Issues for Multi-Band Multi-Access Radio Circuits in 5G Mobile Communication

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Outline

- Background
- Requirements for 5G Hardware
- Issues for Tx and Rx
- Advanced DPD techniques
- Post compensation technique for Rx
- Reconfigurable BPF
- Conclusion

From 4G to 5G

- 5G Mobile Communication will be changed to accept the diversity of ;

  - ✓ Different access protocols with wide range of spectrum from 700 MHz to more than 6 GHz (~millimeter wave)
  - ✓ Heterogeneous deployment with different cell sizes,
  - ✓ Carrier aggregation (CA) and dual access from UEs,
  - ✓ Cooperated multiple transmission (CoMP), massive MIMO and distributed antenna systems (DSA).

In order to achieve more efficient and flexible use of radio resources, separation of C-plane and U-plane has been studied.

Requirements for 5G Hardware

- High bandwidth of 10 Gbps or more
- Utilizing widely-spread frequency bands from current UHF to low SHF, high SHF and millimeter waves
- Low-power/cost small base station and Dual Access to both Macro- and small-cells with different frequency bands
- High Accuracy RF signals are required to increase spectral efficiency

5G hardware is required to be more flexible, accurate, linear and low-cost.

Issues for Transmitter

- Keeping linearity and power efficiency in a wider unit RF bandwidth of 100MHz or more.
- Keeping linearity and power efficiency under concurrent multiband operation

⇒ Nonlinear Compensation Techniques should be developed that can work in a wider bandwidth and multi-band environments.

We proposes advanced Digital Predistortion (DPD) techniques called SENF and SFFB

Issues for Receiver

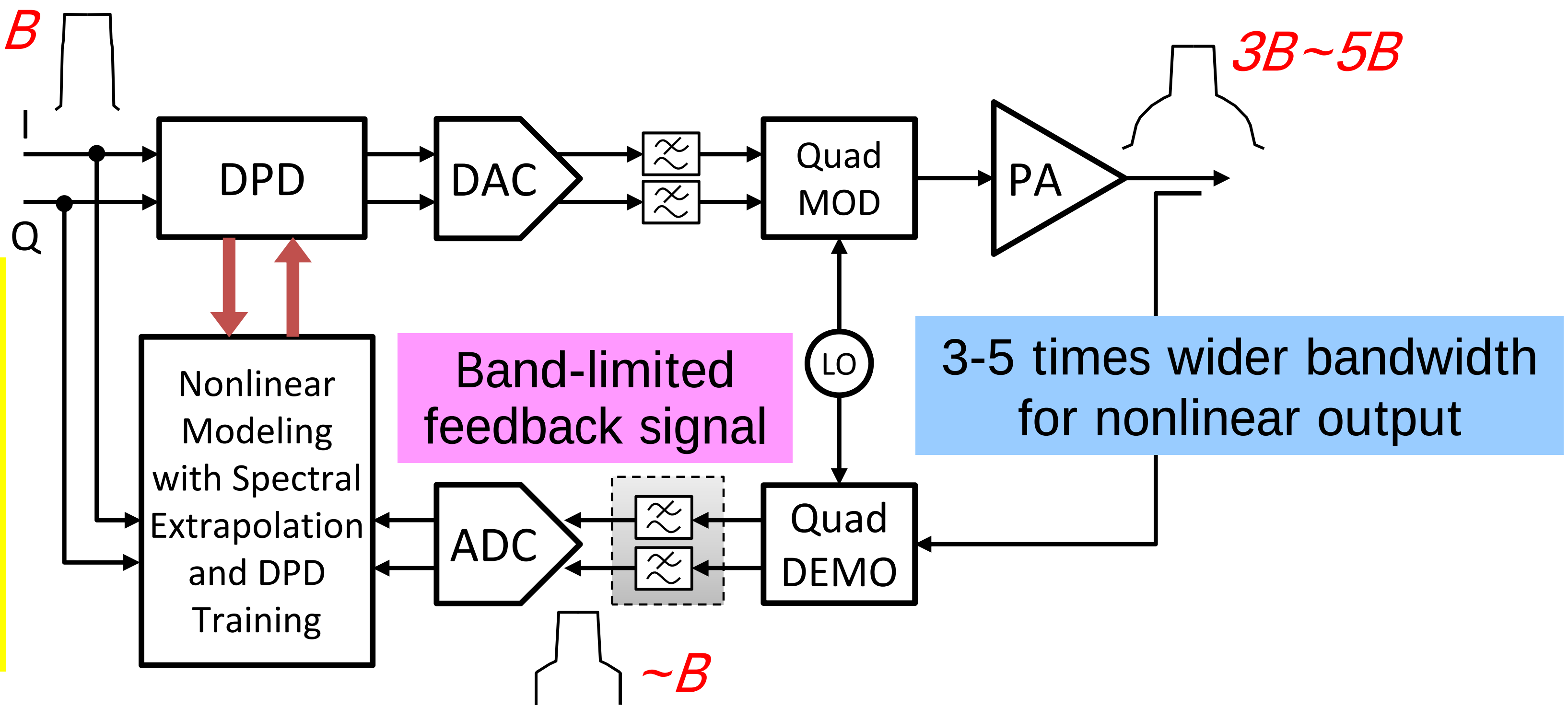
- Receiver front-end faces a variety of incoming signals with power of wide dynamic range.
  Desired signals are not always stronger than others.
- Under concurrent multiband operation, near-far problem increases chance of inter-band modulation called "cross-modulation distortion".

➡ Receiver Nonlinearity Compensation technique and reconfigurable RF BPF as pre-selector mitigate the issues.

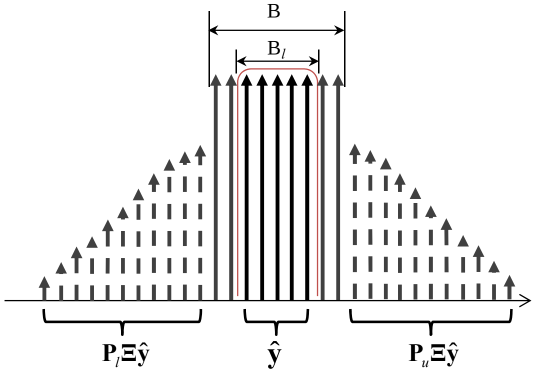
We proposes a Post Compensation technique and Reconfigurable BPF for concurrent dual-band receiver.

1. Wideband DPD Design Method

- Existing DPDs have been designed to feedback full bandwidth of nonlinear output signal, requiring 3 to 5 times wideband ADC.

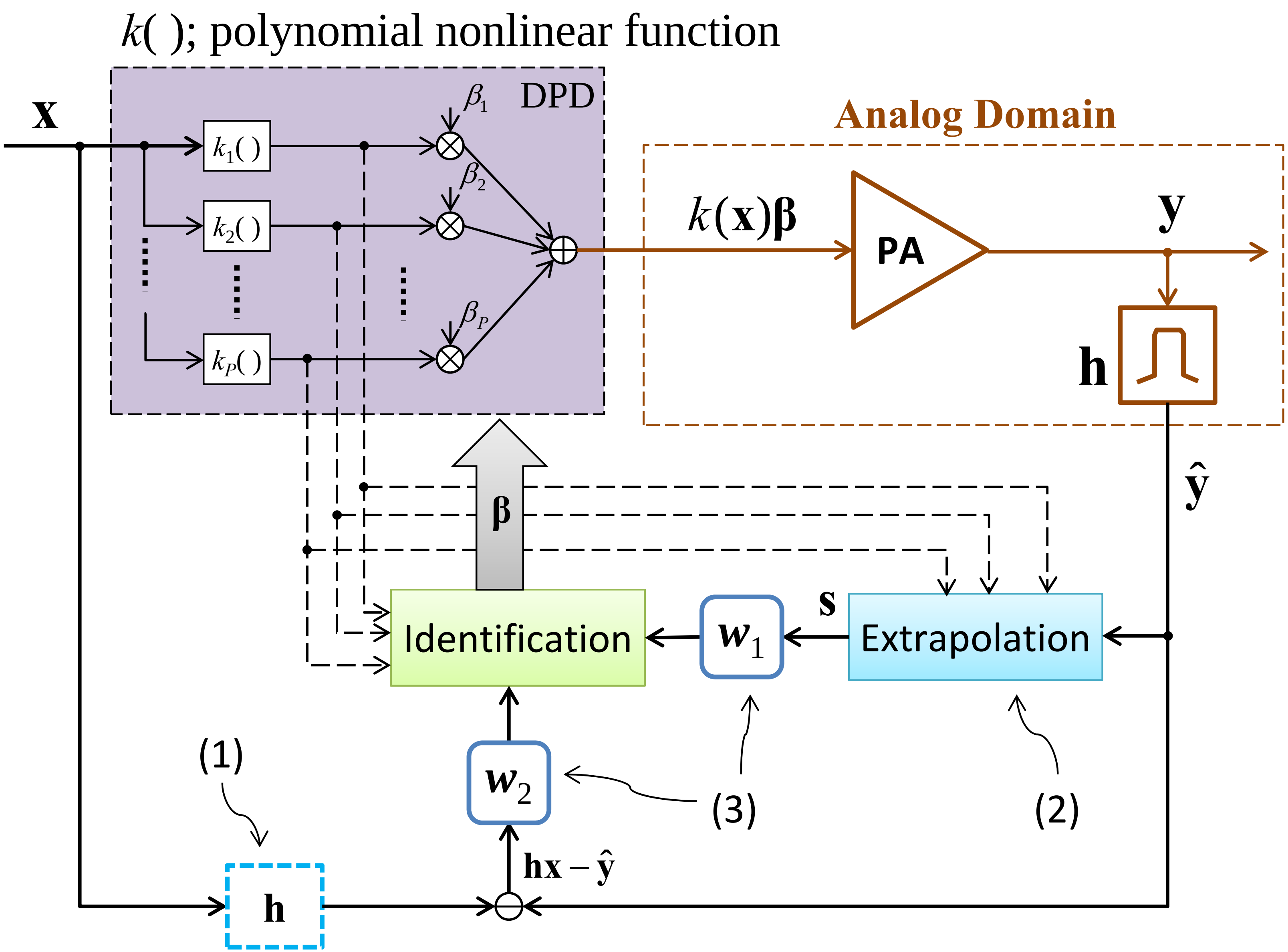


Iterated Nonlinear Modeling with Spectral Extrapolation of Narrowband Feedback signal



With SENF (Spectral Extrapolation of Narrowband Feedback) technique, feedback bandwidth can be same as the signal bandwidth (or even less) [1].

SENF DPD Equivalent Baseband Diagram

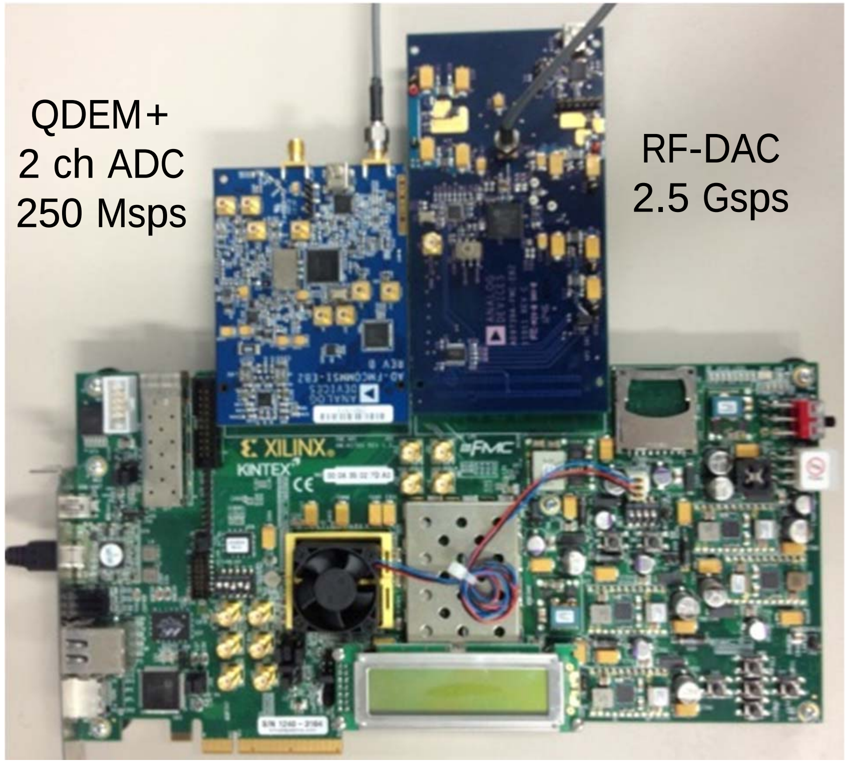


SENF DPD by FPGA

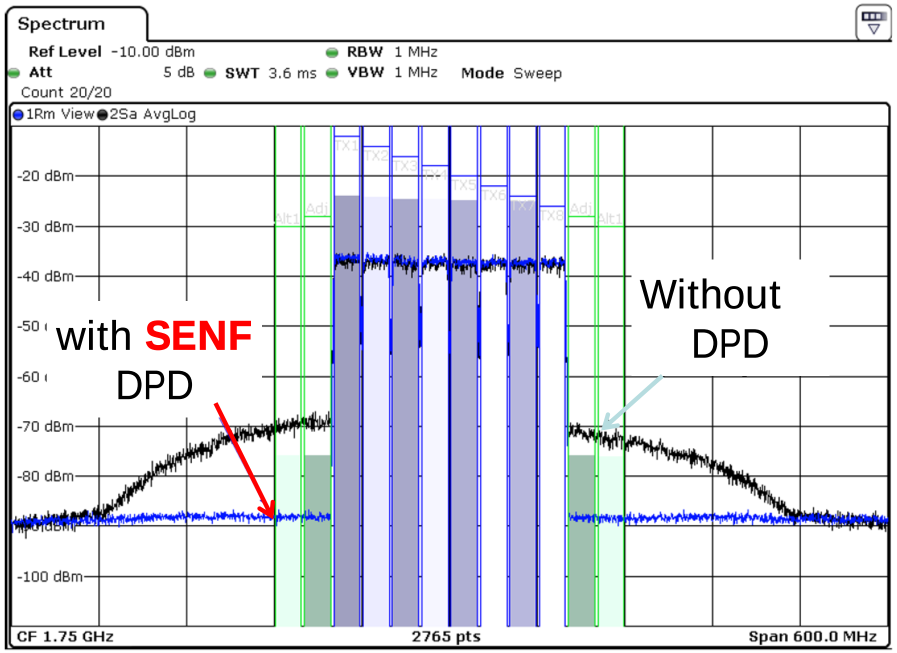
- More than 100 MHz Linearization is possible with current FPGAs with 250 Msps ADC by SENF method.

RF: 1.75 GHz

In Out



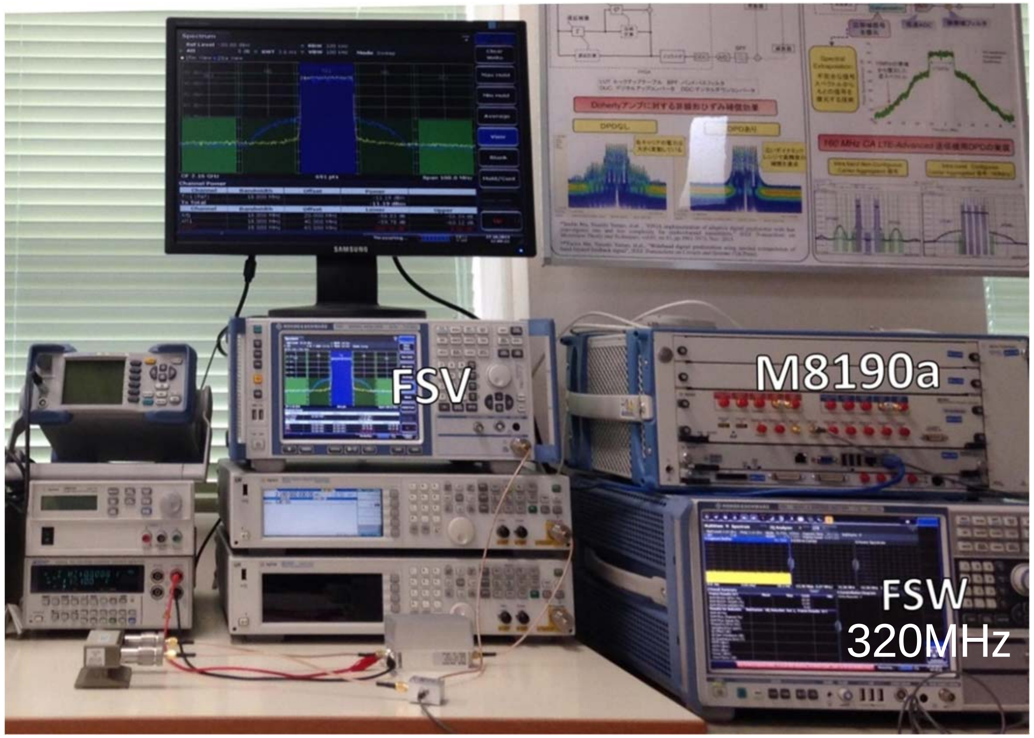
160MHz bandwidth DPD
by Xilinx Kintex7 FPGA



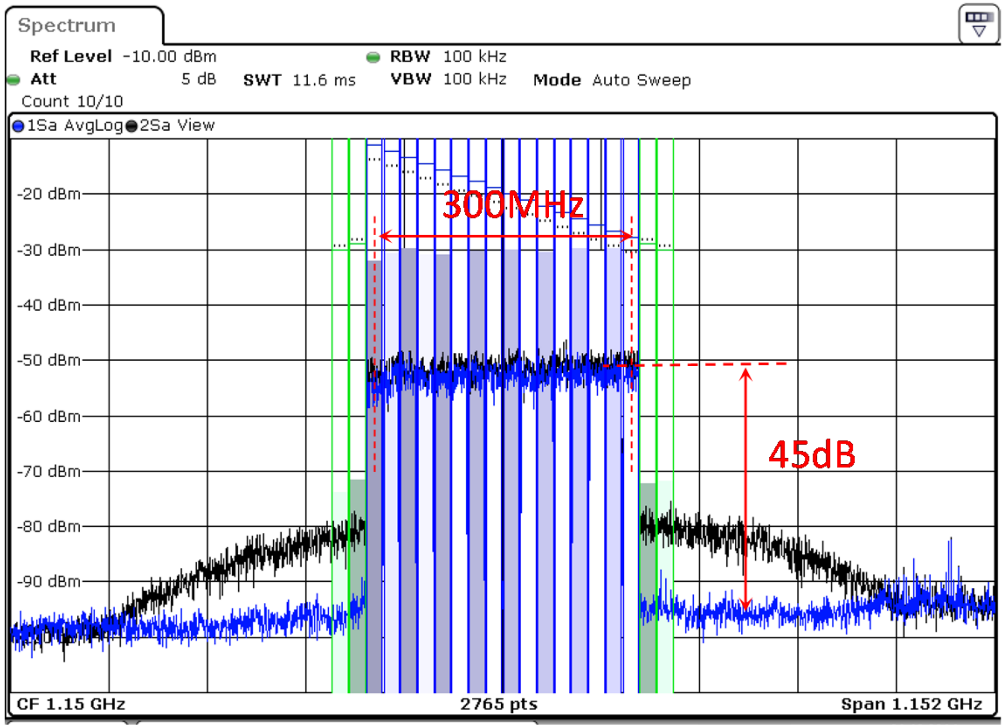
8 x 20MHz LTE CA signal (160MHz)

SENF DPD by Experiment (1)

- More than 300 MHz Linearization is confirmed in Experiment [2].



320MHz feedback bandwidth DPD
by measurement set up

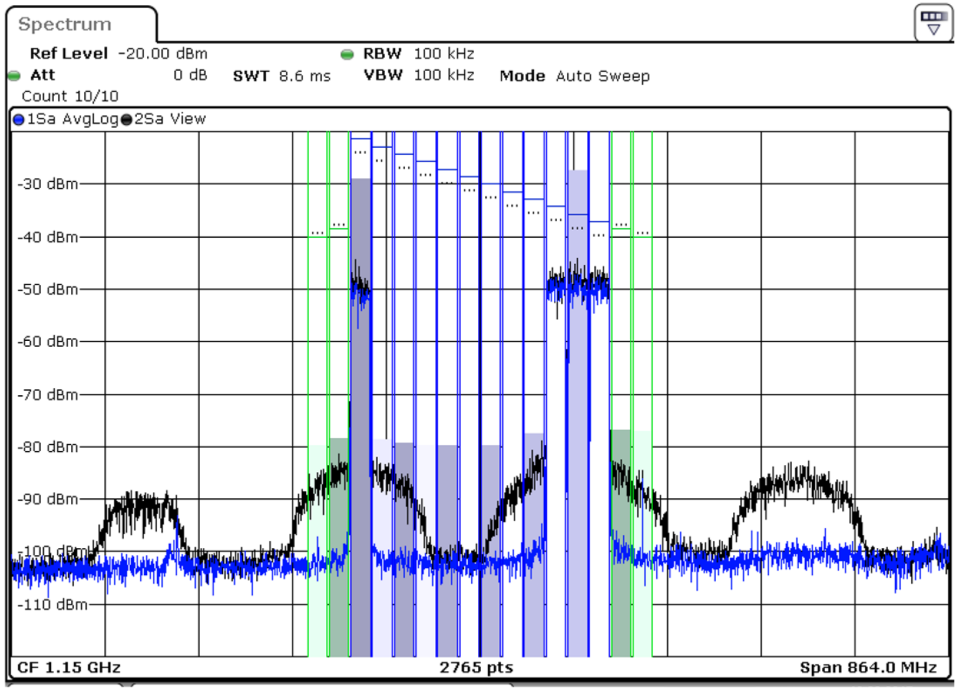


16 x 20MHz LTE CA signal (320MHz)

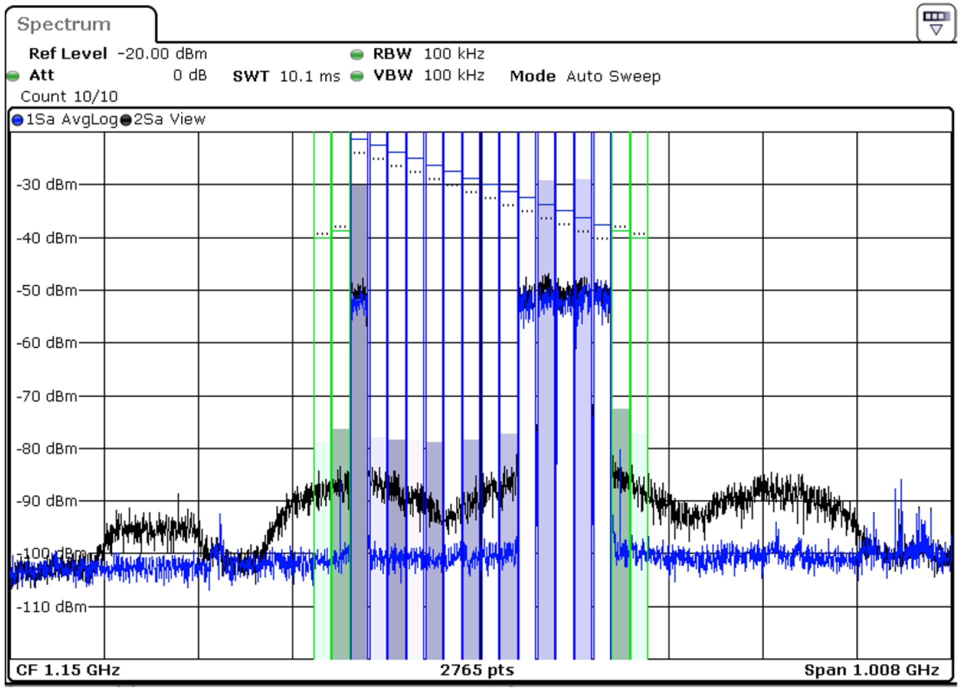
Linearization of signal with 500 MHz and beyond bandwidth will be achieved soon by DPD.

SENF DPD by Experiment (2)

- Proposed DPD can compensate non-continuous CA signal.



4 x 20MHz LTE CA signal (240MHz)

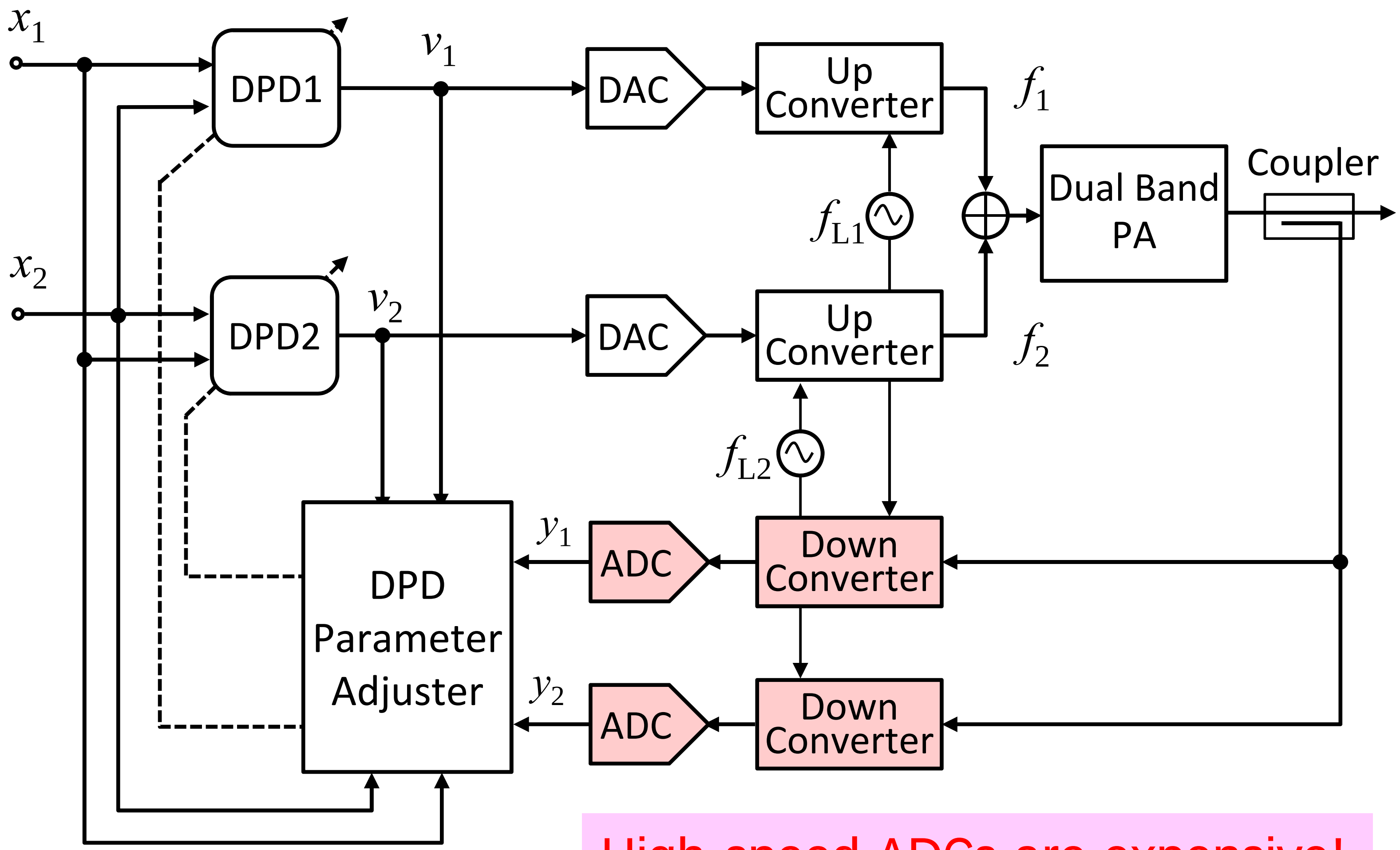


6 x 20MHz LTE CA signal (280MHz)

Linearization of 900 MHz and beyond RF bandwidth is achieved by SENF DPD.

2. Concurrent Dual-Band DPD Design

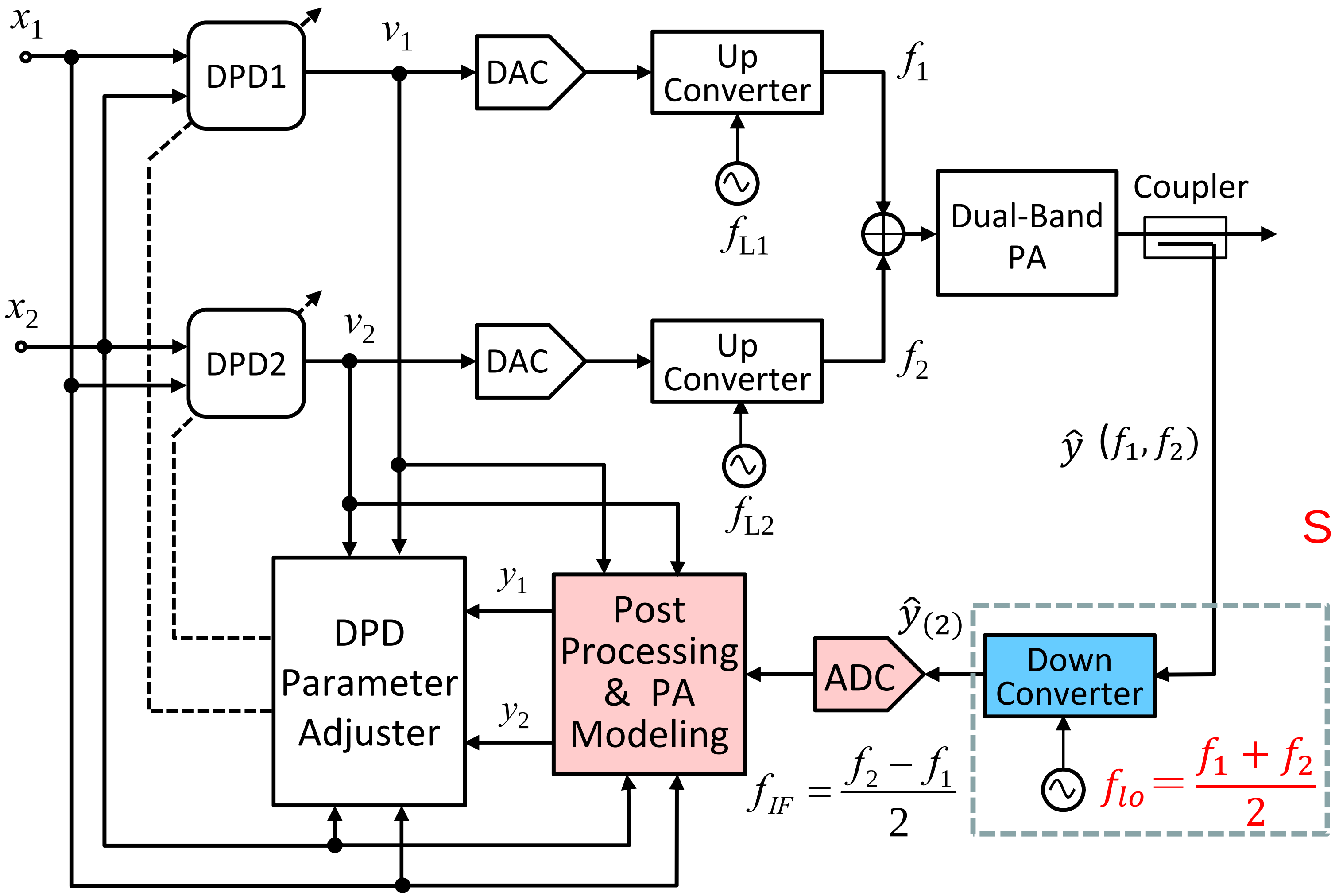
- Existing Dual-Band DPDs have two feedback path with two sets of Down Converter and ADC.



High-speed ADCs are expensive!

SFFB Dual-Band DPD

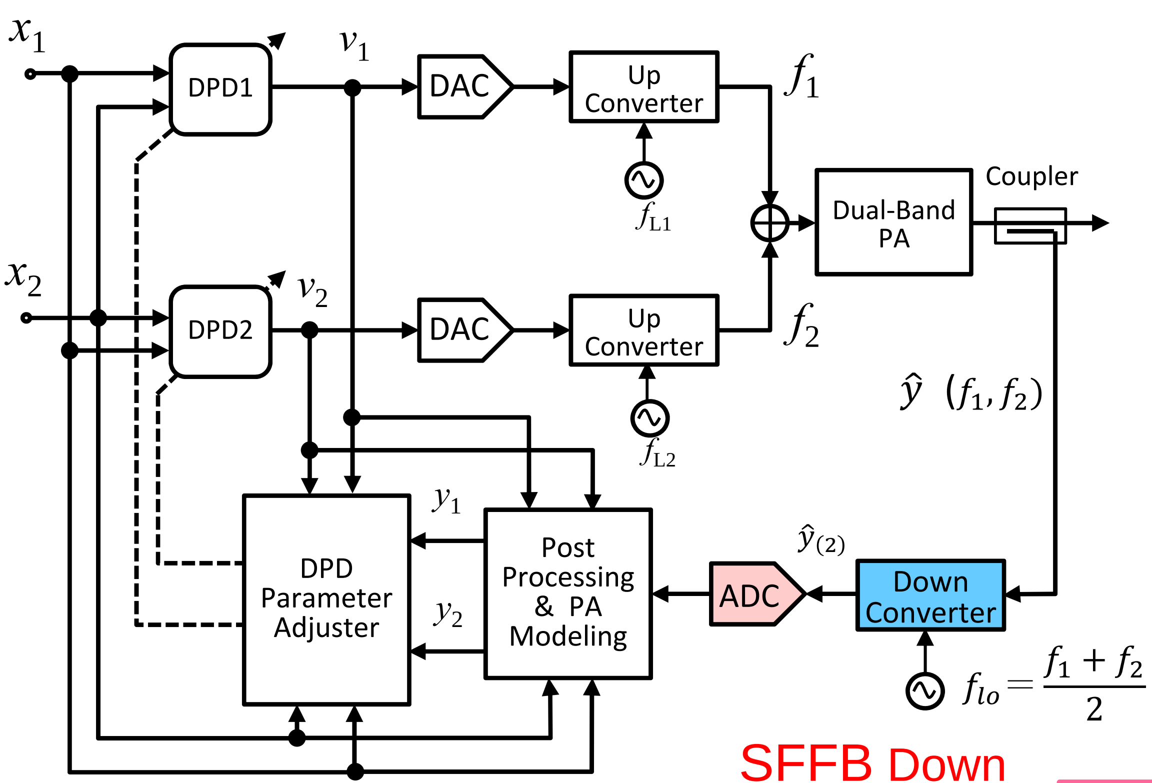
- Spectrum Folding Feedback (SFFB) DPD multiplexes two RF spectra into common IF [3].



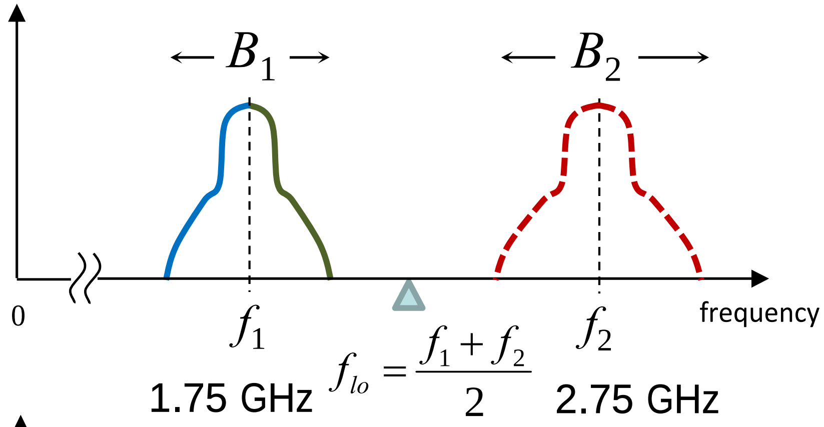
Two RF signals are down-converted into a common IF as a multiplexed signal.

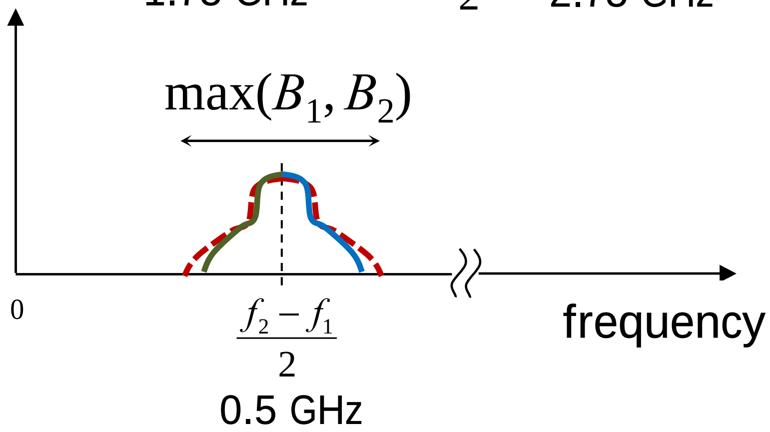
SFFB Dual-Band DPD

- Spectrum Folding Feedback (SFFB) DPD multiplexes two RF spectra into common IF [3].



SFFB Down Converter





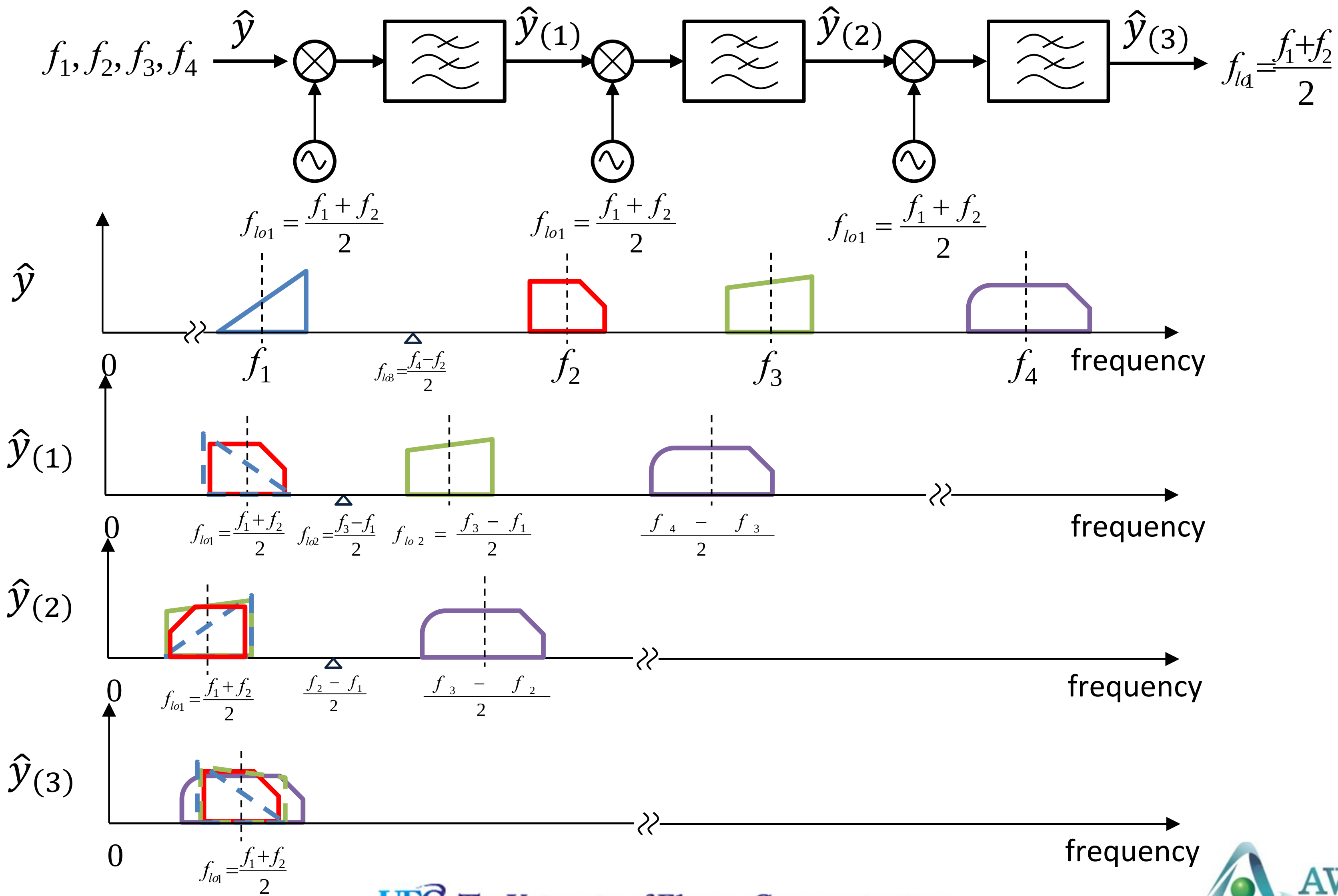
Lower RF-band signal spectrum is inverted.

Compensated in baseband by inverting input x_1

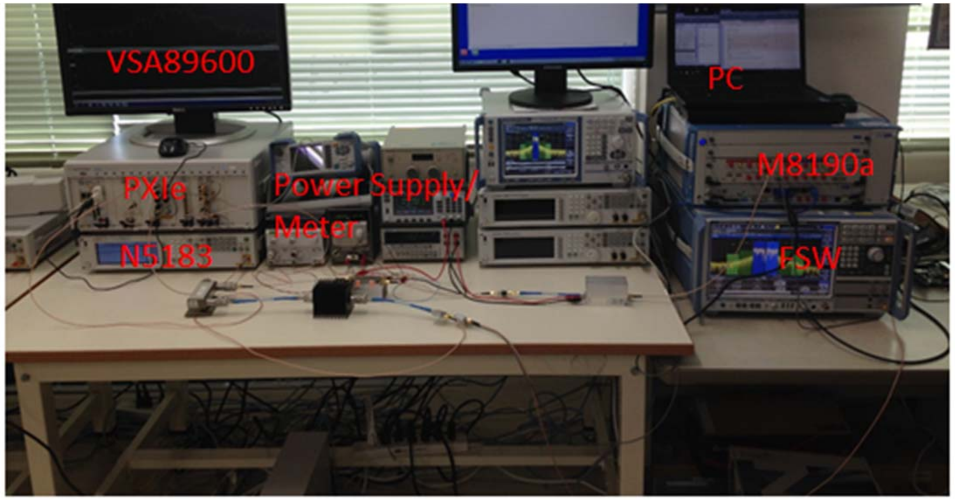
$$y(t) = y_1^*(t) + y_2(t)$$

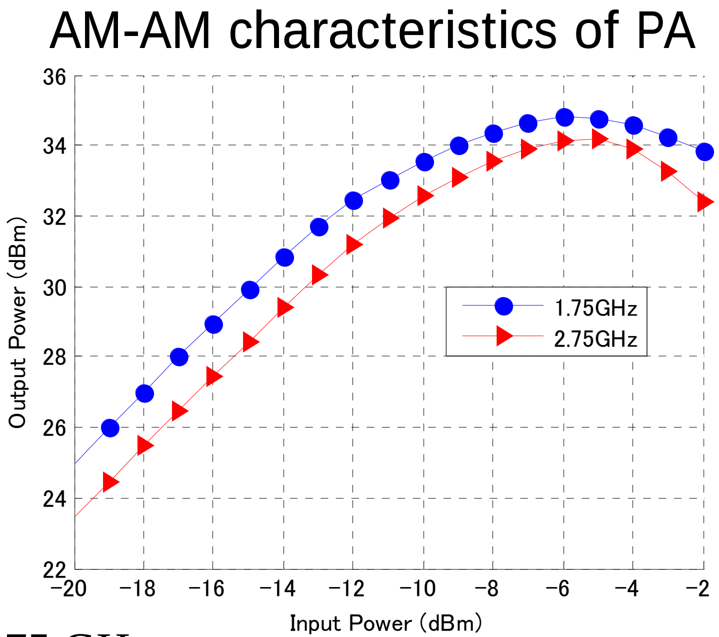
SFFB Multi-Band Extension

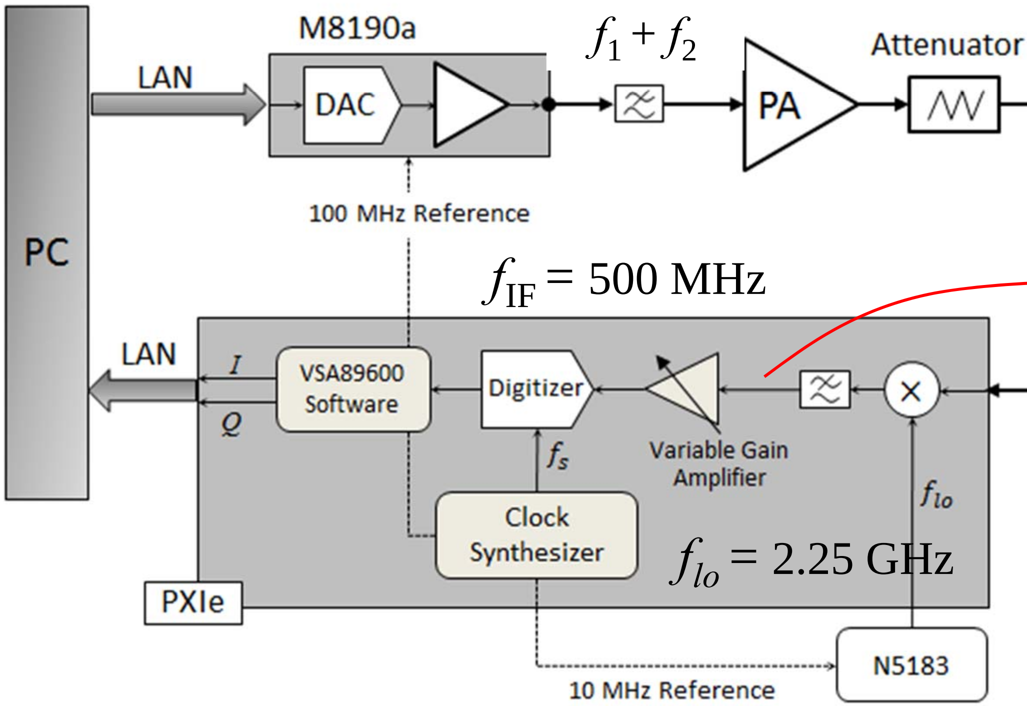
With SFFB (Spectral Folding Feedback) technique, multiband signals can be folded into one IF bandwidth.



SFFB Dual-Band DPD by Experiment

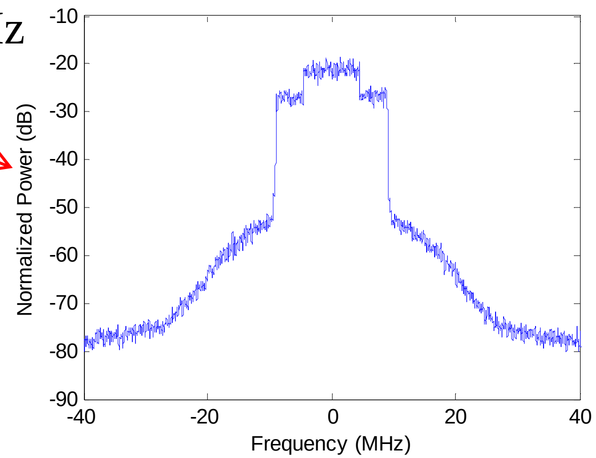






f_1 = 1.75 GHz

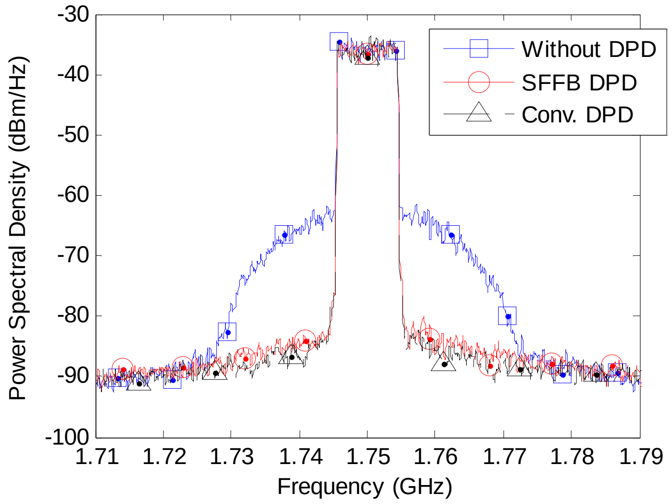
f_2 = 2.75 GHz

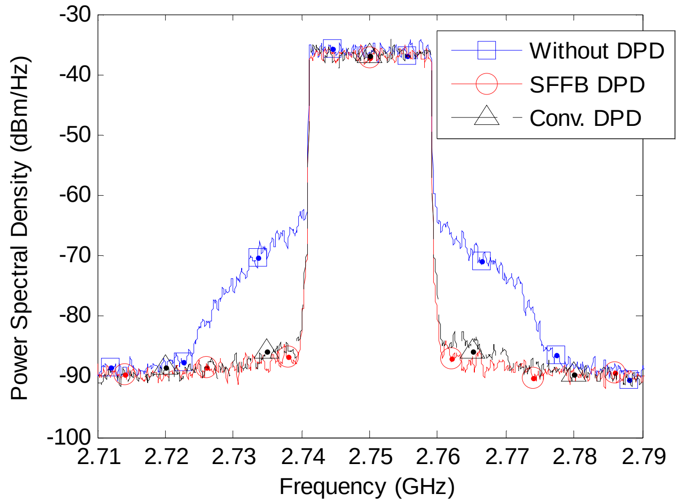


Folded feedback signal without DPD

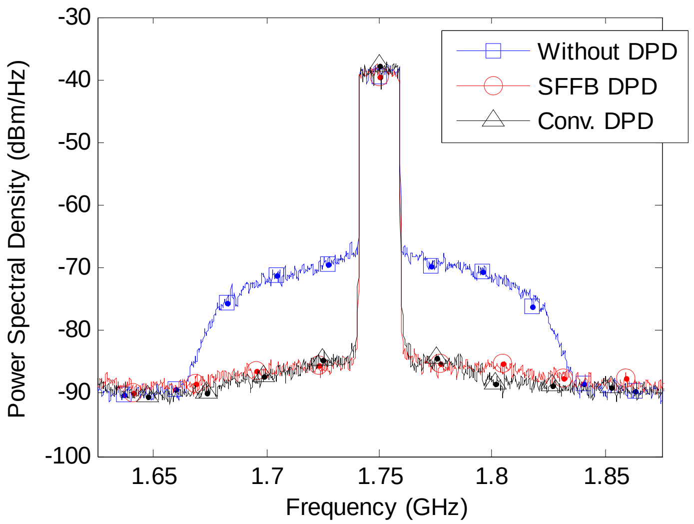
SFFB Dual-Band DPD by Experiment

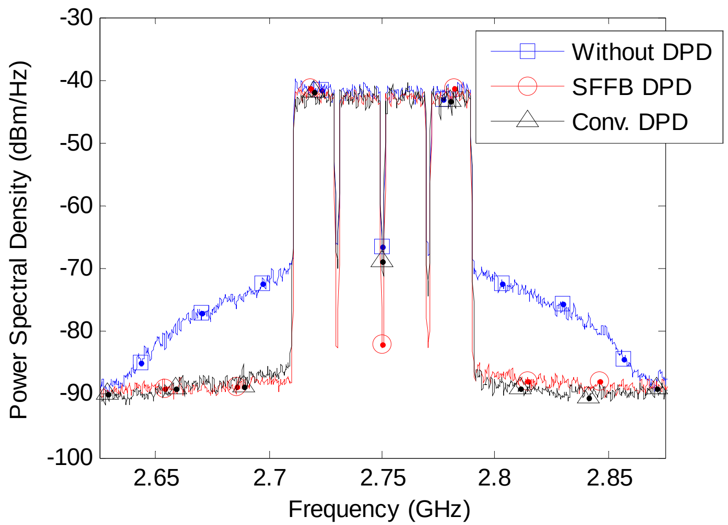
Scenario 1; 10 MHz LTE(1.75 GHz) + 20 MHz LTE (2.75 GHz)





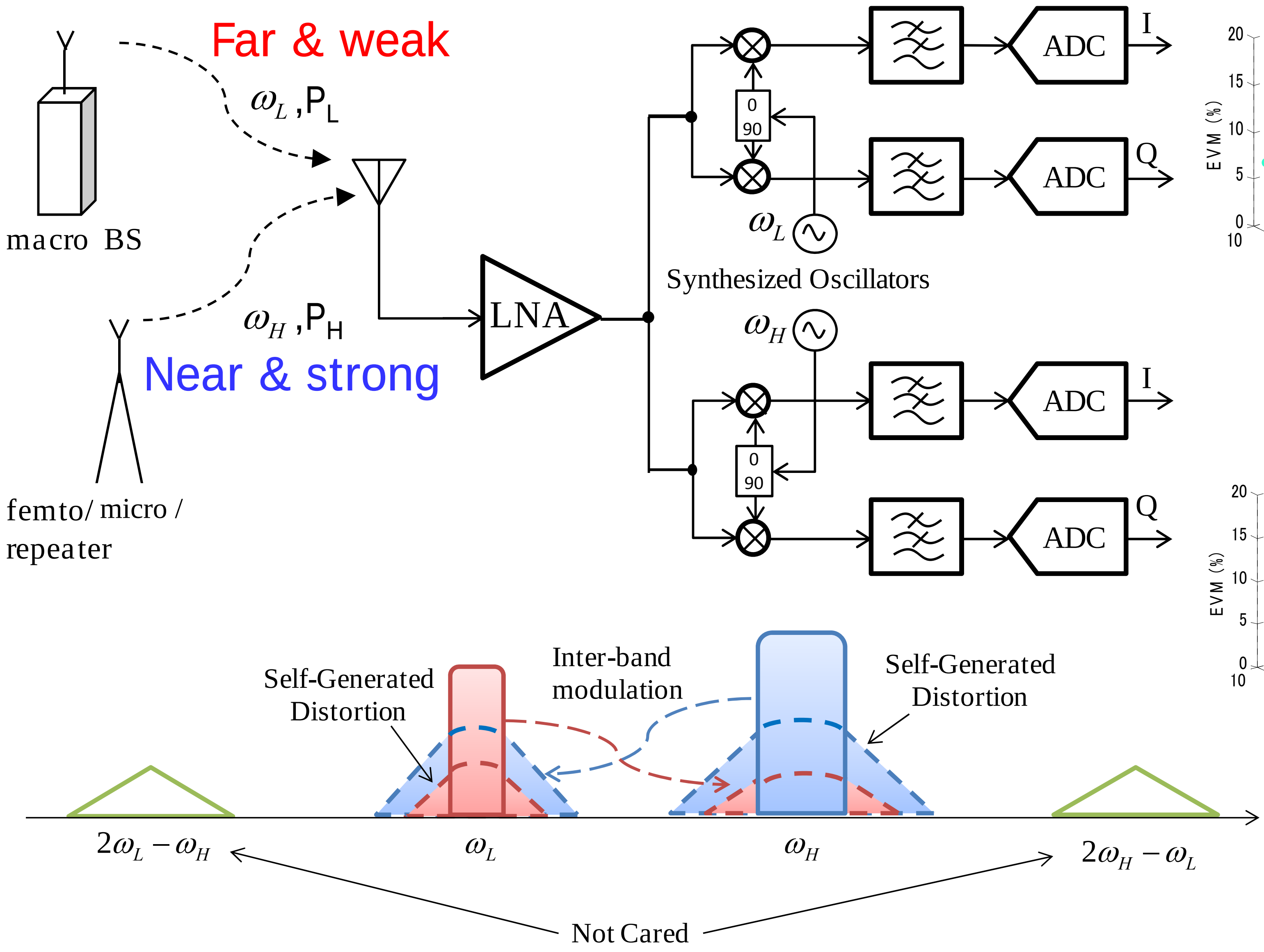
Scenario 2; 20 MHz LTE (1.75 GHz) + 4 x 20 MHz LTE CA (2.75 GHz)

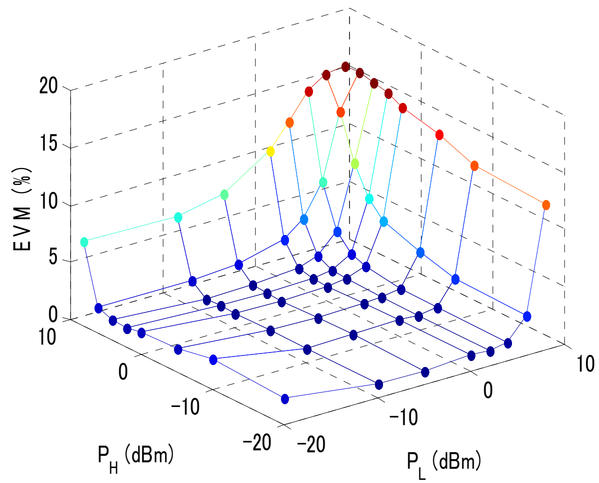




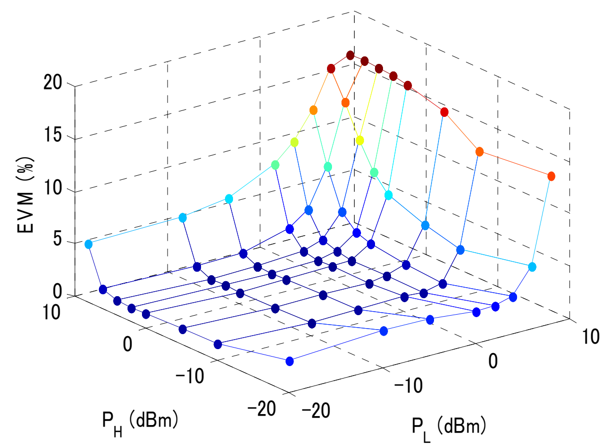
3. Cross-Modulation due to Multi-Band Access

- Near-far problem increases chance of inter-band modulation



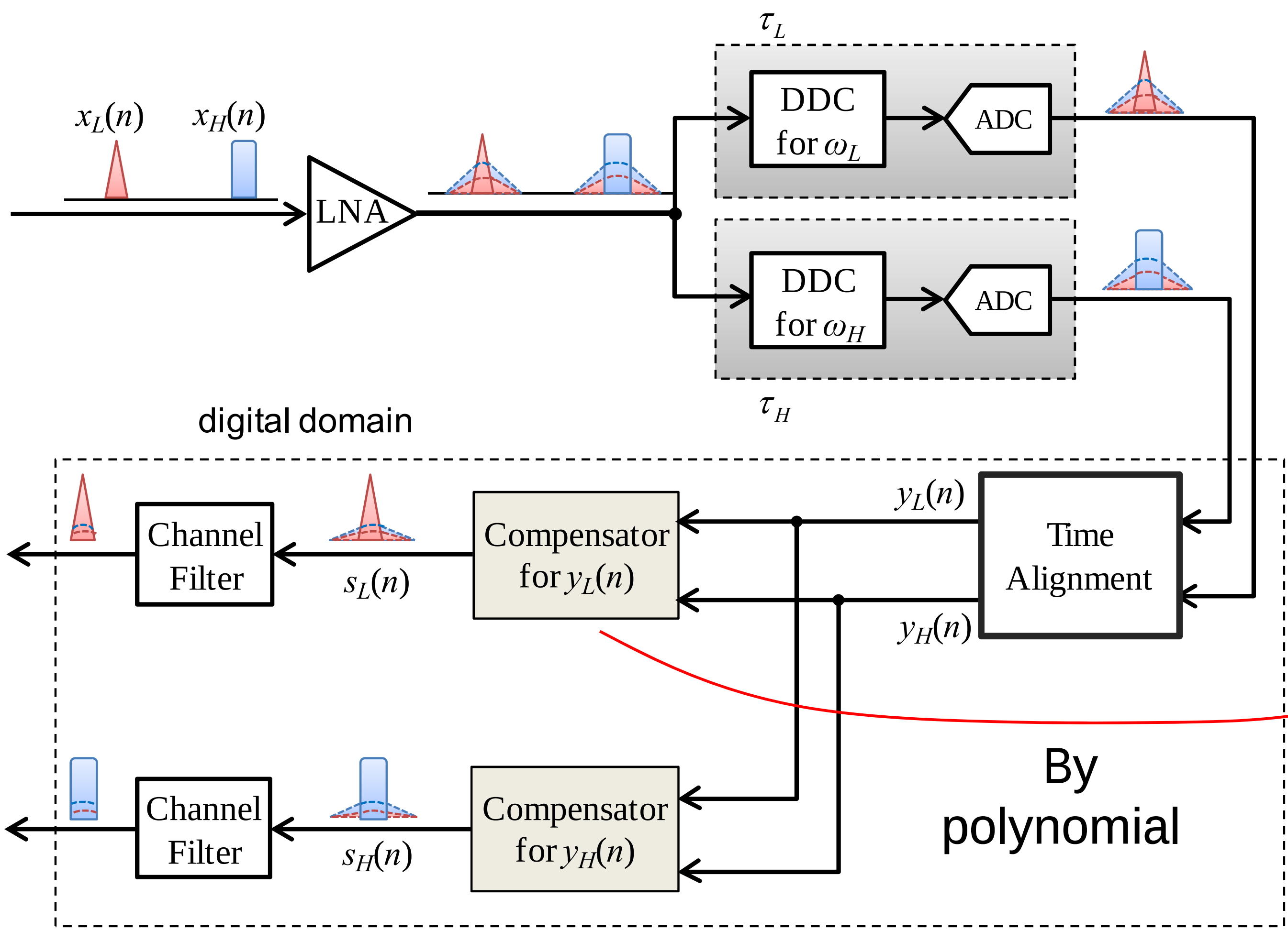


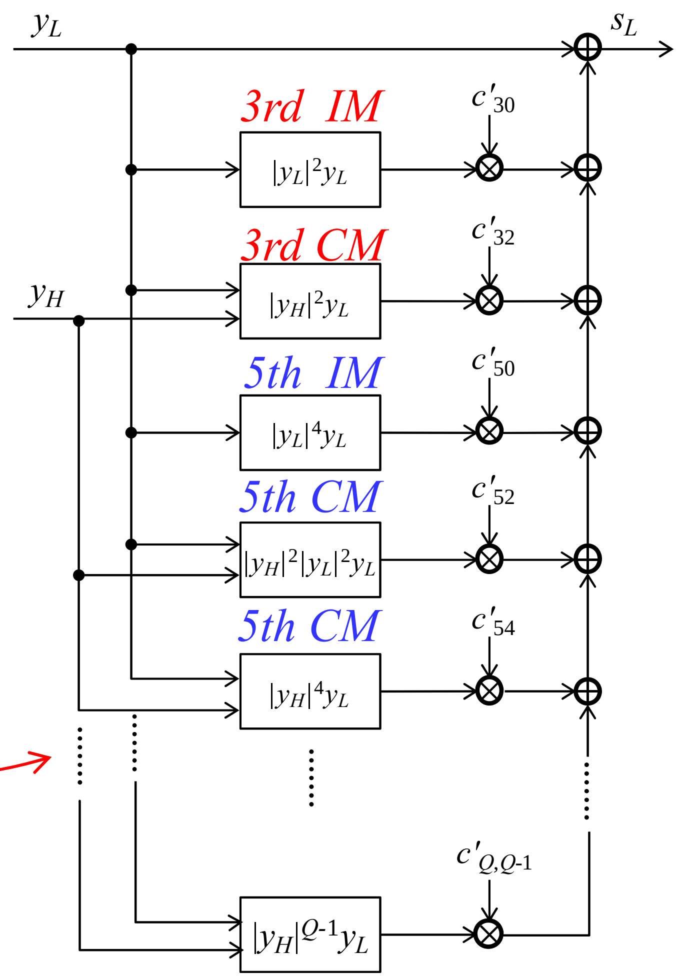
(a) EVM for ω_L



(b) EVM for ω_H

Post-Compensation of Receiver Nonlinearity



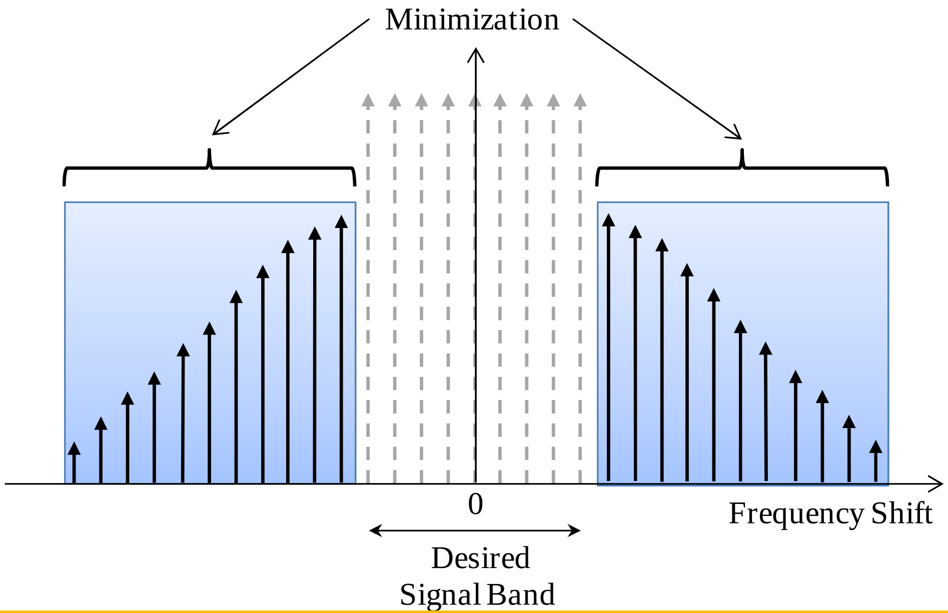


Compensator diagram for y_L

Blind & Adaptive Nonlinear Compensation method is necessary [4].

How to Determine Compensator Coefficients?

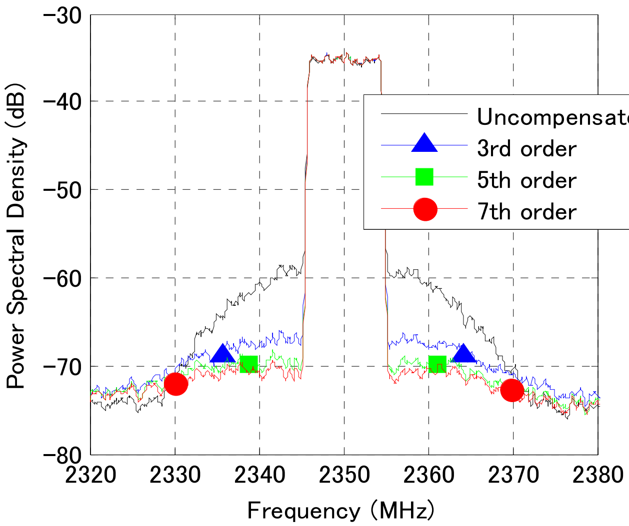
- Proposed algorithm determines the compensator coefficients so as to minimize outband spectra power for each band.



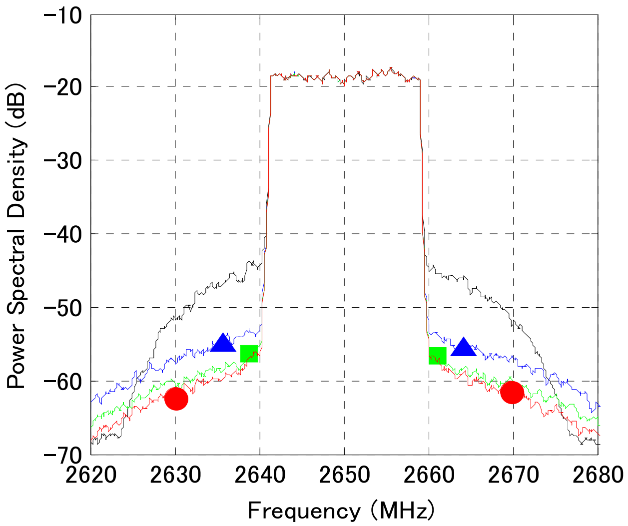
This works successfully because nonlinearity generates both inband and outband components and they are correlated.

The key is separation filter that eliminates the in-band signal and maximizes SNR of outband distortion detection.

Experimental Results



(a) Output spectra at ω_L



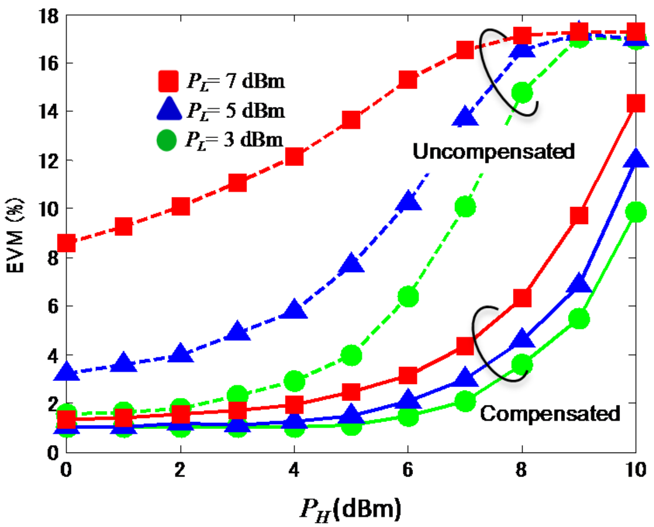
(b) Output spectra at ω_H

$f_1 = 2.35$ GHz

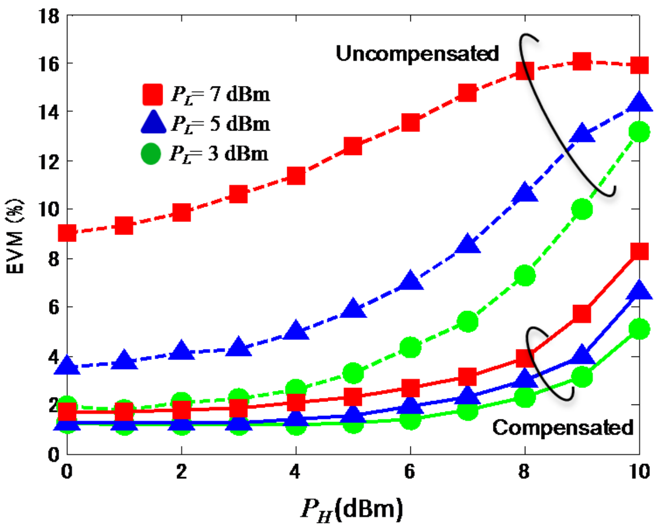
$f_2 = 2.65$ GHz

Power levels of ω_L and ω_H in (a)/(b) are -10 dBm and 6 dBm, respectively.

7th-order compensation presents the best results.



(c) EVM for ω_L signal



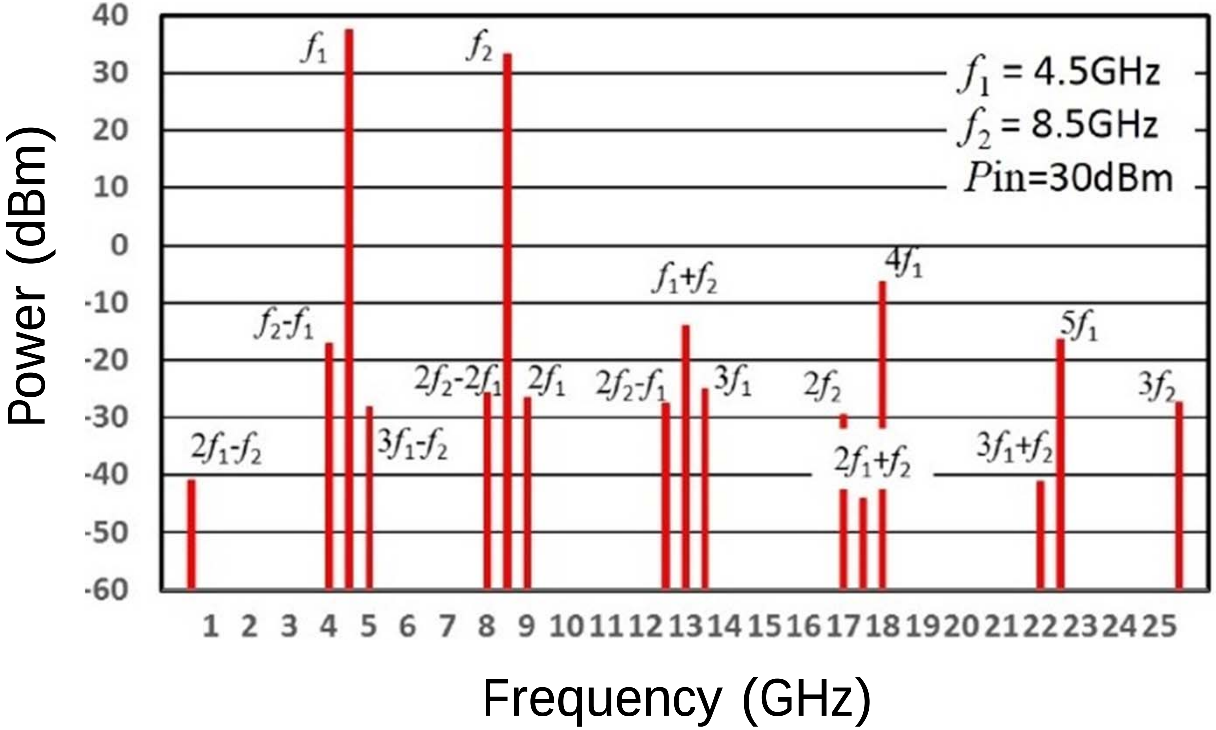
(d) EVM for ω_H signal

Proposed compensator improves EVM in both bands.

Maximum acceptable input power increases more than 4 dB.

4. Reconfigurable RF BPF

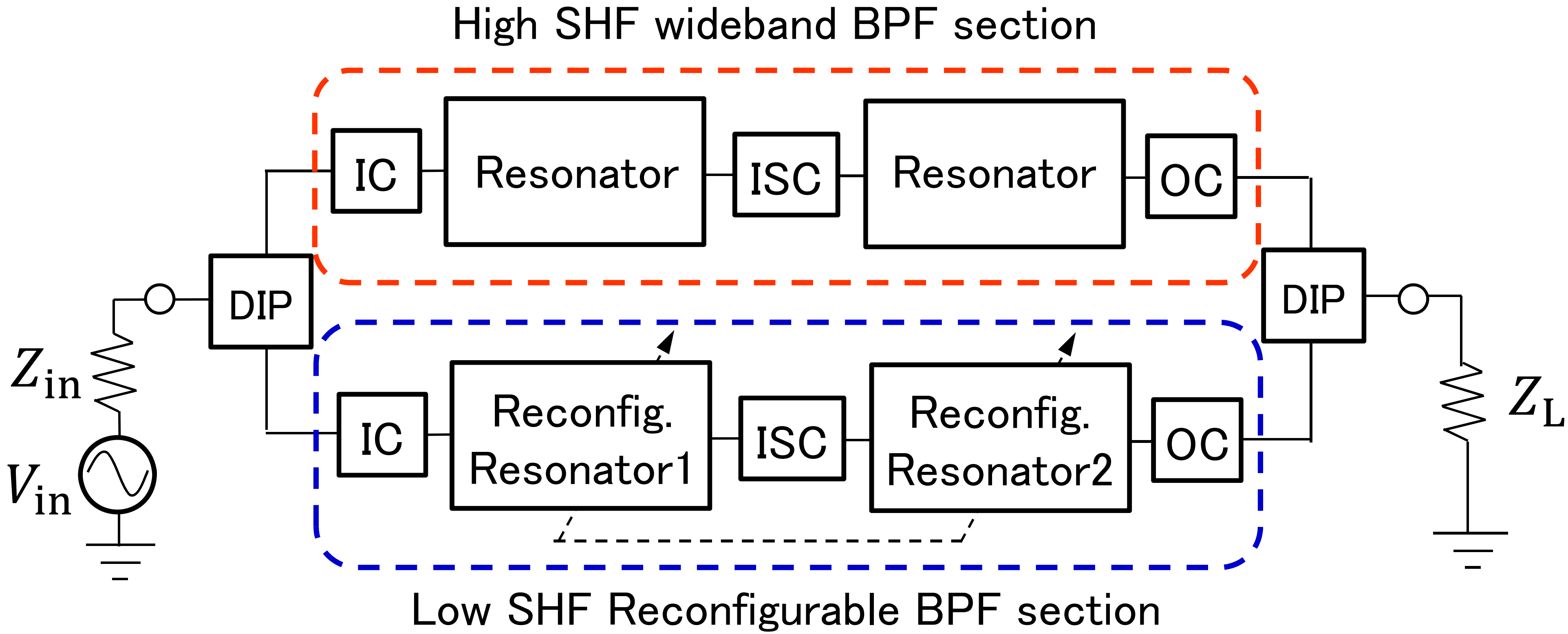
- Reconfigurable BPF can adapt the receiver flexibly to the change of access channels and prevent unexpected cross-modulation distortions in multi-band/multi-access operation.



Example of nonlinear output spectrum under concurrent dual-band operation. Some of them locate near the operating band.

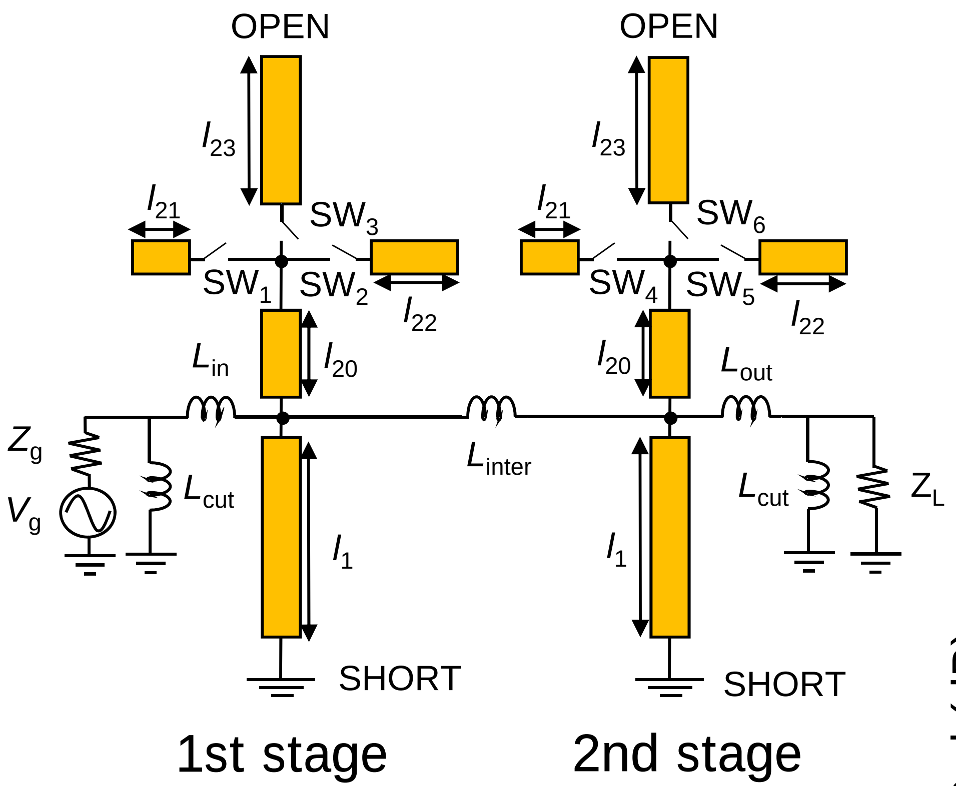
SHF Dual-band Reconfigurable BPF

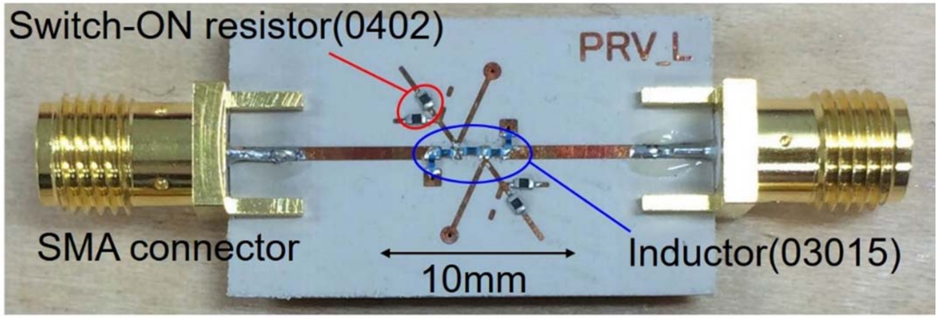
- Low SHF (< 6 GHz) reconfigurable BPF and High SHF wideband BPF are integrated for concurrent dual-band access.

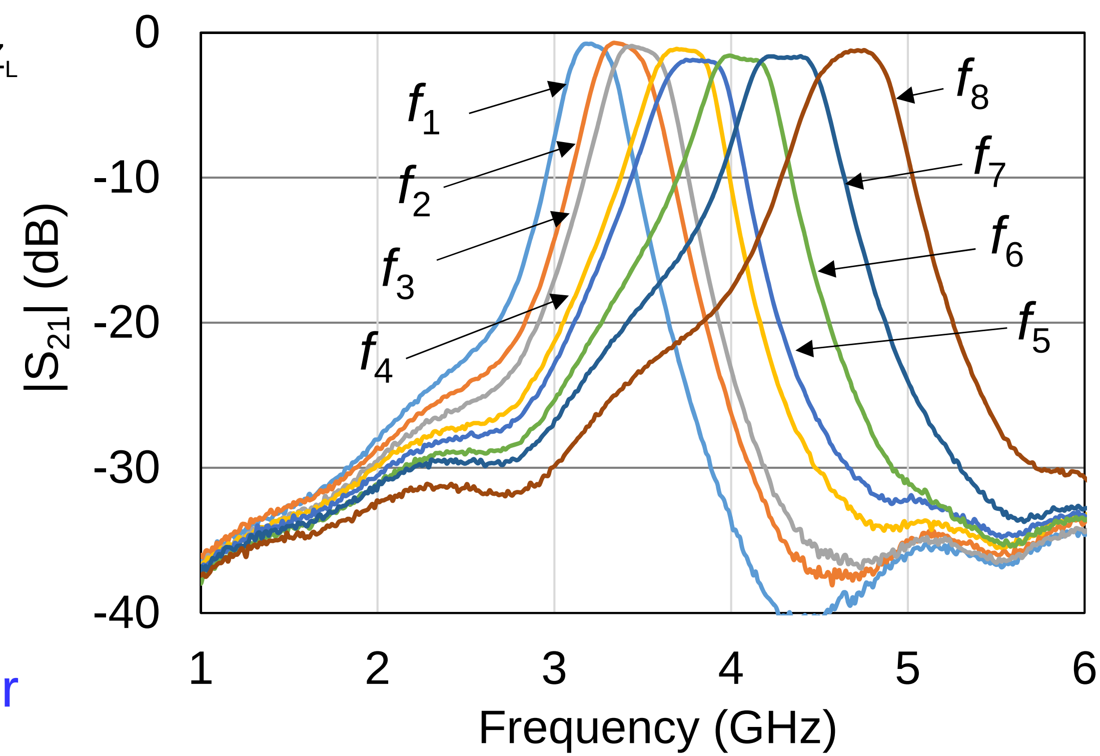


DIP: Diplexer IC: Input Coupling circuit
ISC; Inter-Stage Coupling circuit OC: Output Coupling circuit

2-stage 3-bit Low-SHF Reconfigurable BPF







Center Frequency; 3.1 to 4.6 GHz
Insertion loss; 1.0~2.1 dB

High SHF BPF and diplexers are under design process.

Conclusions

- 5G hardware is required to be more flexible, accurate, linear and low-cost.
- For Txs, advanced DPD techniques called SENF and SFFB are proposed.
  - SENF saves feedback bandwidth, which enables wider compensation bandwidth.
  - SFFB enables simple feedback for concurrent dual-band operation.
- For concurrent dual-band Rxs, Post Compensation technique and Reconfigurable BPF are proposed.

The results will contribute to improve practical performance of the 5G system.

Related Works

1) Y. Ma, Y. Yamao, Y. Akaiwa, K. Ishibashi, “Wideband digital predistortion using spectral extrapolation of band-limited feedback signal,” IEEE Trans. Circuit and Systems-I, vol. 61, no. 7, pp. 2088-2097, July 2014.

2) Y. Ma and Y. Yamao, “Experimental results of digital predistorter for very wideband mobile communication system,” Proc. IEEE VTC2015-Spring, 6PB-2, Glasgow, UK, May 2015.

3) Y. Ma and Y. Yamao, “Spectra-folding feedback architecture for concurrent dual-band power amplifier predistortion,” IEEE Trans. Microw. Theory & Tech., Vol. 63, No. 10, pp. 3164-3174, Oct. 2015.

4) Y. Ma, Y. Yamao, K. Ishibashi and Y. Akaiwa, "Adaptive compensation of inter-band modulation distortion for tunable concurrent dual-band receivers," IEEE Trans. Microw. Theory & Tech., vol.61, no.12, pp.4209-4219, Dec. 2013.

5) R. Kobayashi, T. Kato, K. Azuma and Y. Yamao, “Design and Fabrication of Two-Stage Three-Bit Reconfigurable Bandpass Filter Using Brunch Line-Type Variable Resonator,” IEICE Trans. Electronics, Vol. E98-C, No. 7, pp. 636-643, July 2015.

Acknowledgement

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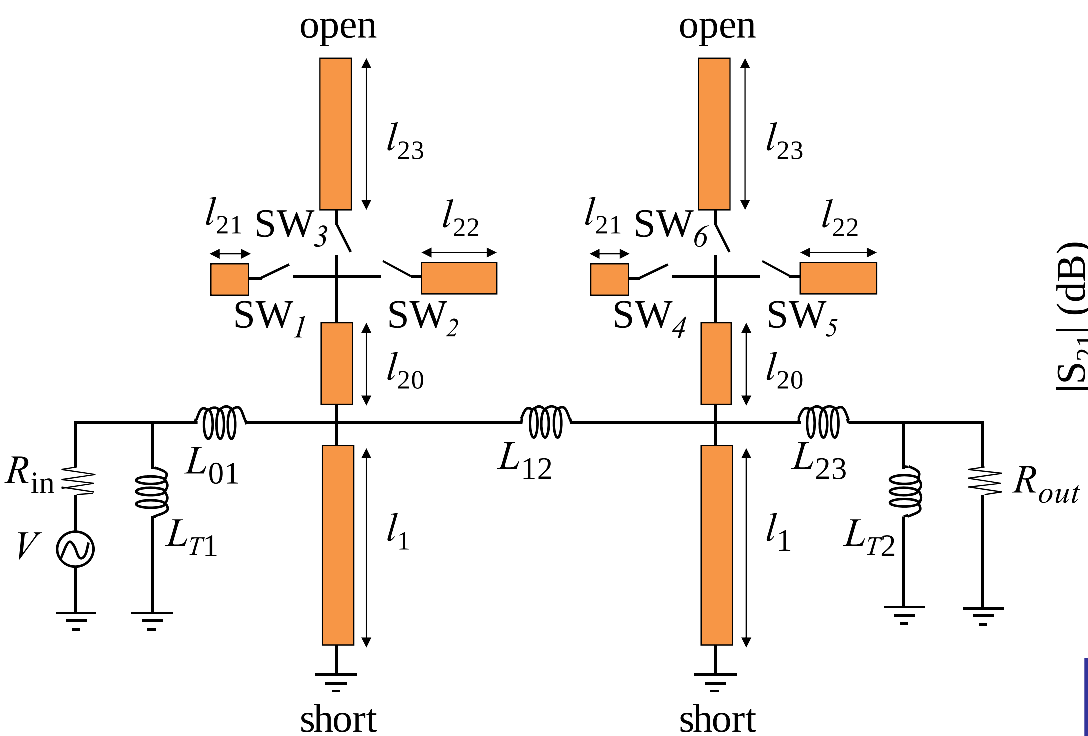
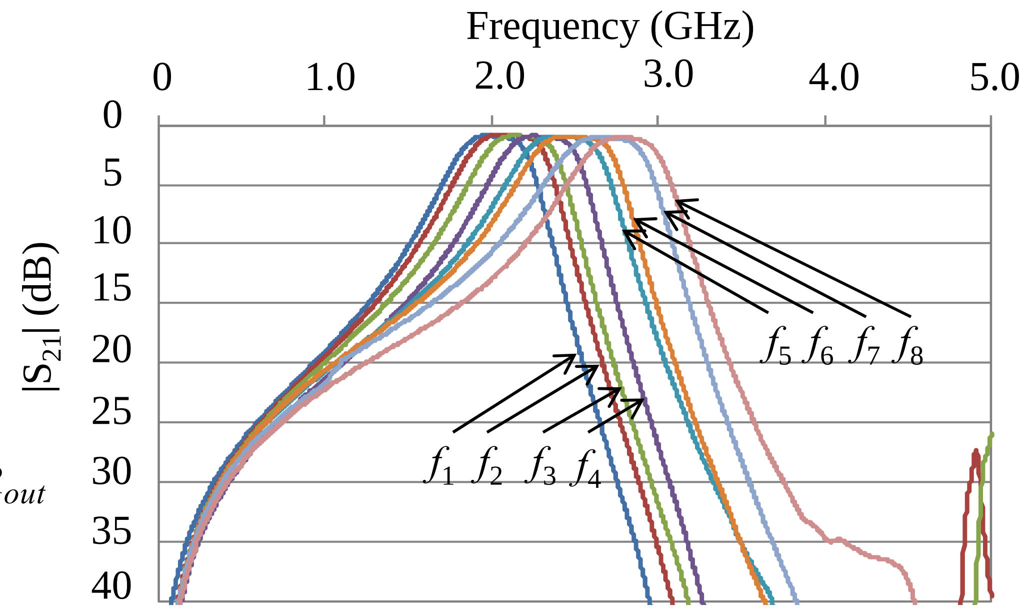
Thank you for listening!

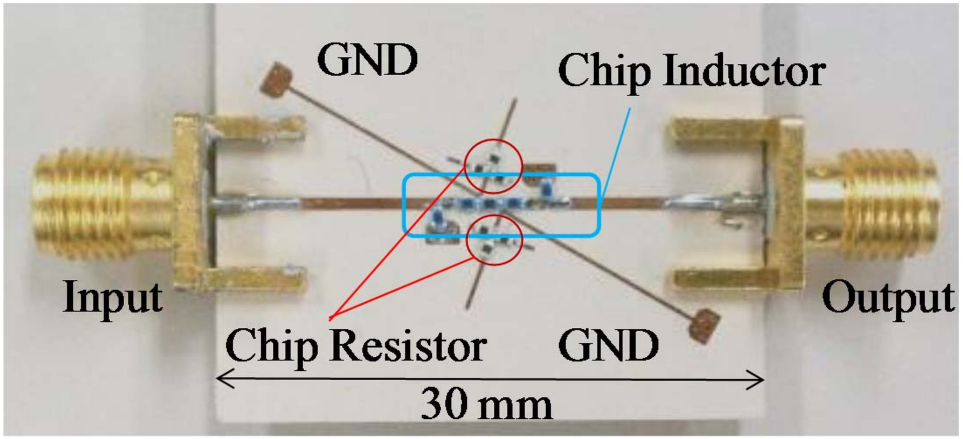
AWCC Advanced Wireless and Communication Research Center

Yamao LABORATORY

2-Stage 3-bit Reconfigurable BPF in UHF Band







(From APMC2012, Kaohsiung Taiwan)

f_i	Center frequency (GHz)	Insertion loss (dB)	Band width (MHz)
f_1	2.01	0.90	505
f_2	2.09	0.81	542
f_3	2.13	0.90	520
f_4	2.24	0.92	528
f_5	2.38	0.94	548
f_6	2.44	0.93	552
f_7	2.72	0.96	574
f_8	2.80	0.98	567