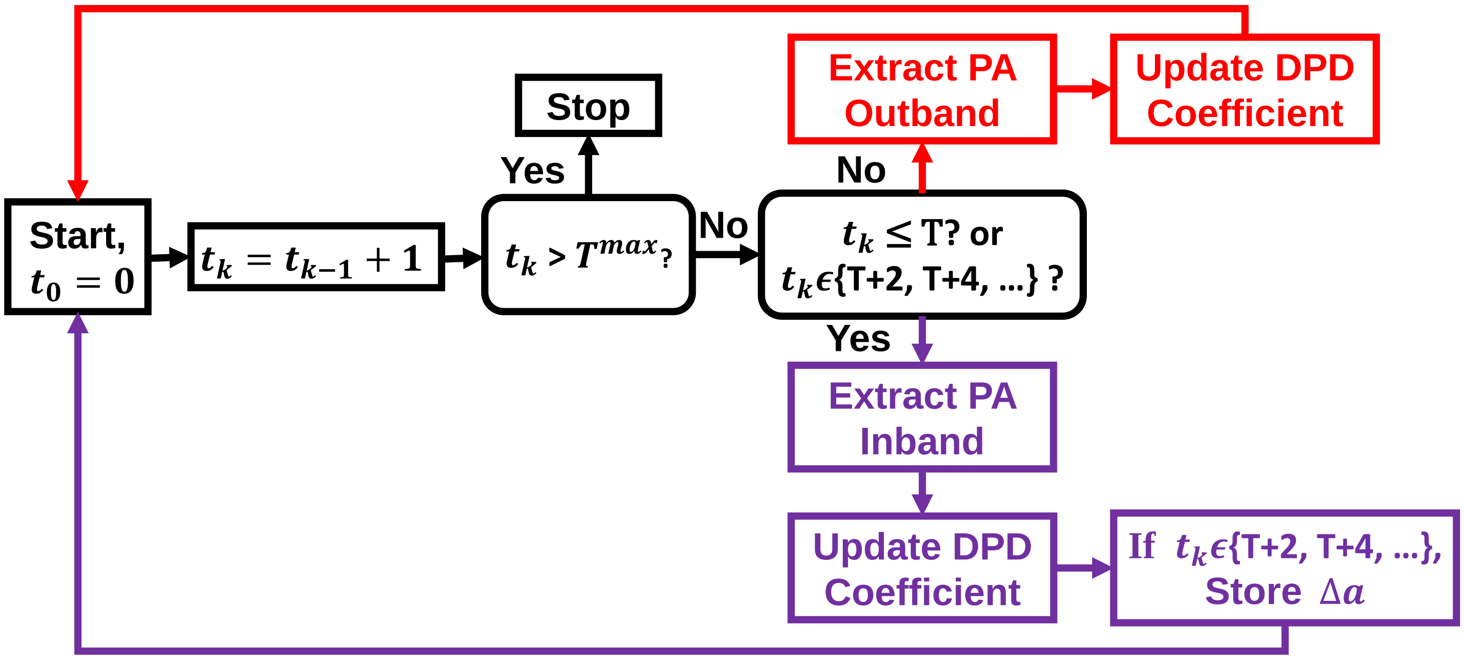
The DPD model used:

$$\sum_{(p,m)} a_{i,p,m}|x(n-m)|^{p-1}.\,x(n-m) + \sum_{(p,m)} a_{j,p,m}|x(n-m)|^{p-1}.\,x(n)$$
$$+\sum_{(p,m)} a_{k,p,m}|x(n)|^{p-1}.\,x(n-m)$$

p is nonlinearity order and m is the memory tap

$a_{i,p,m}$, $a_{j,p,m}$ and $a_{k,p,m}$ **are DPD coefficients**

Error Restoration & Coefficient Estimator



Reconstruct the previous error:

$$\varepsilon^{t_{k-1}}(n) \approx \boldsymbol{\psi}_{t_{k-1}}(n).\Delta \boldsymbol{a}^T$$

Reconstruct the residual nonlinearity:

$$\varepsilon^{r+l+i,t_k}(n) = \delta.G_o^{-1}.y^{r+l,t_k}(n) + \varepsilon^{t_{k-1}}(n)$$

Cost function for closed-loop estimator:

$$\boldsymbol{K_{DPD}} = \boldsymbol{E}[|\varepsilon^{r+l+i,t_k}(n) - \boldsymbol{\psi}_{r+l+i}(n).\boldsymbol{\Delta a}^T|^2]$$

Residual error in PA inband:

$$\varepsilon^{t_k}(n) = G_o^{-1}y^{t_k}(n) - x(n)$$

Cost function for the estimator:

$$J_{DPD} = E[|\varepsilon^{t_k}(n) - \boldsymbol{\psi}_{t_k}(n).\Delta \boldsymbol{a}^T]$$

Obtain the update:

$$\boldsymbol{a}(t_k) = \boldsymbol{a}(t_{k-1}) - \beta.\boldsymbol{\Delta a}$$