Engineering and Physical Sciences Research Council

The University Of Sheffield.

RF Sampling in Multiband Receivers for 5G: Analysis and Performance

Presented by

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With

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Presentation Outline

- Introduction
- Conventional Concurrent Multiband Receivers
- Direct RF Sampling Concurrent Multiband Receivers
  - Nyquist sampling
  - Subsampling
- Noise in Direct RF Sampling Concurrent Multiband Receivers
- The effect of ADC Resolution on Concurrent Multiband Direct RF Sampling Receivers
- Conclusions

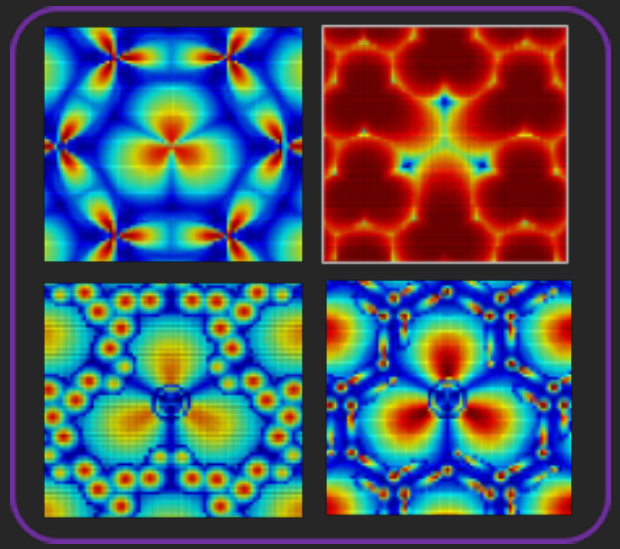
Research Aims

- Develop frequency agile, concurrent, multiband, direct RF sampling receivers for SDRs.
- Reduce receiver costs, complexity and energy consumption.
- Apply in LTE and 5GNR to support, for example:
  - carrier aggregation;
  - dual inter- and intraRAT connectivity, for example, in HetNets;
- Demonstrate proof of concept in hardware-in-the-loop (HWIL) SDR testbeds.
- In this presentation, we report new results on the impact of ADC bit resolution on the system performance

Previous Related Projects

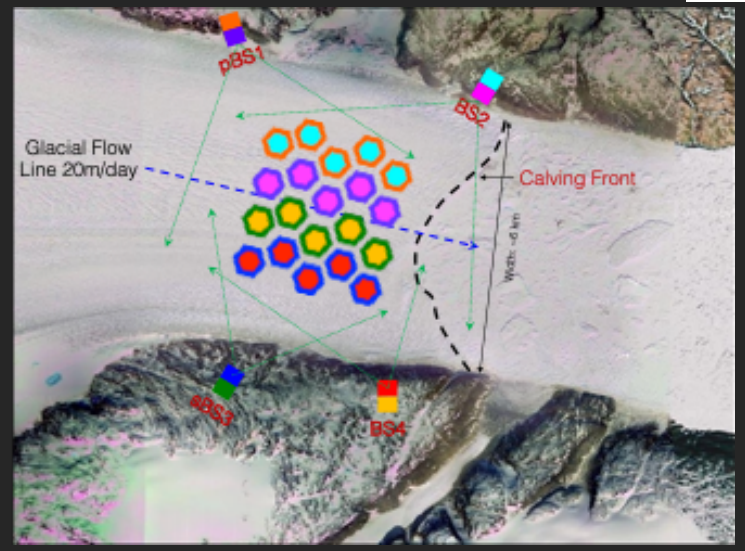
Green Radio

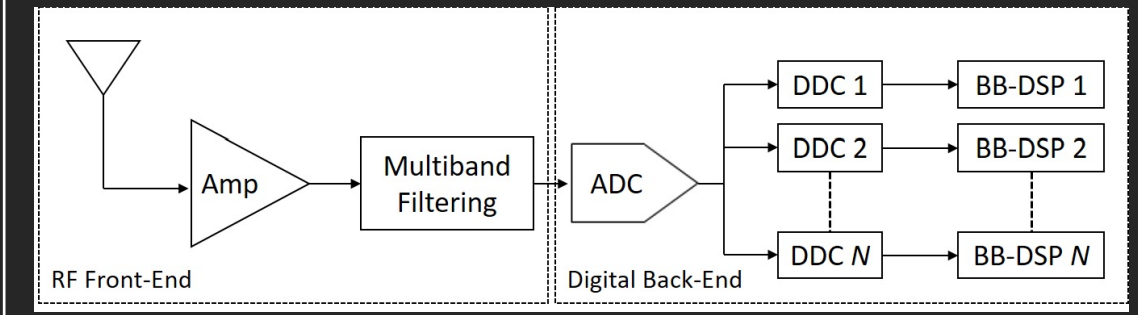
(EPSRC/mVCE, EP/G064105/1, 2009-12)



Networks of Sensors

(NERC, NE/I007148/1, 2011-15)



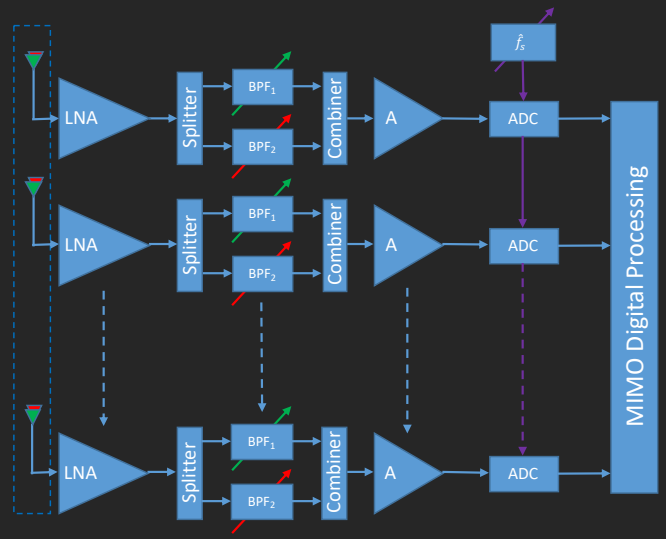


Frequency Agile Radio (FARAD)

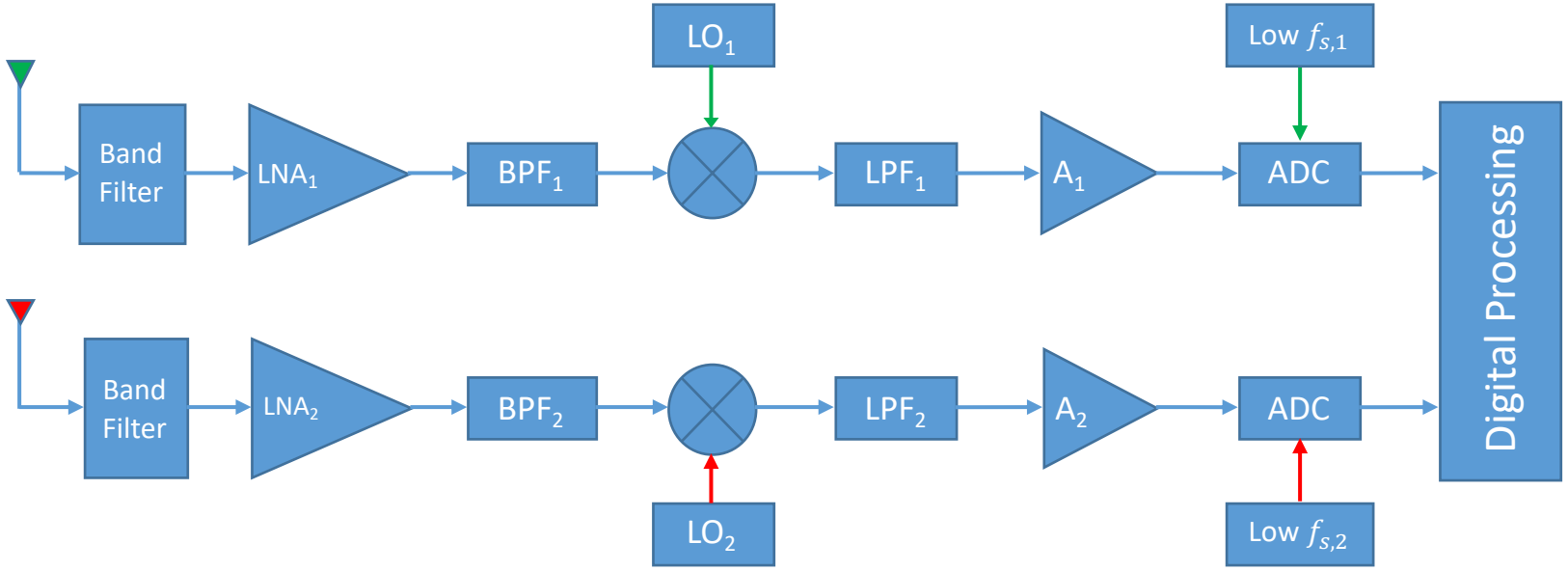
(EPSRC, EP/M013723/1, 2015-19)

Direct Digitisation for Frequency Agile Millimetre Wave Massive MIMO

(EPSRC, EP/S008101/1, 2019-2023)

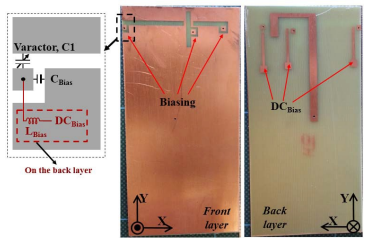


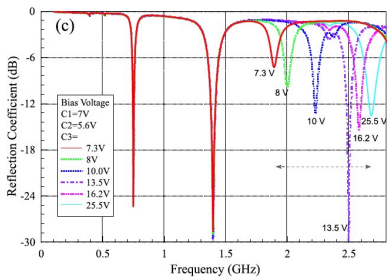
Conventional Concurrent Multiband Receiver



Direct RF Sampling Concurrent Multiband Receiver

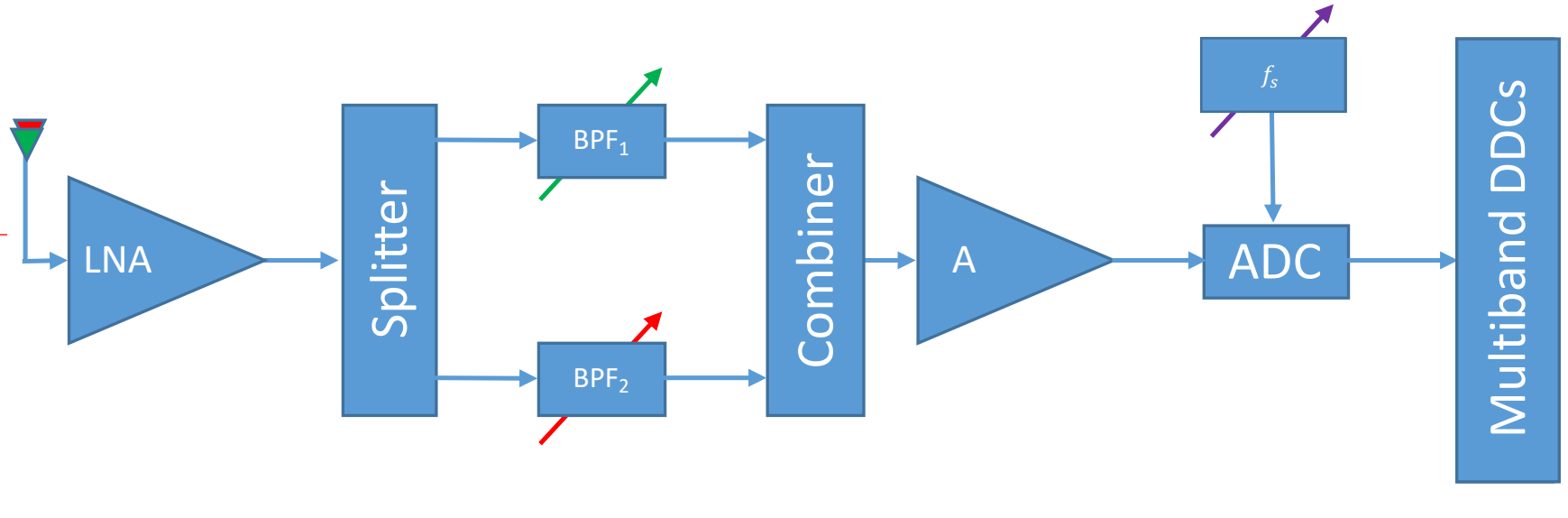
Tunable, Multiband, Slot Antenna





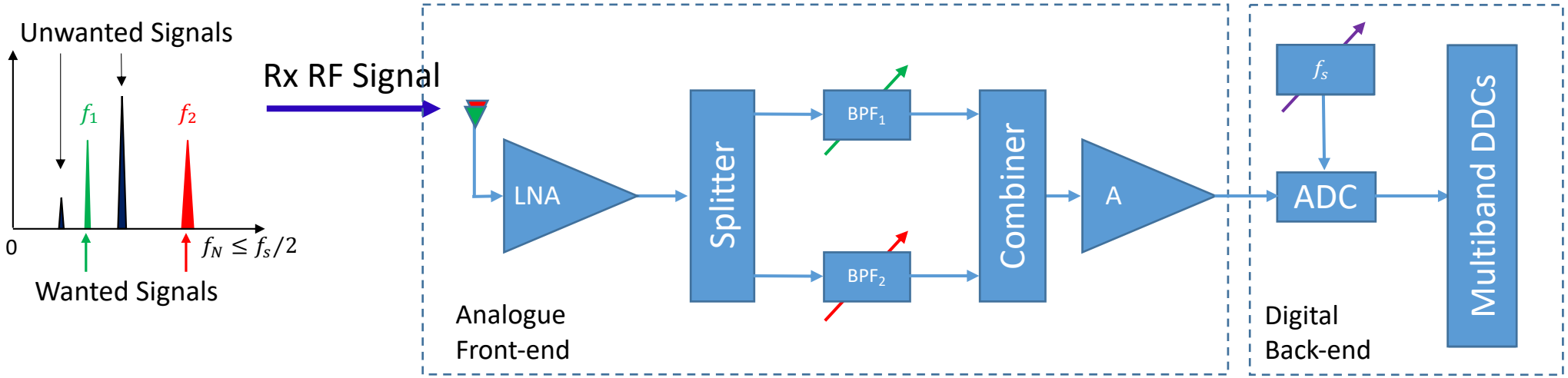
Invited Paper:

O'Farrell, T., Beach, M.A., Singh, R., Bai, Q., Arabi, E., Gamlath, C., Ford, K.L., Morrison, K., Langley, R., (2017). "Tunable, Concurrent Multiband, Single Chain Radio Architecture for Low Energy 5G-RANs." In: International Workshop on Service-oriented Optimization of Green Mobile Networks (GREENNET) - in conjunction with WiOpt 2017 (GREENNET'17), Paris, France, 18 May 2017. DOI: 10.23919/WIOPT.2017.7959932



Bai, Q., Singh, R., Ford, K.L., O'Farrell, T. and Langley, R. (2017) "*An Independently Tunable Tri-band Antenna Design for Concurrent Multi-band Single Chain Radio Receivers*." In: IEEE Transactions on Antennas and Propagation, vol.65, no.12, pp.6290 -6297, September 2017 (DOI: 10.1109/ TAP.2017.2748185)

Nyquist Direct RF Sampling Multiband Receiver



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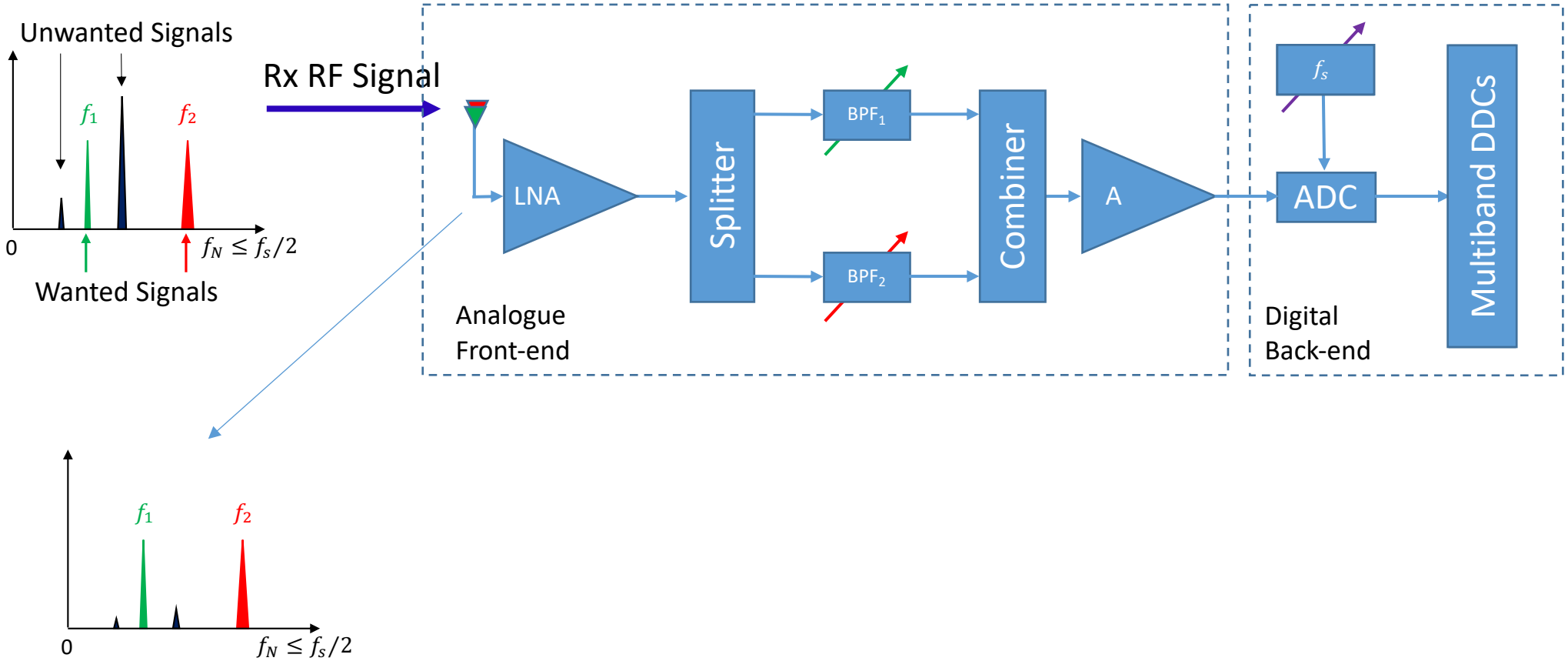

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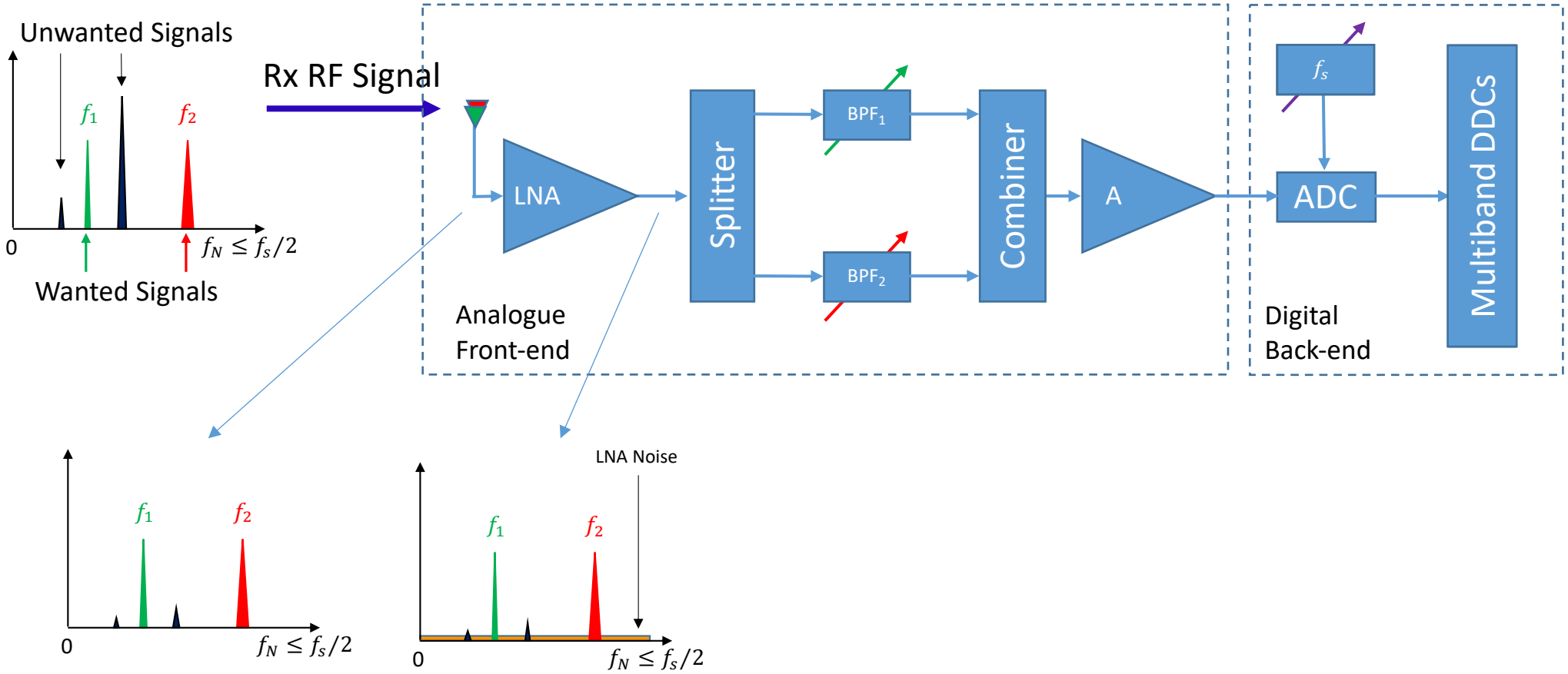

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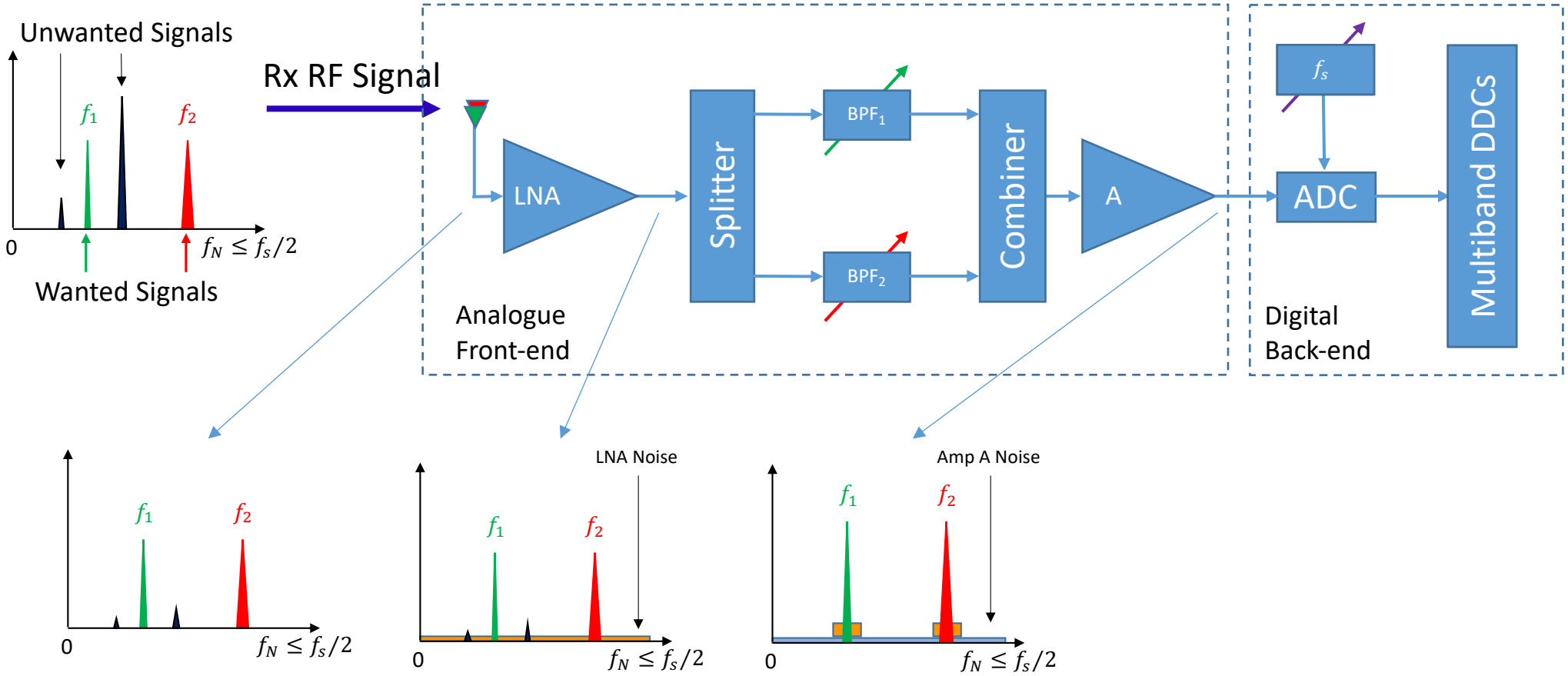

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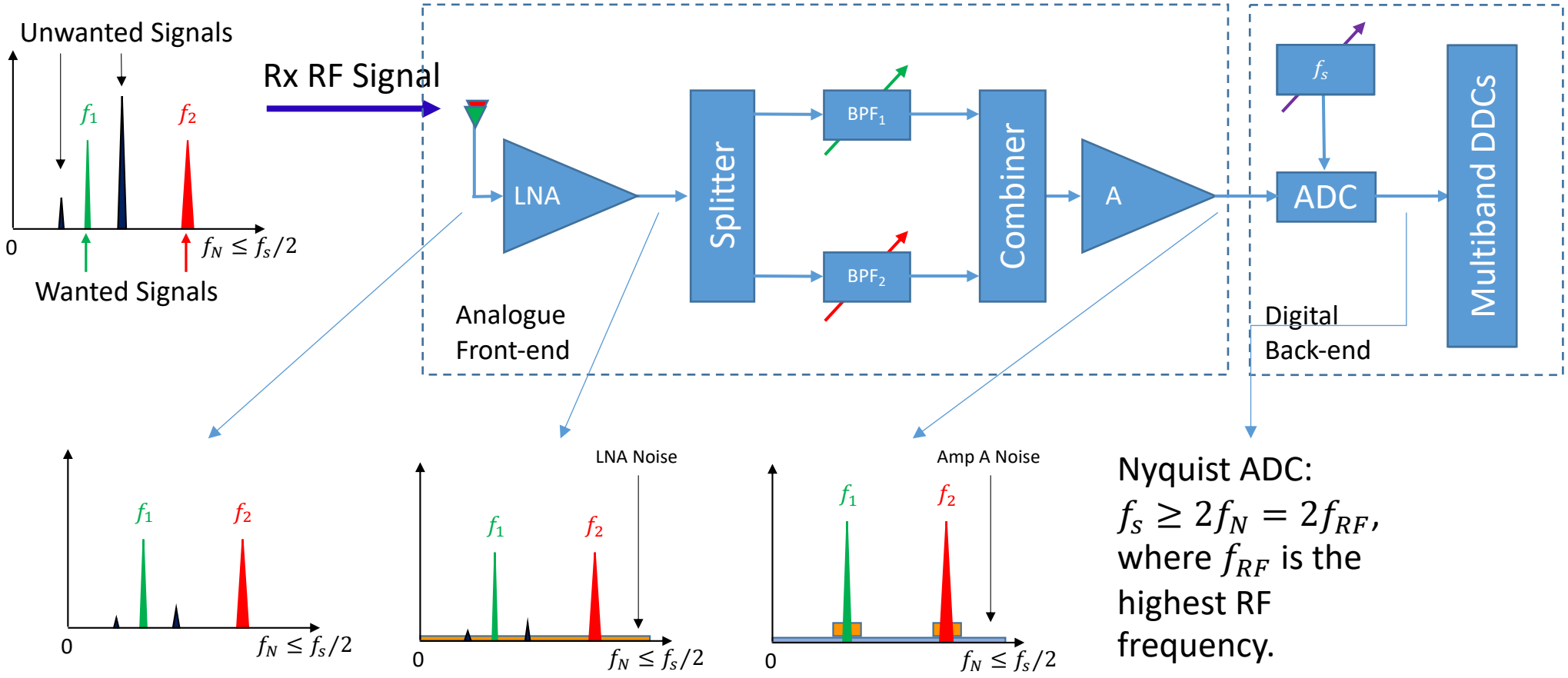
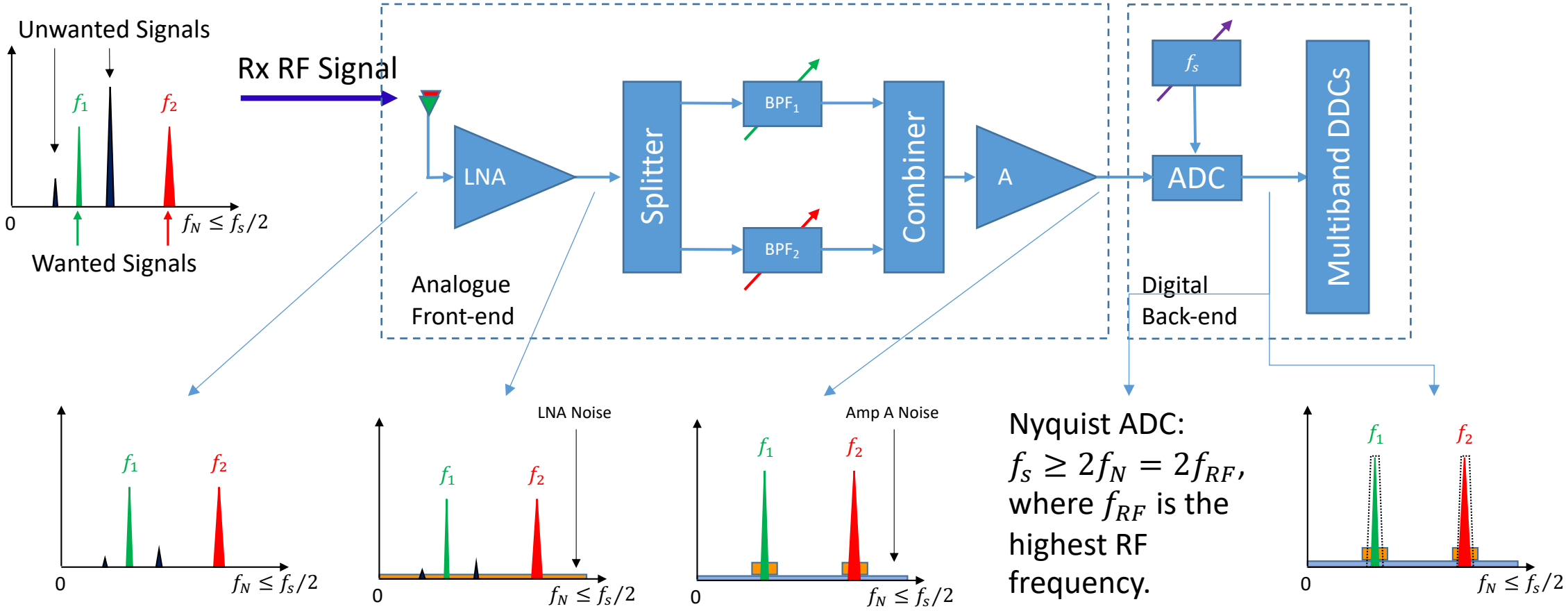
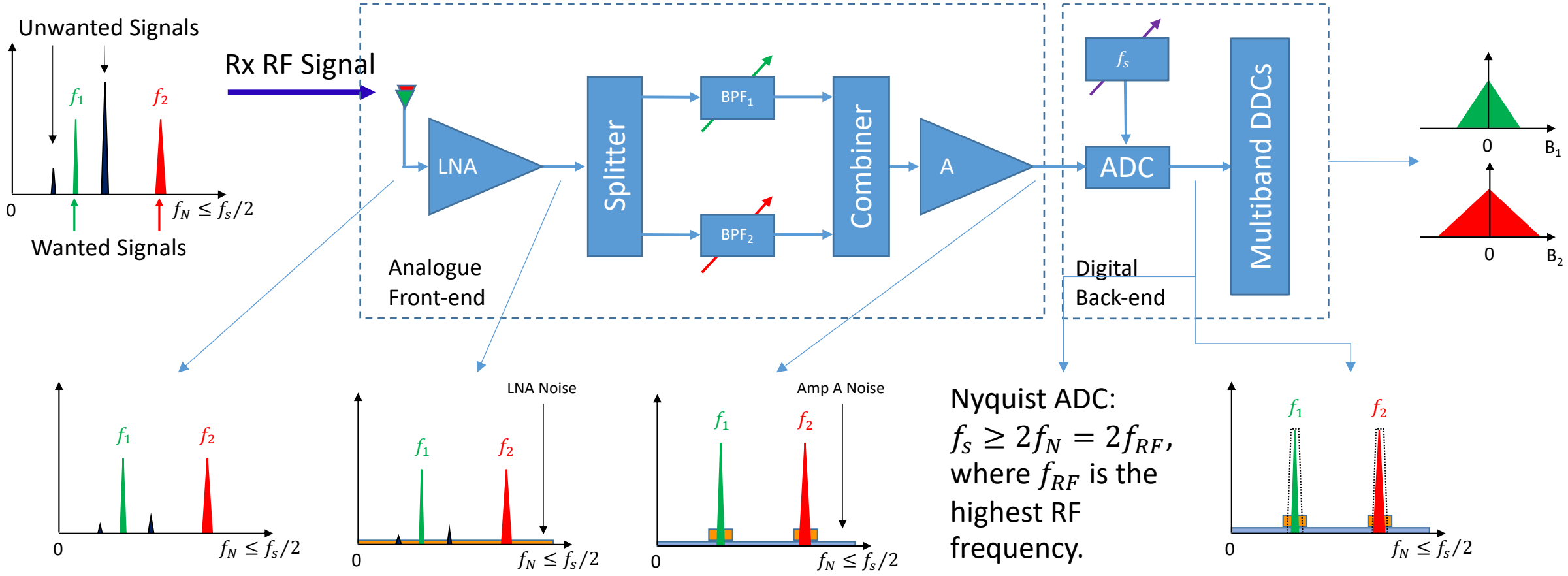


Nyquist ADC:
$f_s \geq 2f_N = 2f_{RF}$,
where f_{RF} is the highest RF frequency.

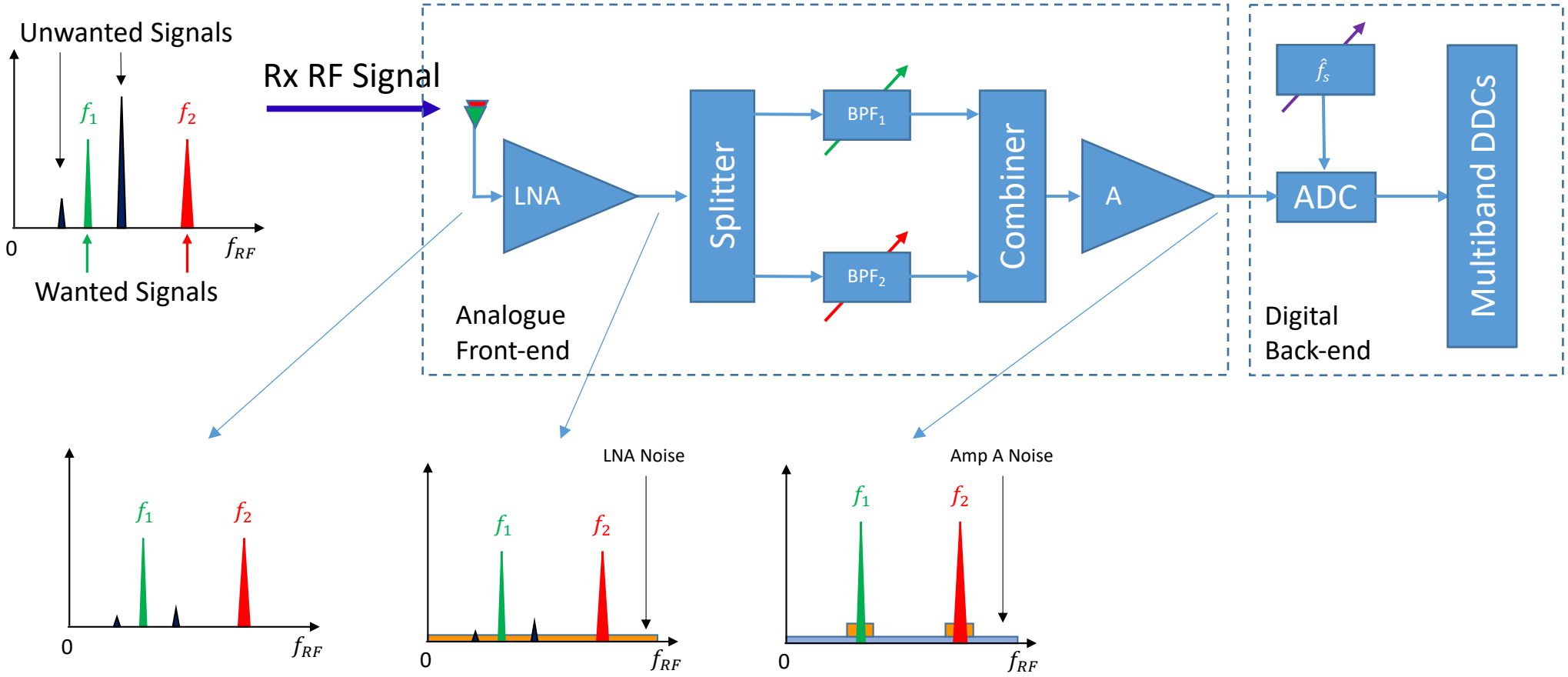
Nyquist Direct RF Sampling Multiband Receiver



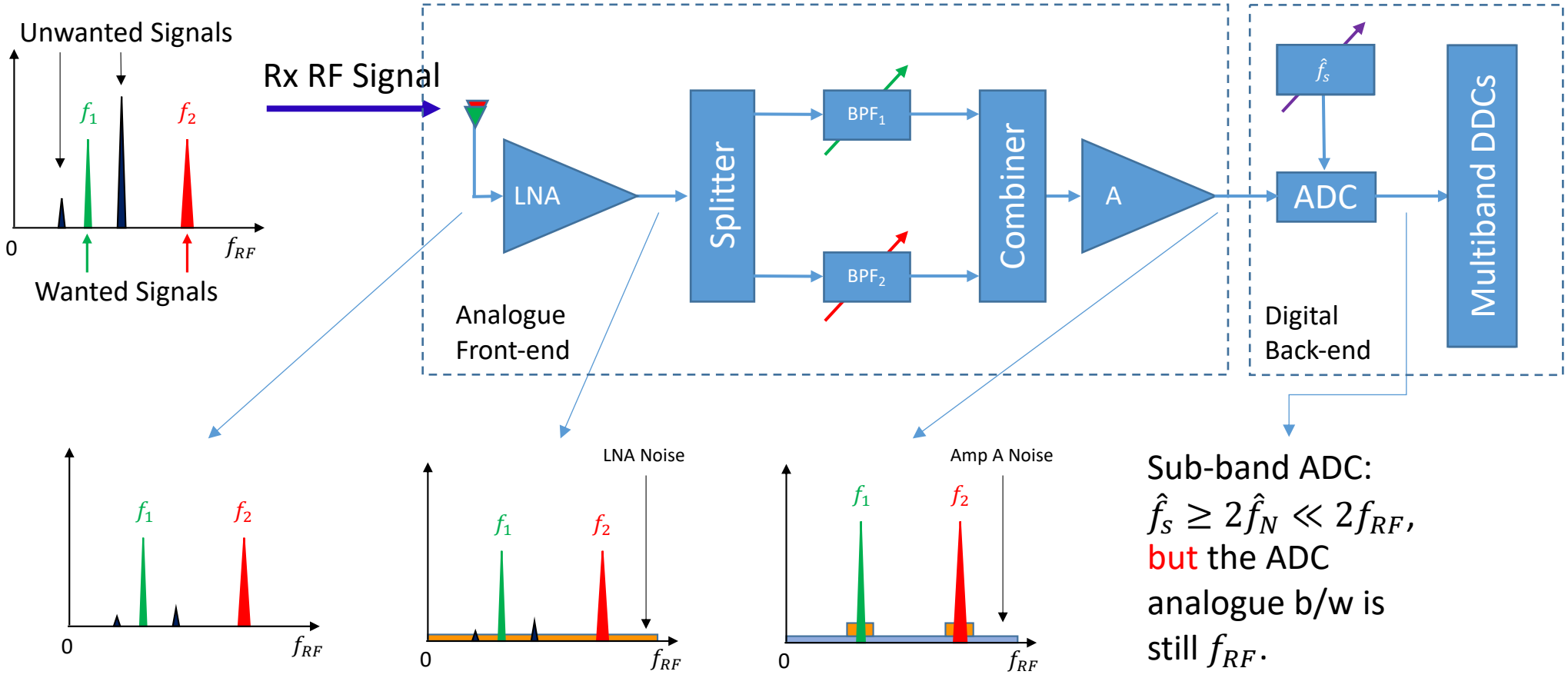
Nyquist Direct RF Sampling Multiband Receiver



Subband Direct RF Sampling Multiband Receiver

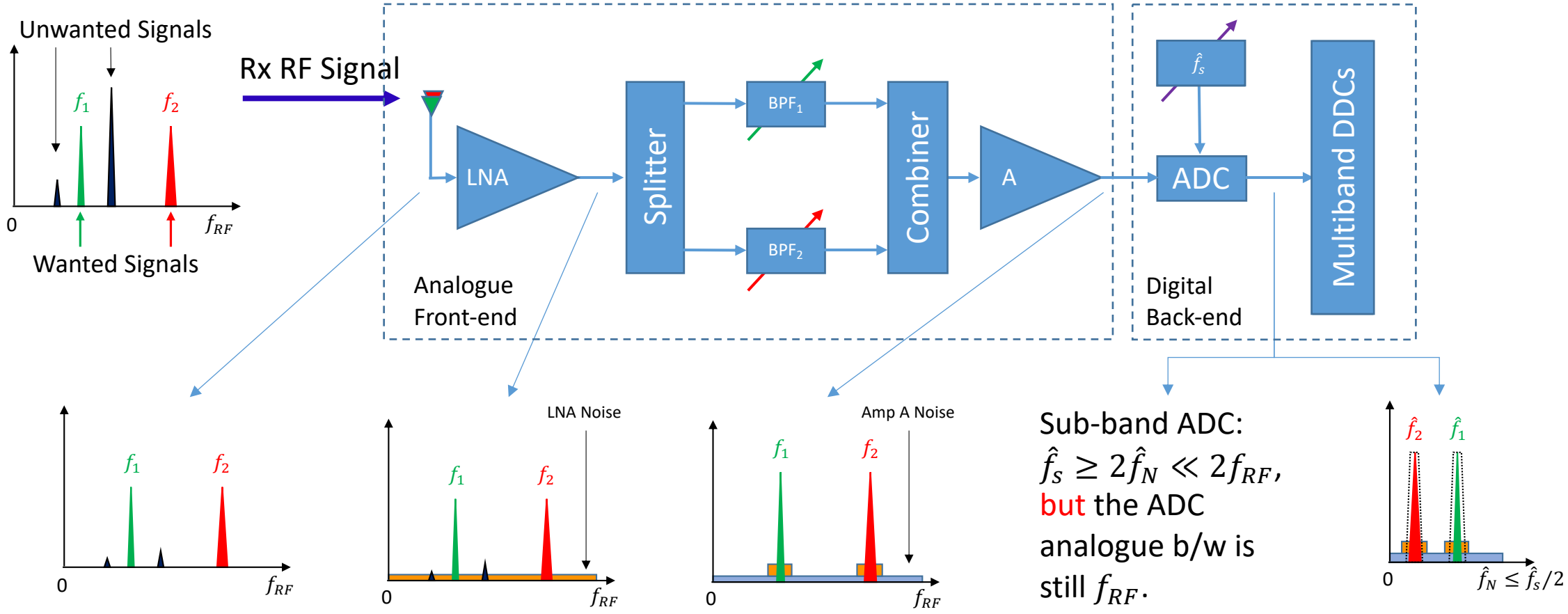


Subband Direct RF Sampling Multiband Receiver



Sub-band ADC:
$\hat{f}_s \geq 2\hat{f}_N \ll 2f_{RF}$,
but the ADC analogue b/w is still f_{RF}.

Subband Direct RF Sampling Multiband Receiver



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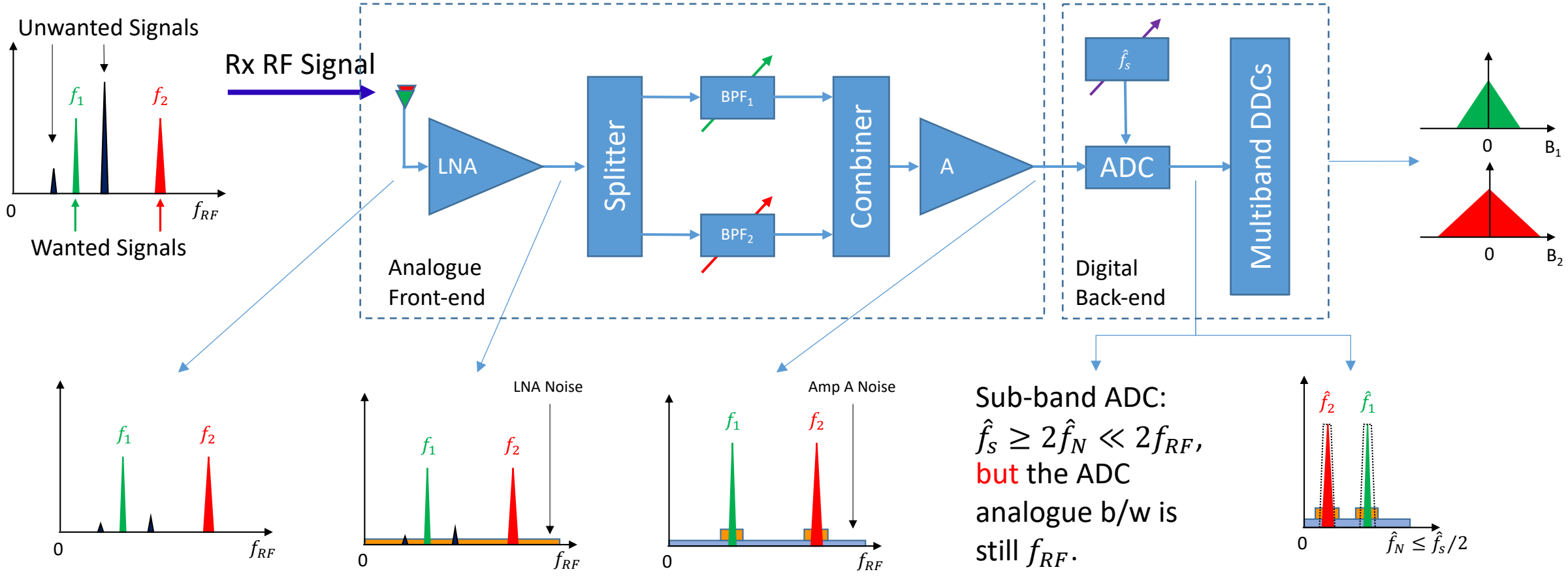
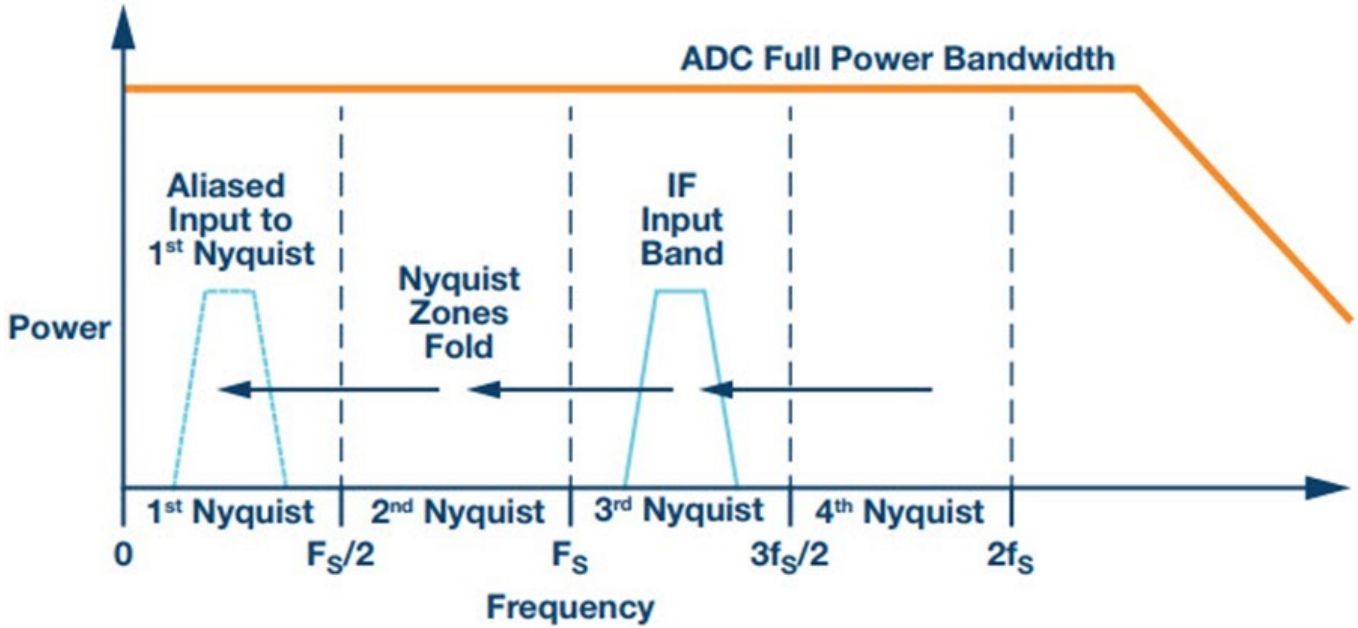


Noise in Direct RF Sampling Concurrent Multiband Receiver

Nyquist sampling – Noise PSD

$$\frac{N_{nyq}}{B_n} \propto \frac{1}{L_q^2} \cdot \frac{\sum_{k=1}^{K} P_k G_k}{f_{nyq}} + N_o$$



Subband sampling – Noise PSD

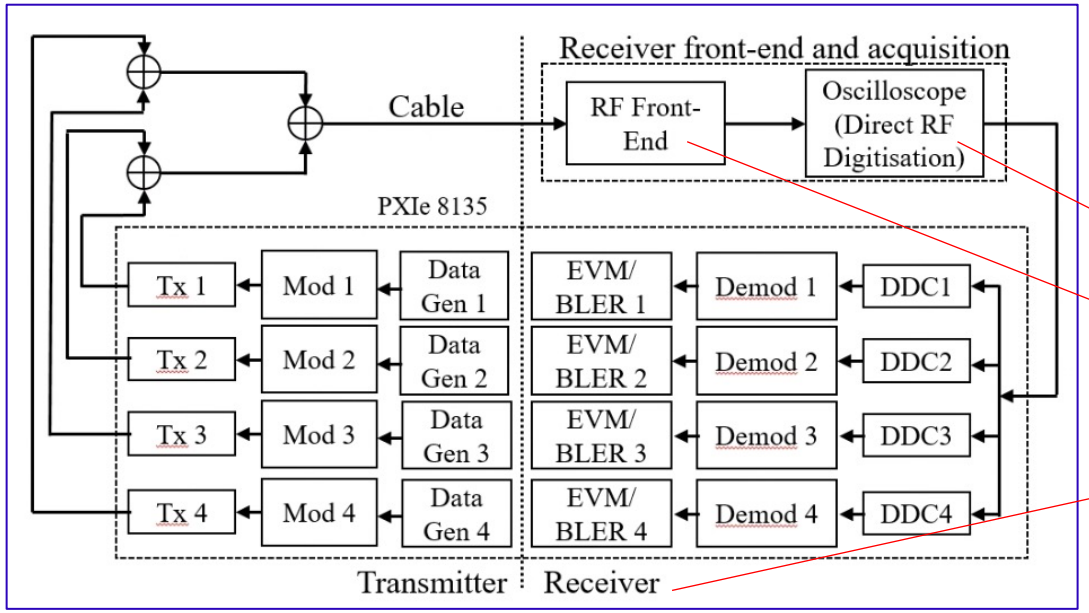
$$\frac{N_{sub}}{B_n} \propto \frac{1}{L_q^2} \cdot \frac{\sum_{k=1}^{K} P_k G_k}{f_{sub}} + N_o + N_F$$

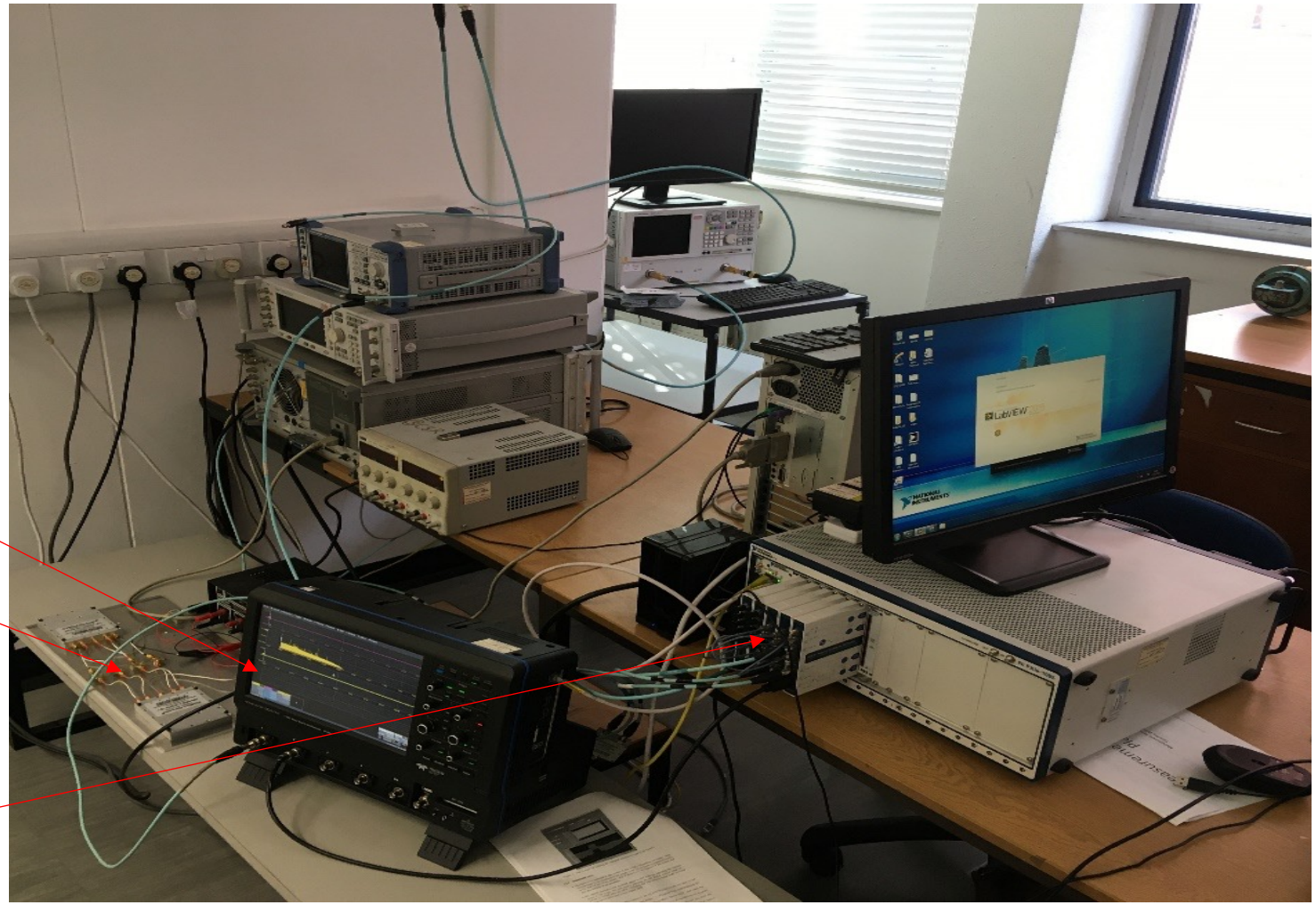
RF noise is increased by $\left(\left\lfloor \frac{2f_{RF}}{f_{sub}} \right\rfloor - 1\right)$ folds

S. Henthorn, T. O'Farrell, R.M. Anbiyaei and K.L. Ford (2021), "*Concurrent Multiband Direct RF Sampling Receivers*", In IEEE Transactions on Circuits and Systems 1, submitted September 2021

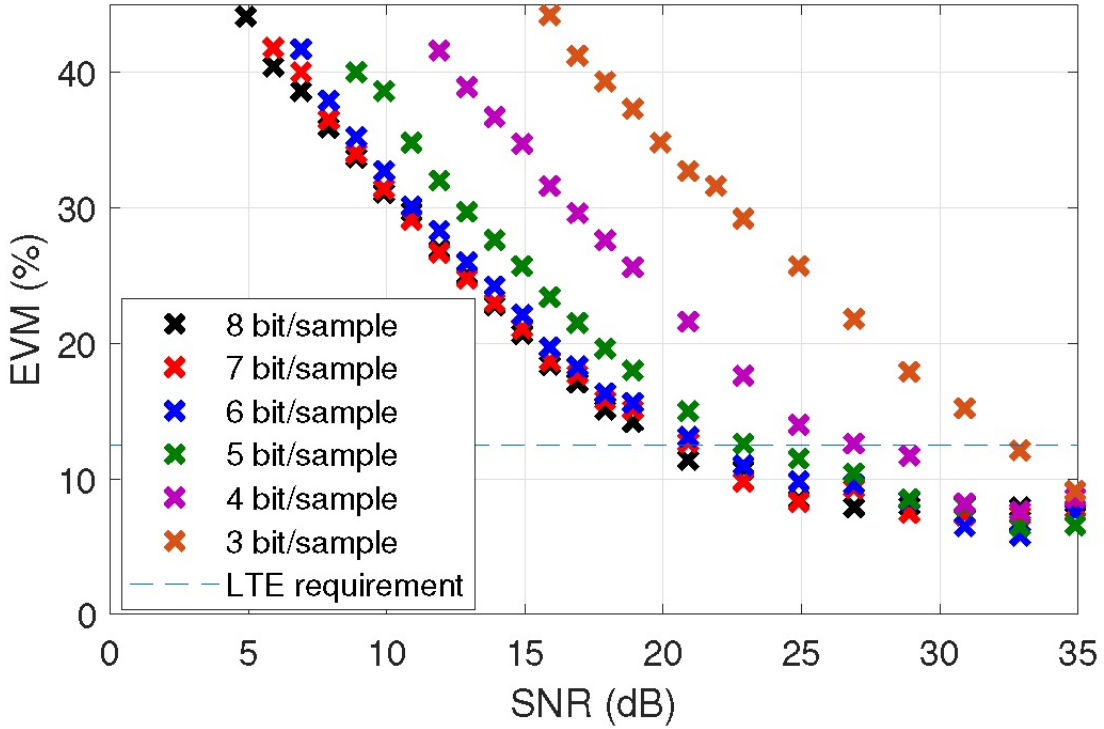
Concurrent Quadband HWIL SDR Testbed

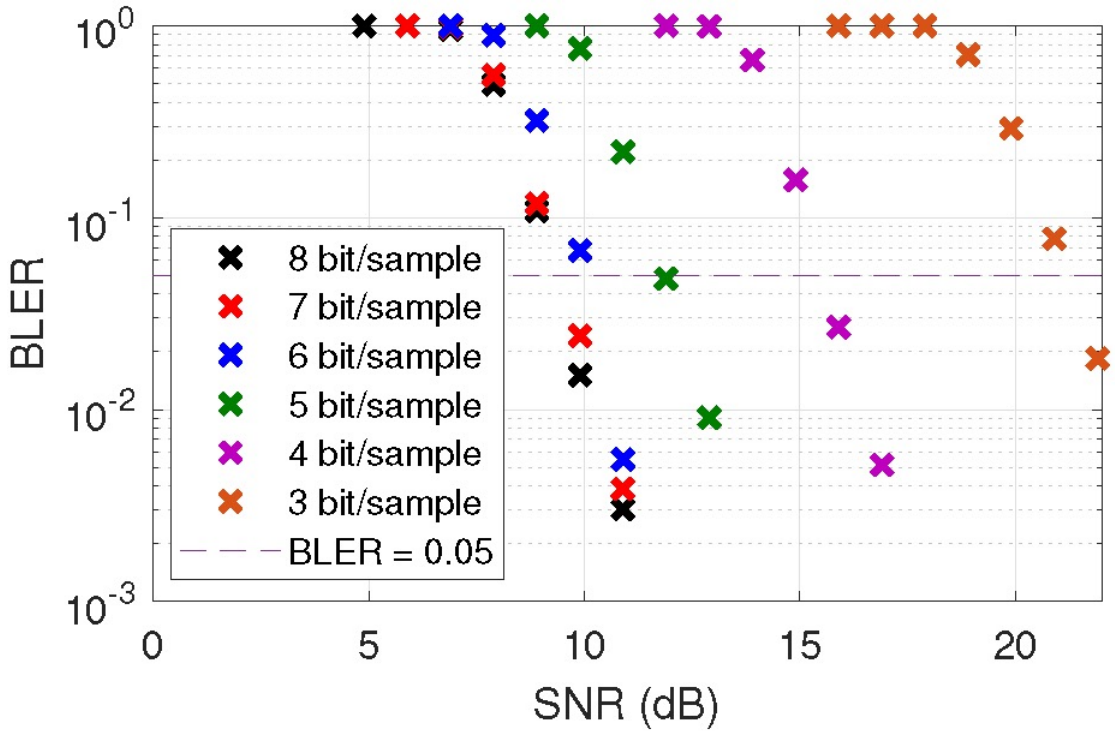
Asif, S.M., Anbiyaei, M.R., Ford, K.L., O'Farrell, T. and Langley, R.J. (2019) "*Low-Profile Independently- and Concurrently-Tunable Quad-band Antenna for Single Chain Sub-6GHz 5G New Radio Applications*." In: IEEE Access, December 2019, open access, doi: 10.1109/ACCESS.2019.2960096





The effect of ADC resolution on concurrent, multiband, direct RF sampling receivers - Nyquist





S. Henthorn, R. Mohammadkhani, T. O'Farrell, K.L. Ford, (2021), "*The effect of ADC resolution on concurrent, multiband, direct RF sampling receivers*", In: Proceedings of IEEE Global Communications Conference (Globecom 2021), Madrid, Spain, 7-11 Dec 2021.

Conclusions

- Direct RF Sampling enables:
  - New concurrent, multiband SDR receiver architectures;
  - Low complexity, cost and power consumption;
  - Scalable RF solutions.
- The concurrent quadband SDR testbed supports many test configurations and is being extended for 5G FR2 operation.
- The techniques migrate to 6G solutions as envisaged at higher frequency bands with appropriate technology changes.
- Crucially, the work supports essential RF Skills development in the UK – presently developing plans to bid for a sub-THz SDR testbed.

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Questions

For further details please contact

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