RF Techniques for Robust and Agile Operation in Congested Spectrum

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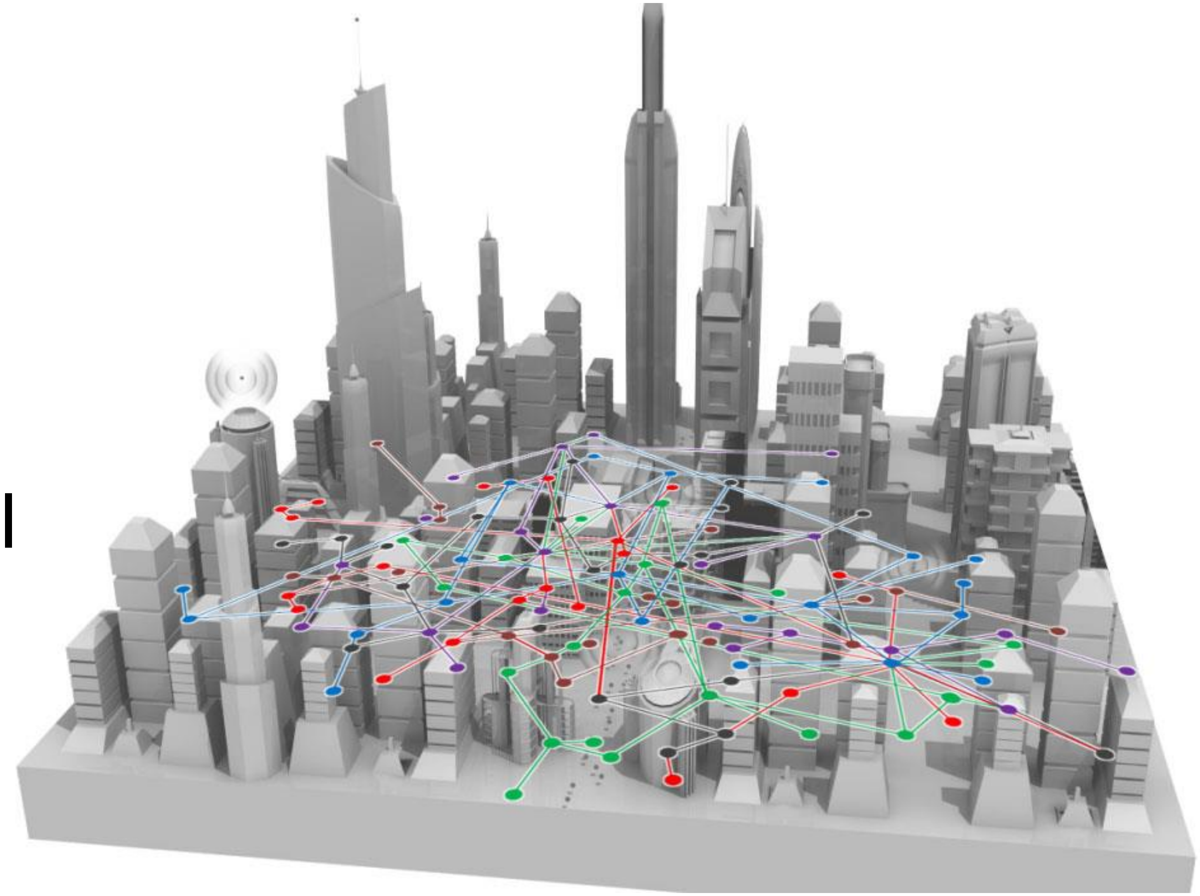
http://www.bristol.ac.uk/engineering/research/csn/

University Defence Research Collaboration, 25th Nov 2020
Themed Meeting on Signal Processing for the Electromagnetic Environment

Summary

- Why Congested Spectrum ?
- RF Requirements?
  - Analogue sub-system for Digital SDR
  - Frequency Agile & Resilient RF
- Underpinning Research from Bristol
  - Multi-band blocker resilient LNAs
  - Enhanced IP3 LNAs
  - Multiband RF Power Amplifiers
  - Frequency Agile Duplexing
- Take Aways



The Value of Spectrum: Italian 5G Auction

Band	Lot	Spectrum [MHz]	Winner	Price [€]	+% *vs* reserve price
700 MHz FDD	700_R	2x10	Iliad	676.472.792	0%
	700_FDD	2x5	Vodafone	345.000.000	2%
	700_FDD	2x5	Vodafone	338.236.396	0%
	700_FDD	2x5	TIM	340.100.000	0,6%
	700_FDD	2x5	TIM	340.100.000	0,6%
		2x30		***2.039.909.188***	***0,52%***
3.7 GHz	3700_C1	80	TIM	1.694.000.000	970%
	3700_C2	80	Vodafone	1.685.000.000	962%
	3700_C3	20	Wind Tre	483.920.000	1120%
	3700_C4	20	Iliad	483.900.000	1120%
		200		***4.346.820.000***	***997%***
26 GHz	26G	200	TIM	33.020.000	1,3%
	26G	200	Iliad	32.900.000	1,0%
	26G	200	Fastweb	32.600.000	0,04%
	26G	200	Wind Tre	32.586.535	0%
	26G	200	Vodafone	32.586.535	0%
		1000		**163.693.070**	**0,5%**
ALL		***1260***		**6.550.422.258**	**162,0%**

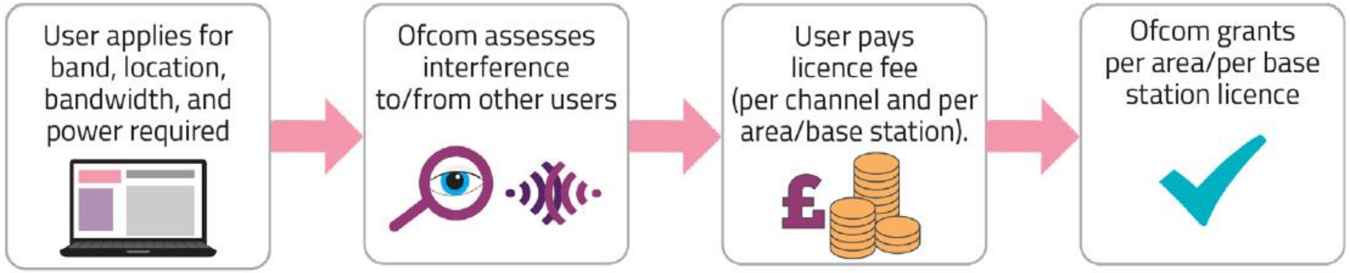
https://operatorwatch.3g4g.co.uk/2018/10/italys-5g-spectrum-auction-controversy.html

- Vodafone Italia and Telecom Italia each spent €2.4 billion to grab the largest share of spectrum on offer in an Italian auction of 5G-suitable frequencies, which raised €4 billion more than the minimum amount targeted by the government.

- Philip Marnick, spectrum group director at Ofcom, said: "*Wireless spectrum is a valuable, finite resource, so it's vital we use it efficiently.*"

Spectrum Sharing

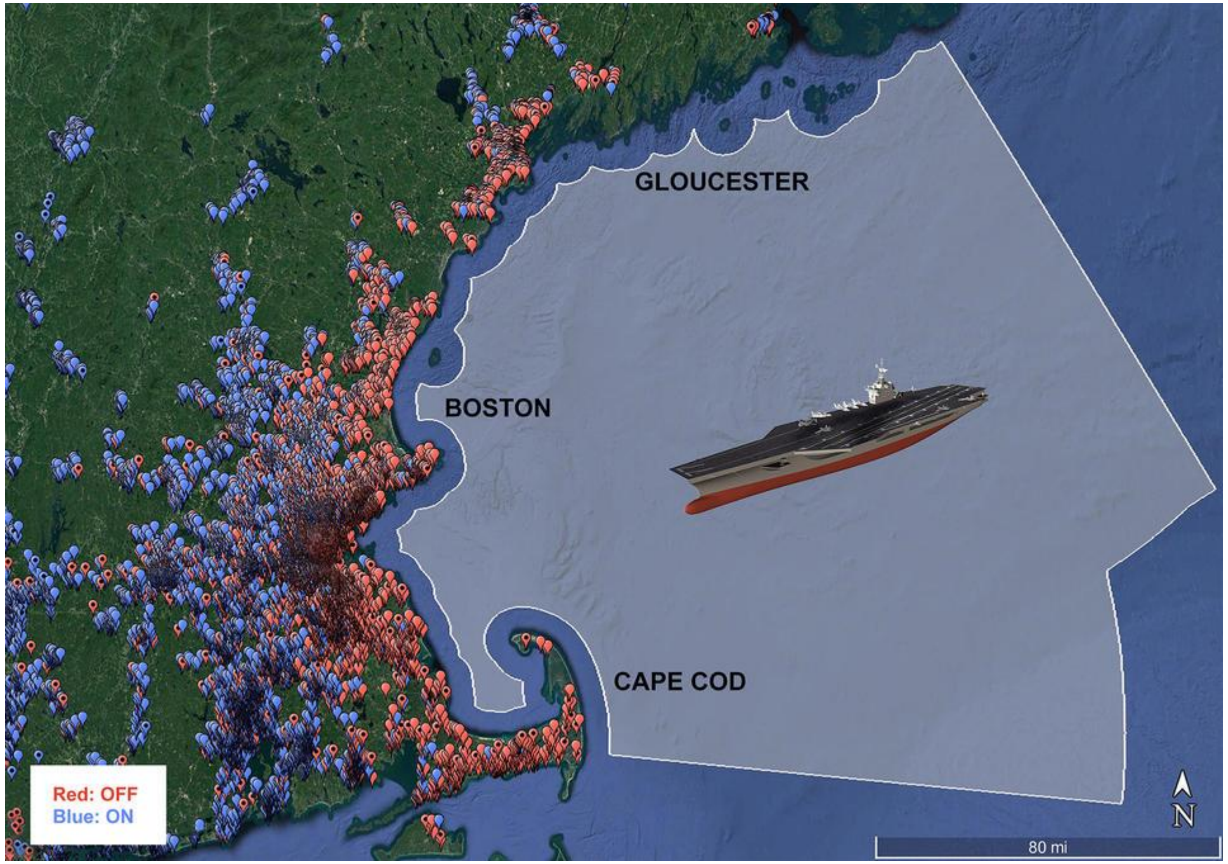
- Part of Ofcom's 2019 Spectrum Strategy
  - *Enabling wireless innovation through local licensing*
  - Opens up spectrum for local use by small businesses or start-ups. Includes use of un-used mobile operators spectrum
  - 3.8-4.2 GHz, 1800 MHz and 2300 MHz bands, plus 26GHz



  - Future transition towards a dynamic spectrum access (DSA)

https://www.ofcom.org.uk/__data/assets/pdf_file/0033/157884/enabling-wireless-innovation-through-local-licensing.pdf

Spectrum Sharing



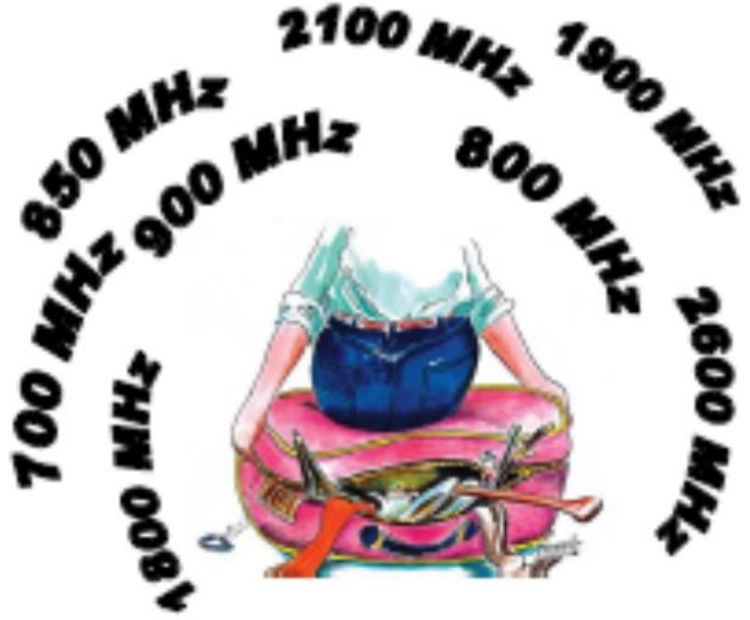
Citizens Broadband Radio Service

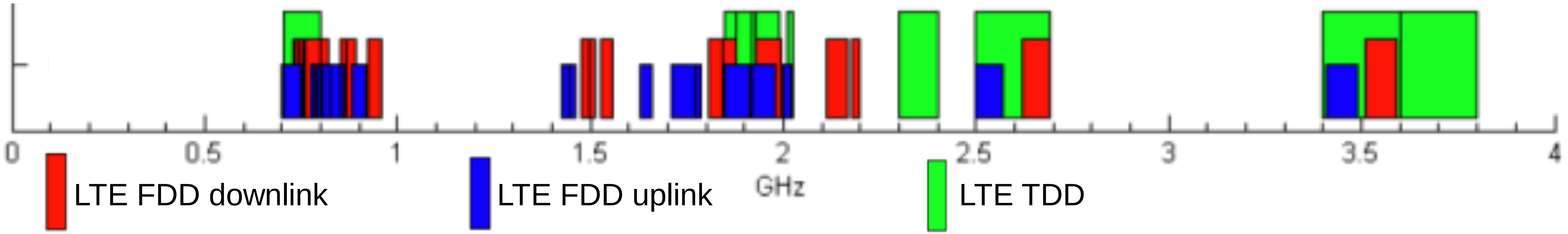
- 3550 MHz to 3700 MHz
  - Bands 42, 43, or 48
- FCC rules allowing incumbent users (military) and new users deploying commercial wireless networks (TDD-LTE) to share spectrum
- No expensive dedicated licensed spectrum required
- Interference is centrally managed:
  - 5 minute sensing update rate

https://www.nist.gov/topics/advanced-communications/spectrum-sharing

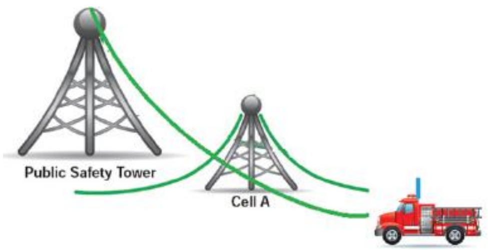
Fragmented Spectrum below 6GHz

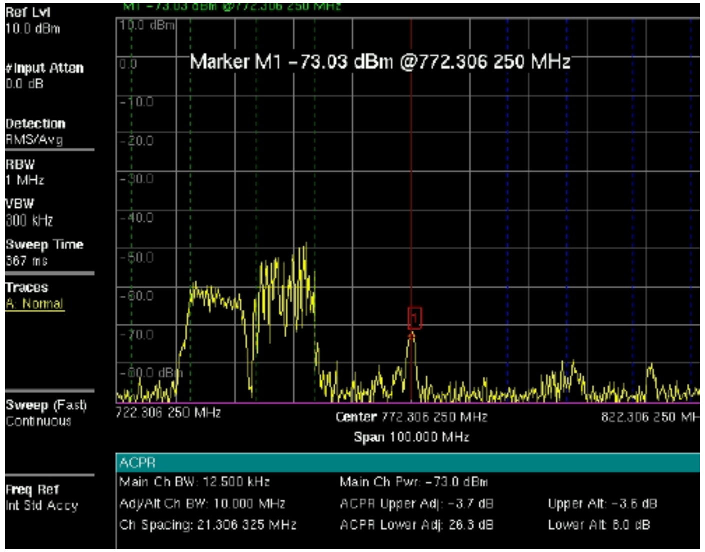
- There are now 50+ bands sub-6GHz bands in LTE, plus also Dynamic Spectrum Access (DSA).
- Current technologies, mobile handsets cannot dynamically support all of theses (too large, expensive, & lossy).
- Advances required in all RF front-end components – especially PAs, Duplexers, LNAs, but still need to meet specs for EVM, ACLR, Rx noise figure.

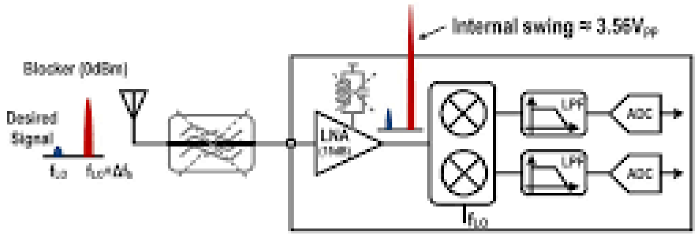




Receiver Blocking







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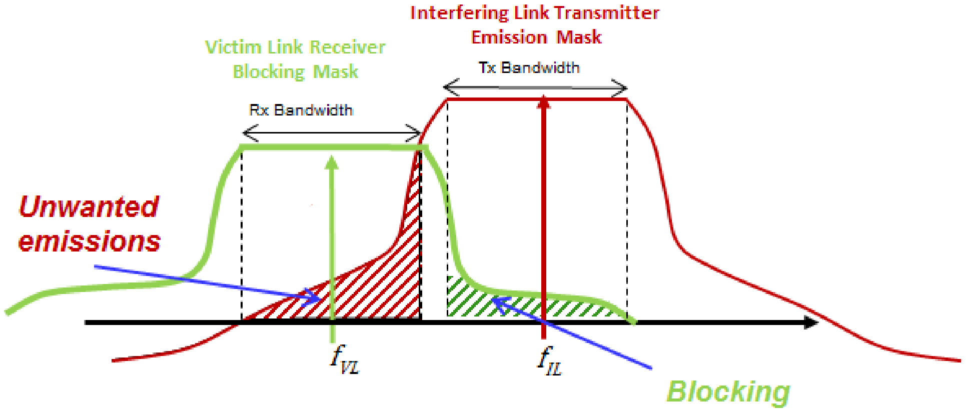
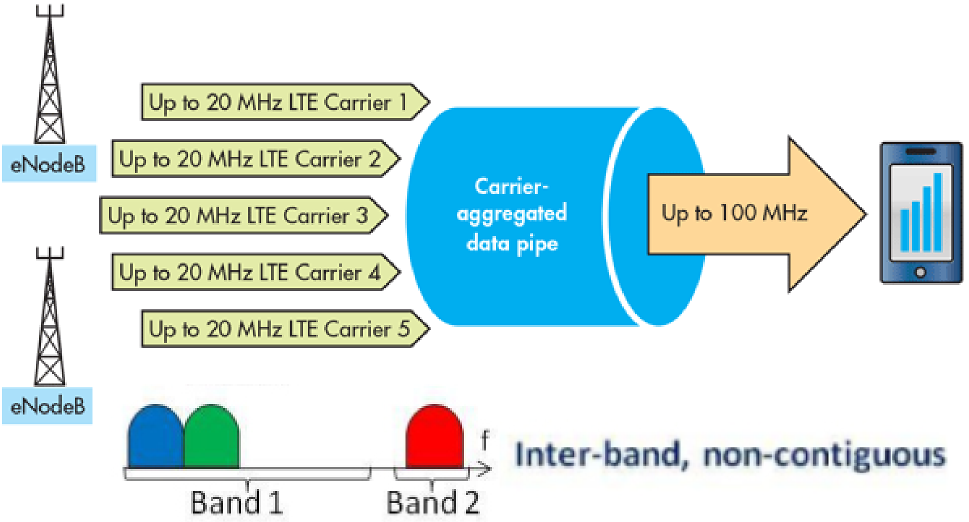


- LNA overload – caused by strong RF signals producing non-linear operation (gain compression of wanted carrier).
- Mixer overload – where strong RF passing through the receiver front end drive the first mixer into non-linearity.
- ADC overload – where the signal levels coming out of the IF section are too large and exceed the dynamic range of the analogue-to-digital converter.

Tuneable Concurrent Multiband Receivers



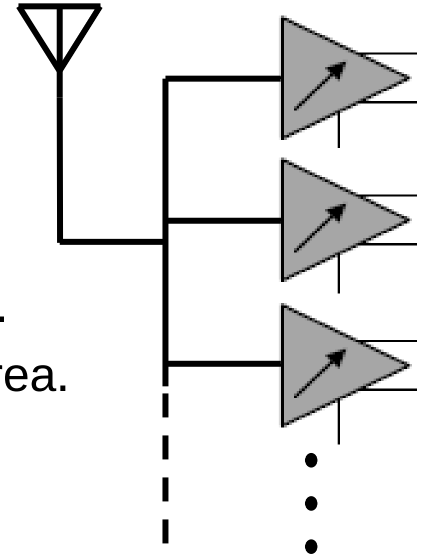
1. Carrier Aggregation for 5G LTE-A

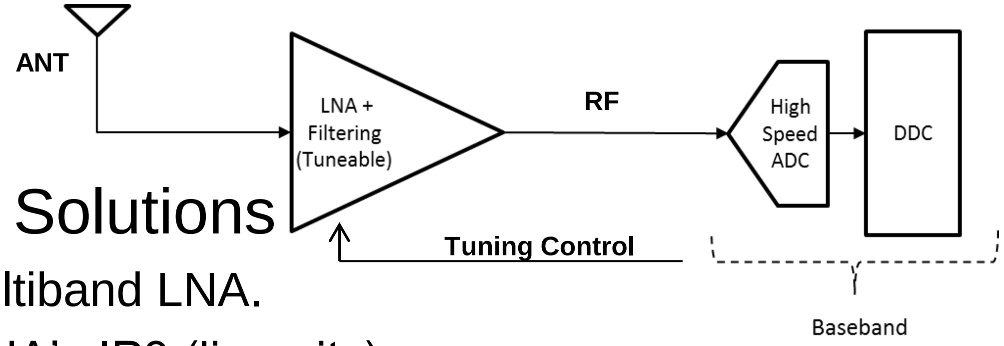
- Channels spread across non-contiguous bands.
- Hardware must cover wider frequency range.
- Requires High Q filtering required up to 6GHz.

Plus a future need to support DSA

2. Current Solution

- Duplicate LNAs for each band.
- Consumes more power and area.

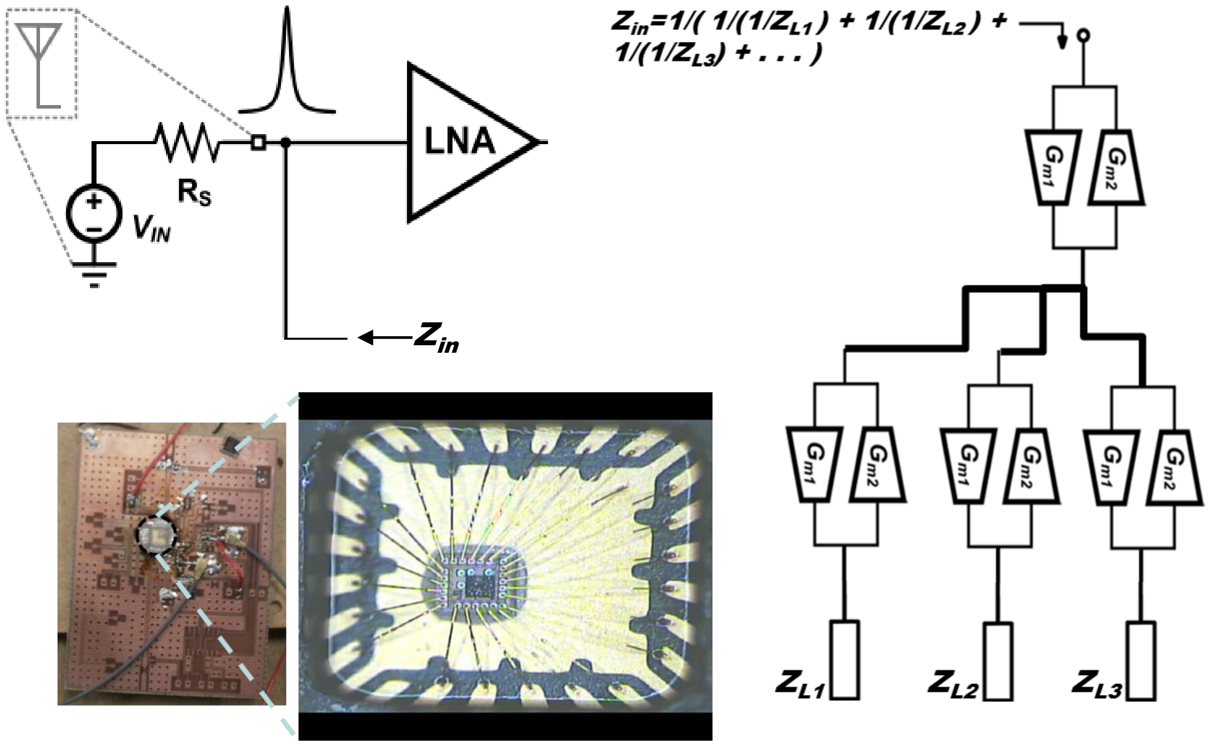


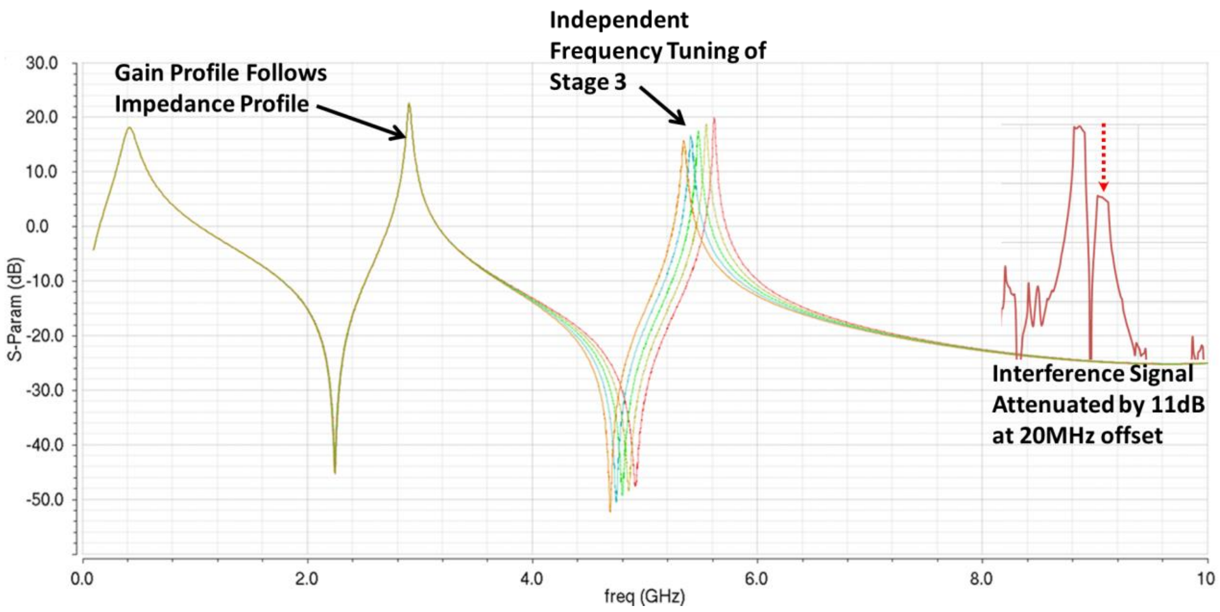


3. Proposed Solutions

- Tuneable Multiband LNA.
- Increasing LNA's IP3 (linearity)

Tuneable Concurrent Multiband Receivers





C. Gamlath, E. Arabi, K. A. Morris and M.A Beach "A design technique for concurrent multiband tunable loads from 0.4–6GHz with independent Q tuning," 2017 IEEE-APMC, doi: 10.1109/APMC.2017.8251615

1. Multiband LNA Architecture

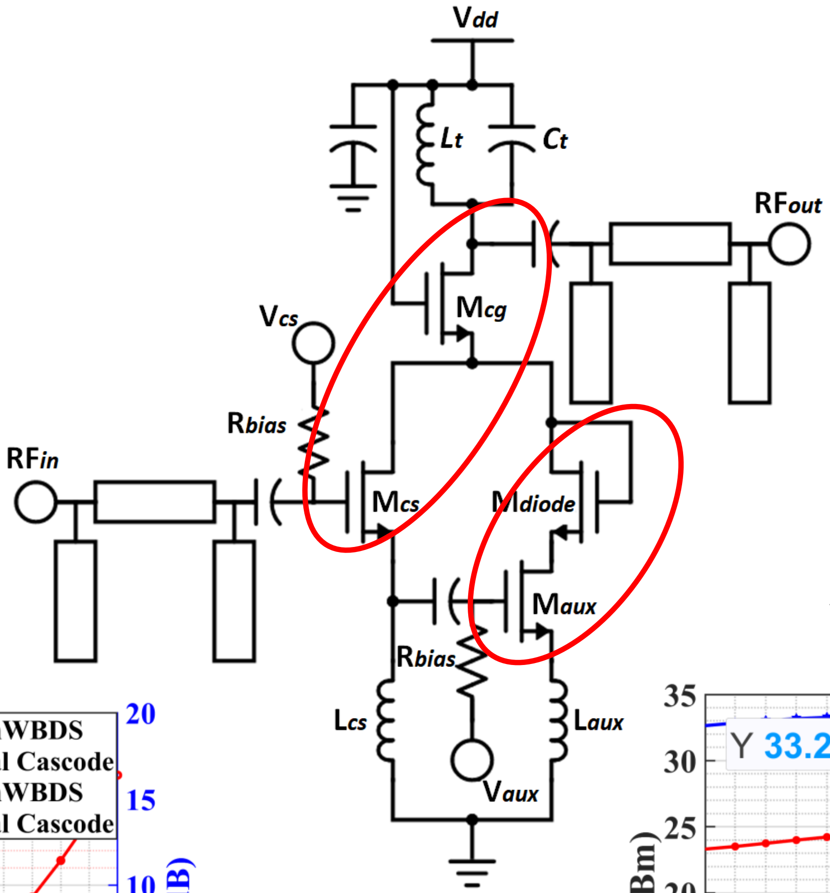
- Use of active impedance inverters (e.g. Gyrators).
- More power efficiency.

2. Results

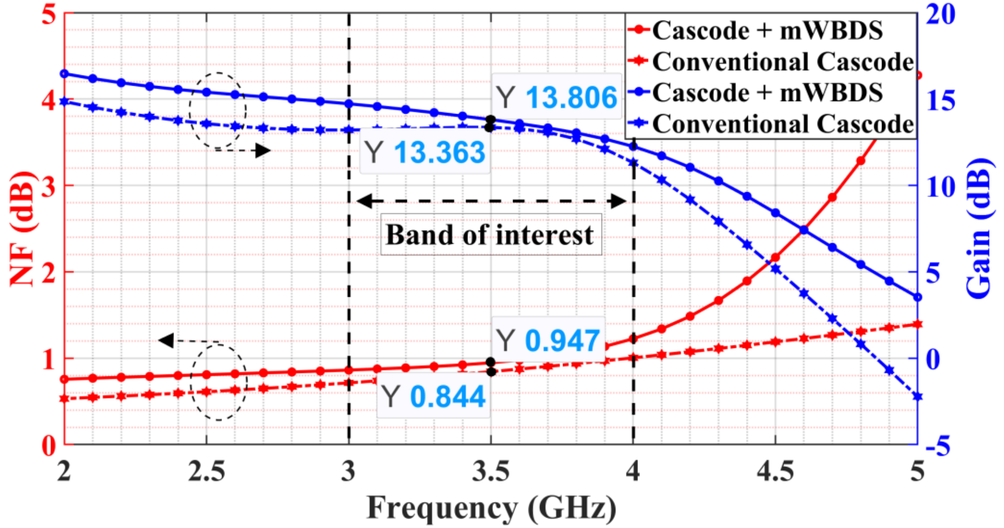
- Shows each band independently tuneable.
- N-path filtering gives high Q response.

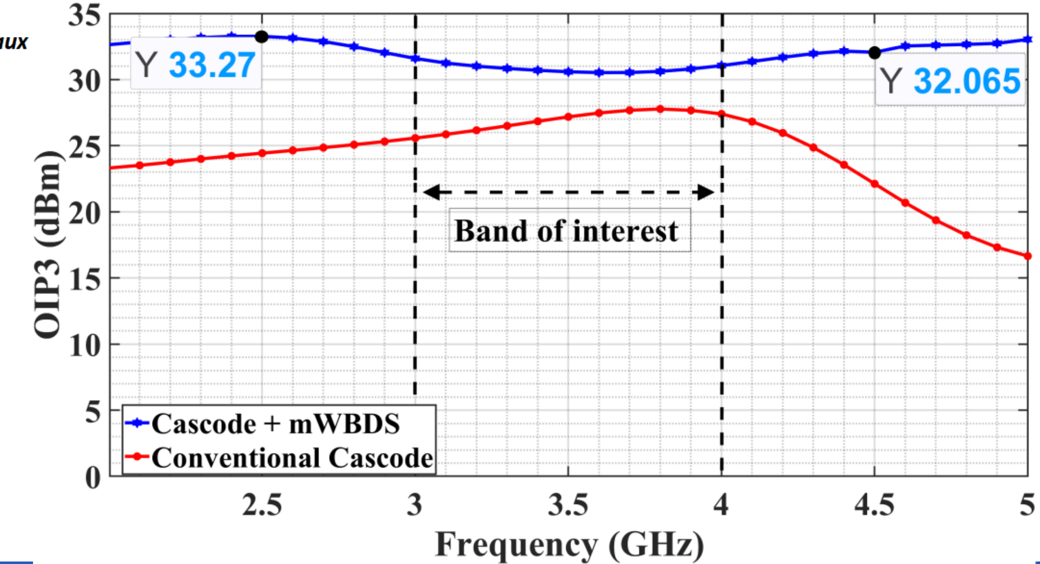
Increasing IP3

- Conventional Cascode
- Plus, linearisation technique for LNA using feedforward wideband derivative superposition.



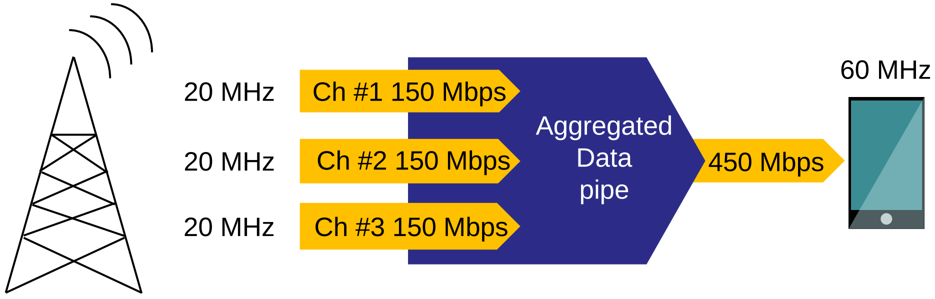
Third-order intercept points (IP3) to illustrate the wideband nature of the LNA.

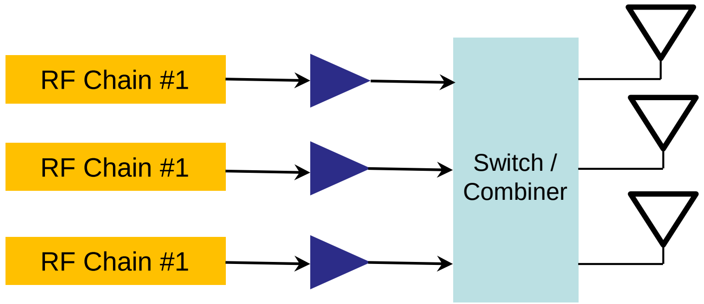


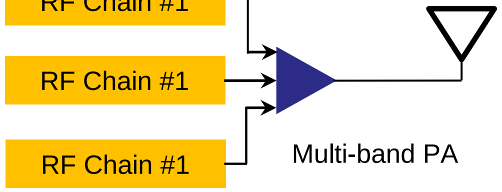


Multi-band Power Amplifiers: Why ?

Increase the data-rate through carrier aggregation



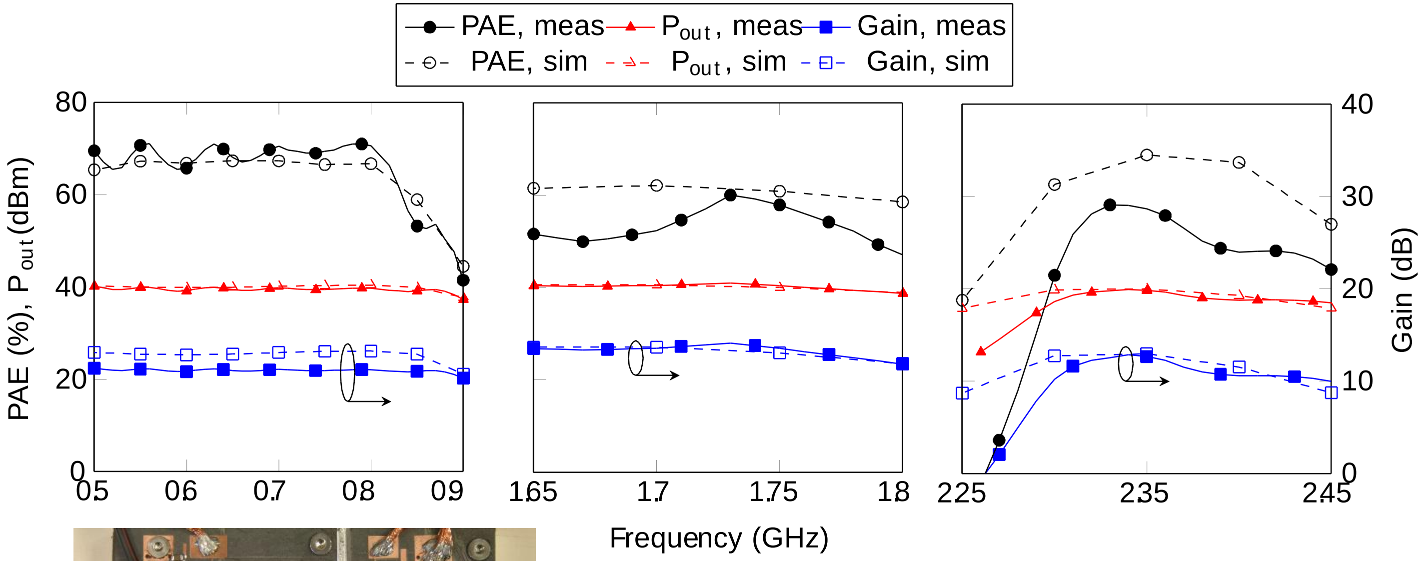




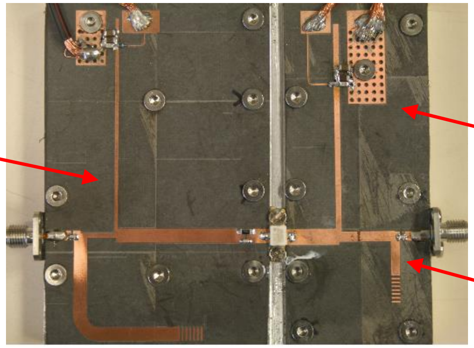
Reduce the number of RF chains/components

Tripple-band Power Amplifiers: Results

Constant Input Power of 27 dBm

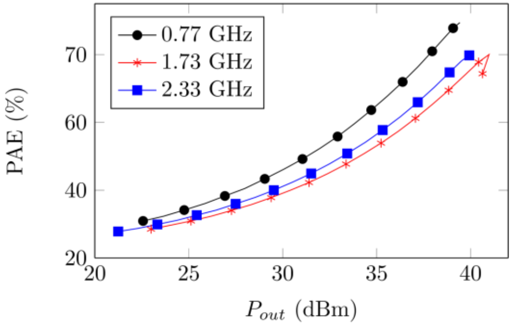


Input matching network



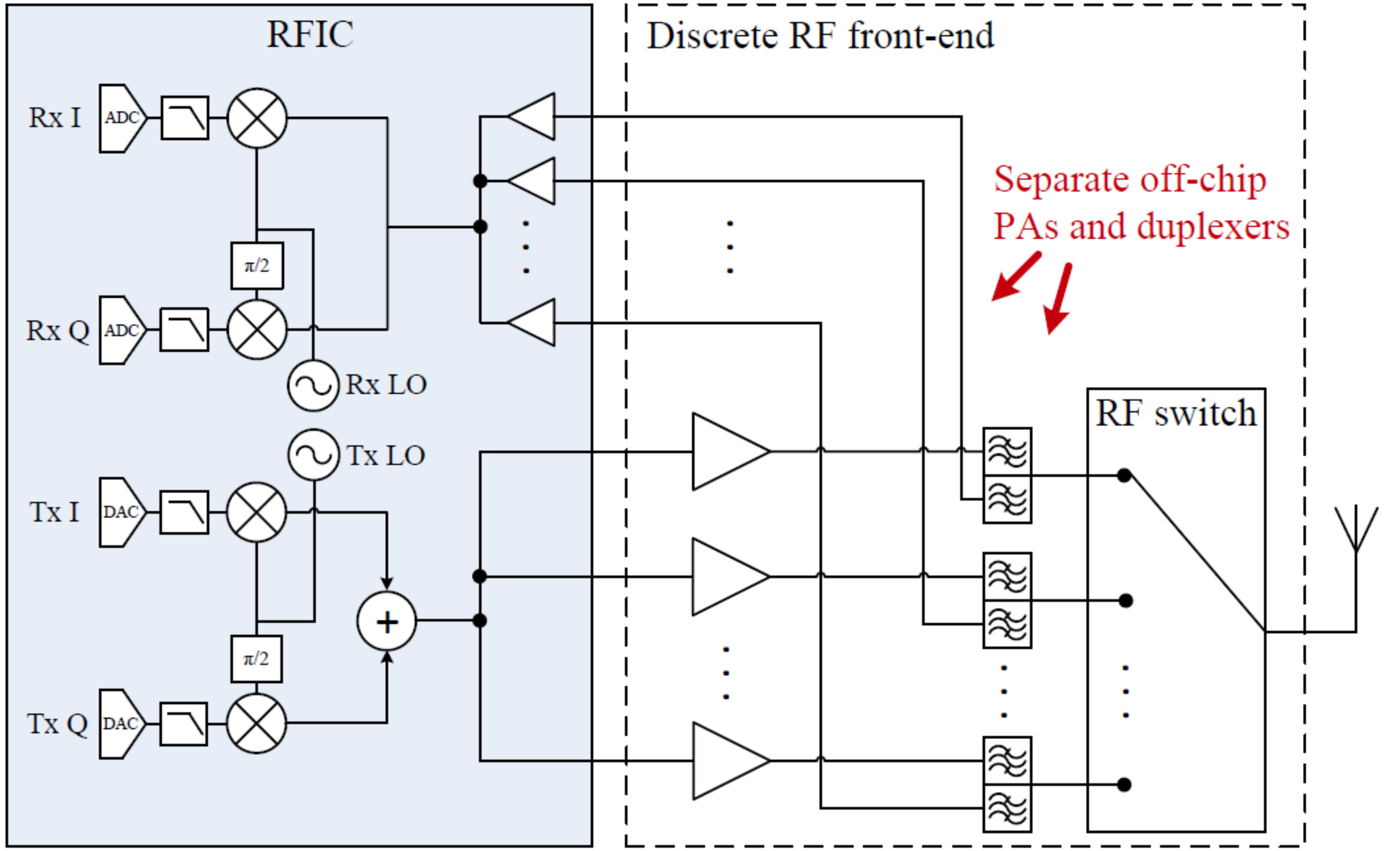
Simple Bias Network

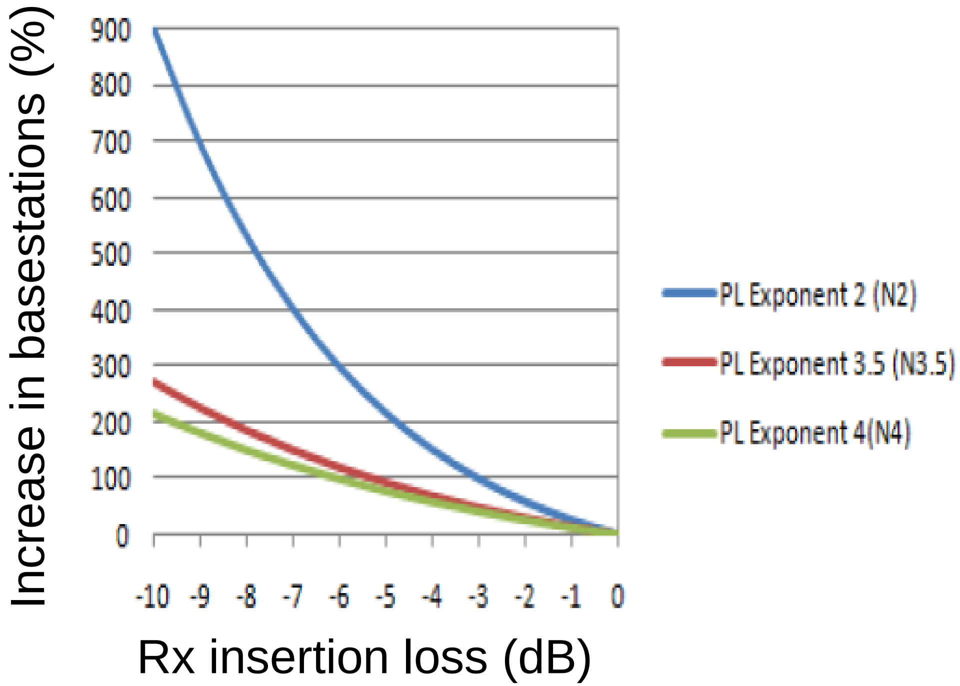
Output matching network



E. Arabi, P. Bagot, S. Bensmida, K. Morris, and M. Beach, "An Optimization-Based Design Technique for Multi-Band Power Amplifiers," *Progress In Electromagnetics Research C*, Vol. 80, 1-12, 2018.

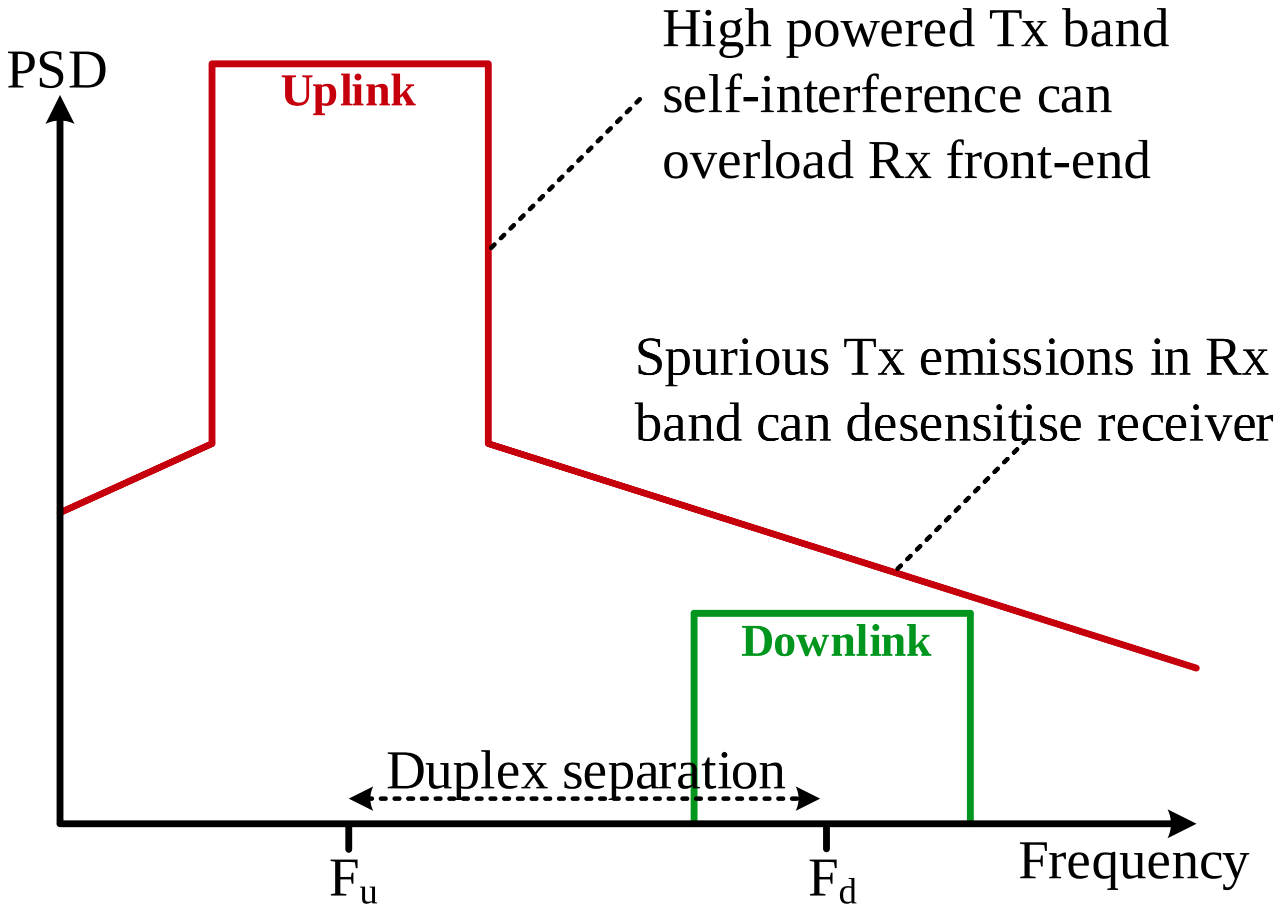
Multiband Cellular RFFE using SAW filters

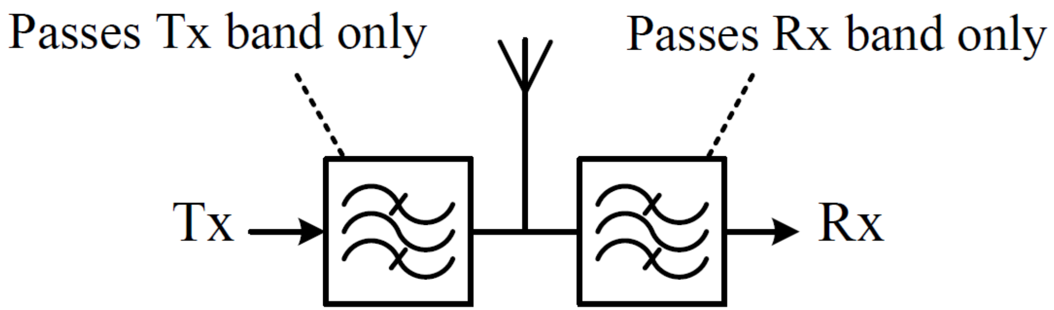


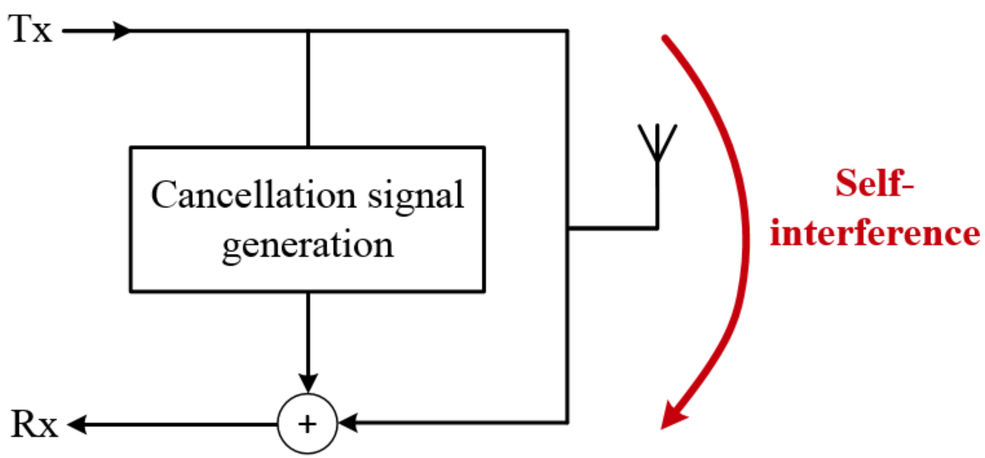


- Rx insertion losses high due to switches
- Limits number of bands and degrades sensitivity

Self-interference cancellation for FDD





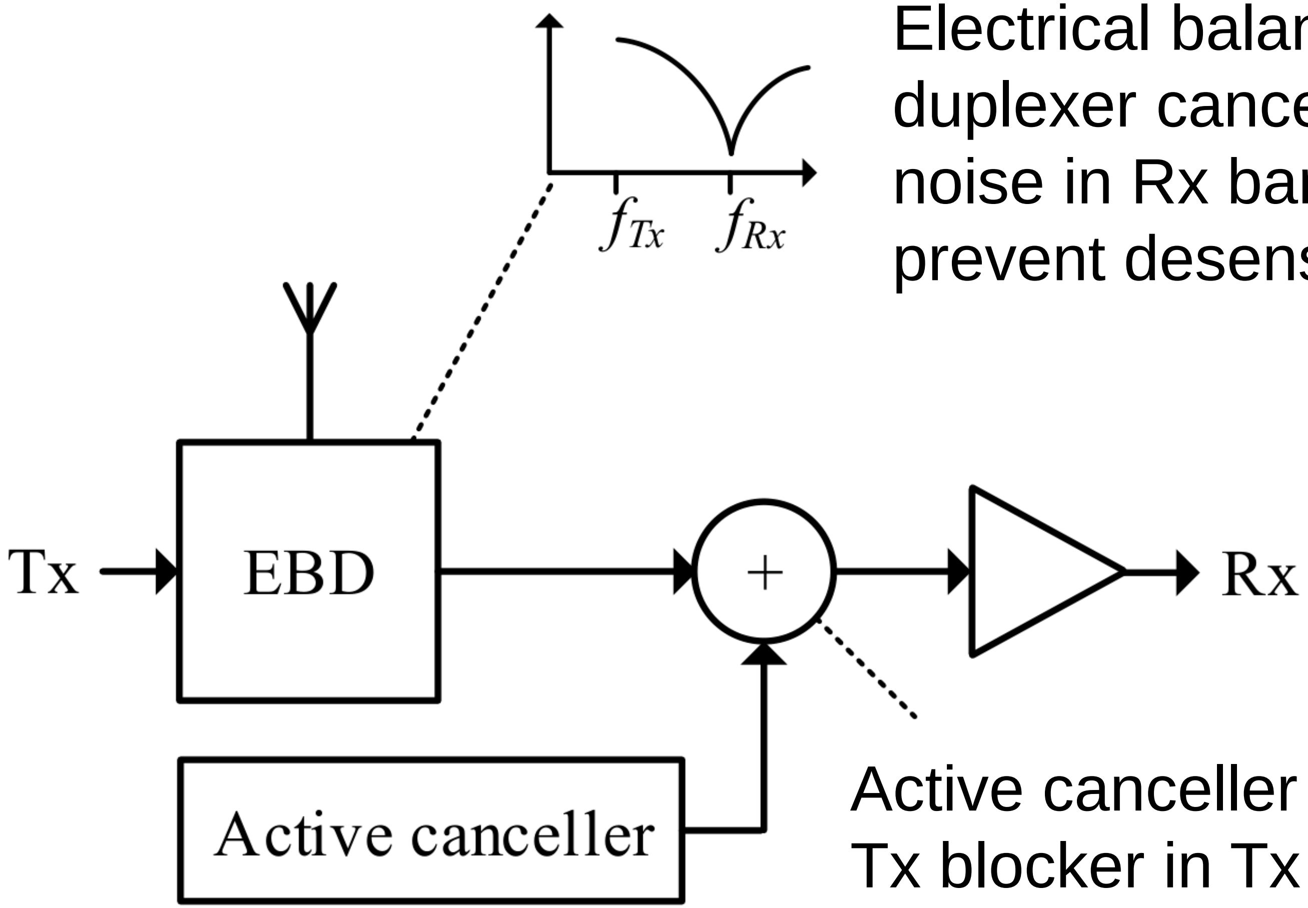


Must cancel self-interference in ***both bands***

Flexible Duplexing by waveform cancellation

- Instead of filtering, this architecture cancels Tx signals leaking to Rx

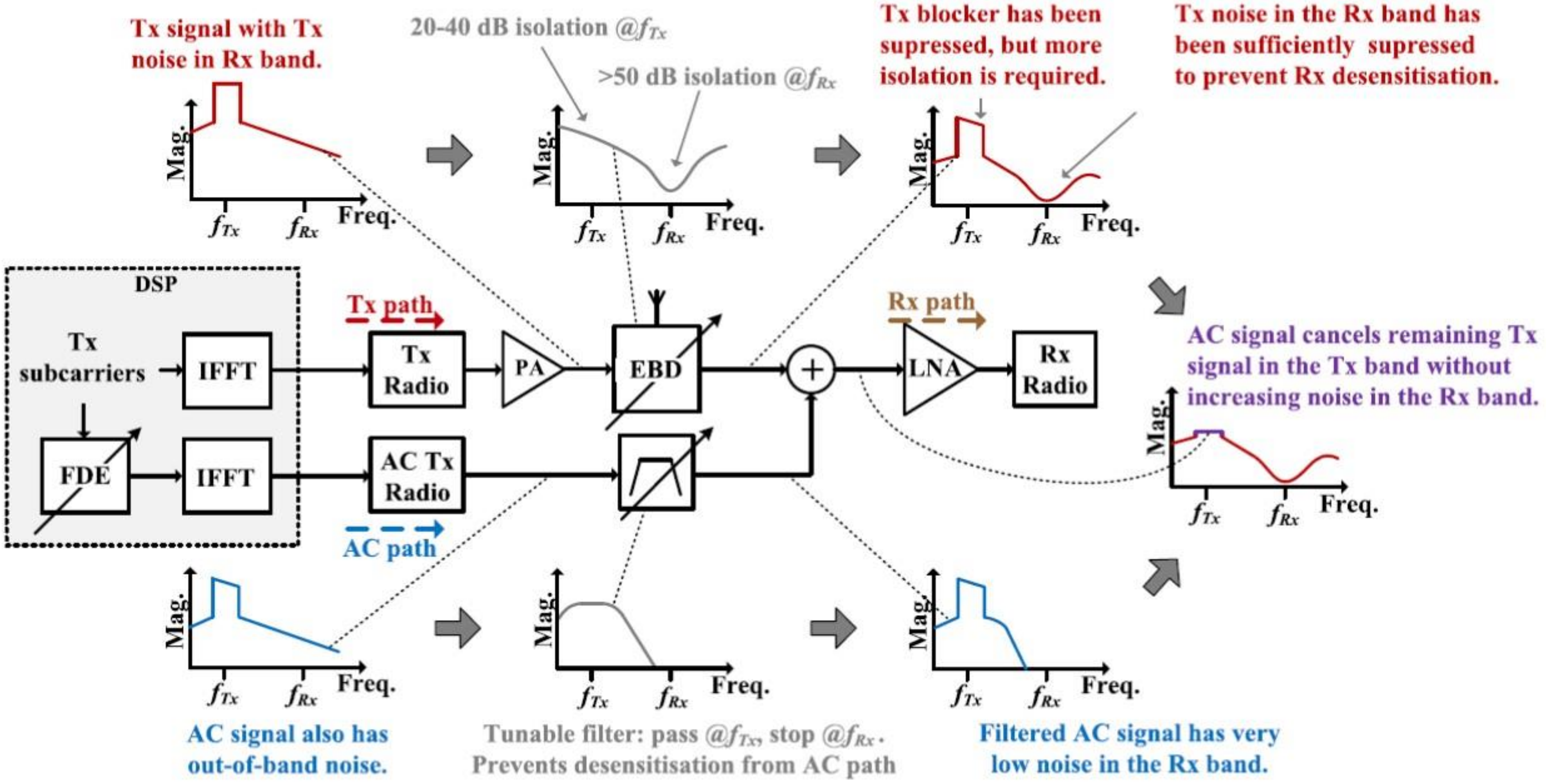
- Provides sufficient isolation with tuneable technologies



Electrical balance duplexer cancels Tx noise in Rx band to prevent desensitization.

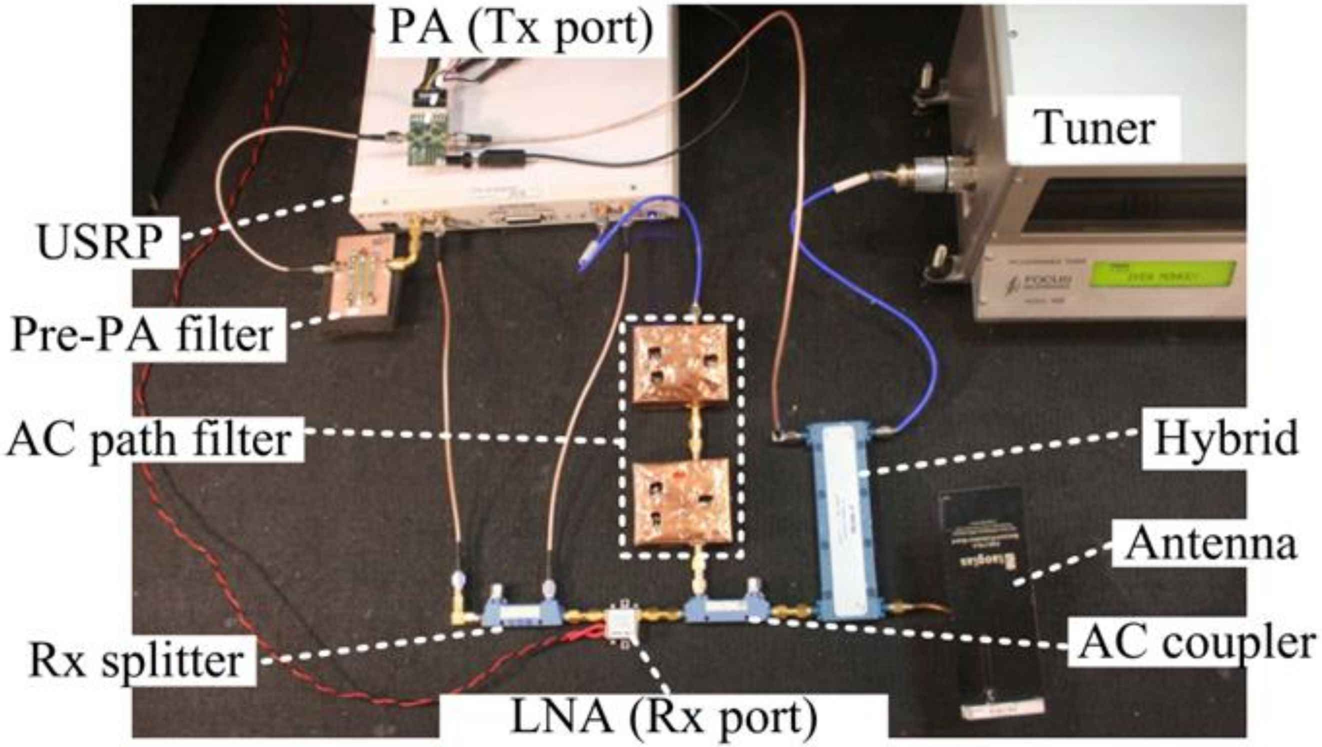
Active canceller suppresses Tx blocker in Tx band to prevent overloading

Flexible Duplexing



Flexible Duplexing – Hardware Prototype

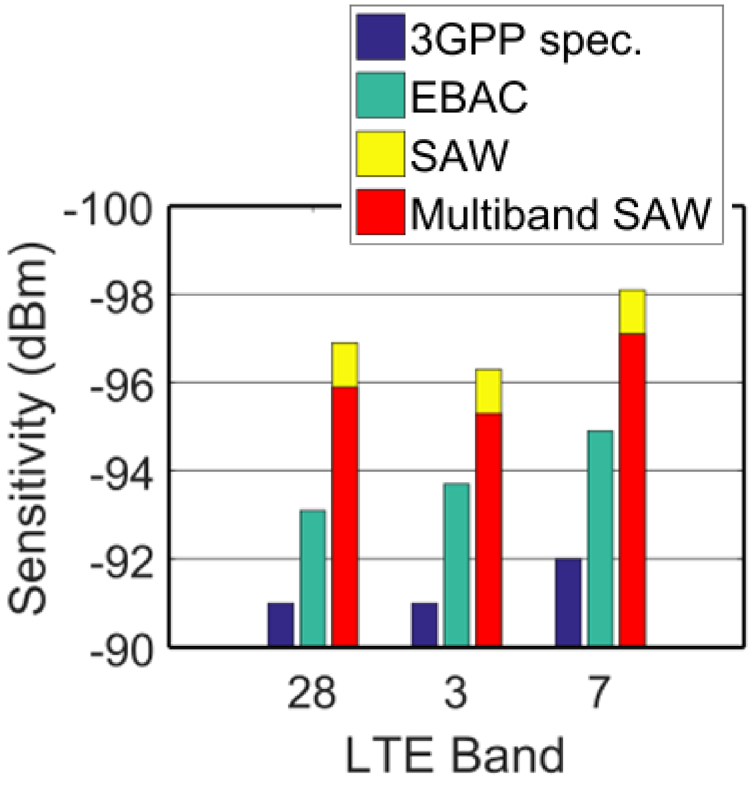
- RF specification is representative of cellular handset

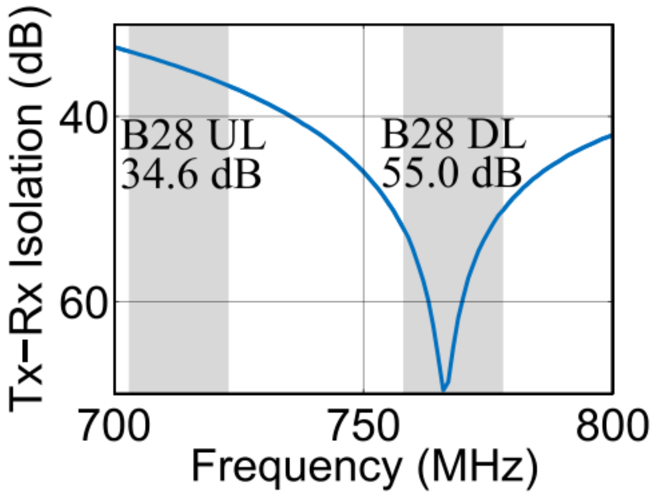


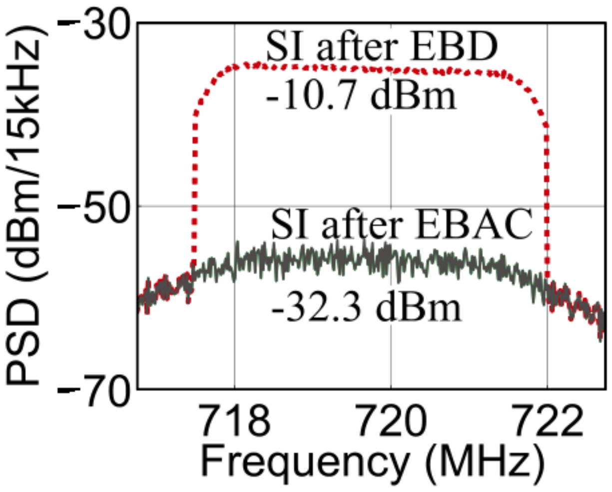
L. Laughlin *et al*., "Tunable Frequency-Division Duplex RF Front End Using Electrical Balance and Active Cancellation," in *IEEE Transactions on Microwave Theory and Techniques*. 2018**.**

Flexible Duplexing - Results

- EBD gives 55 dB isolation in Rx band, but only 35 dB in Tx band.
- AC provides a further 22 dB Tx band suppression.







This architecture achieves LTE specification compliant sensitivity.

Take Aways

- Spectrum Sharing opens-up wireless connectivity to more business and applications
- Dynamic Spectrum Access (DSA) will further enhance the availability of spectrum due to the dynamic use patterns of incumbent users
- R&D required to enhance frequency agility and blocker performance of RF front end circuitry so benefits from DSA can be realised.
- Exploit needs of commercial and defence technology needs

Take Aways

- Joint industrial-academic programme addressing creation of *Secure Wireless Agile Networks (SWAN)*: UKRI EPSRC Prosperity Partnership Scheme
  - Making RF resilient to both cyber-attacks and accidental or induced failures.
  - £6.1M, 5 year, research programme to identify:
    - Vulnerabilities in the RF interfaces;
    - Techniques to detect and mitigate against the effects of cyber-attacks;
    - Create enabling technology for truly Software Defined Radios via “Secure by Design” principals;
    - Creation of more resilient and secure systems.

https://www.bristol.ac.uk/news/2019/october/swan.html
https://www.ukri.org/news/confronting-cyber-threats-to-businesses-and-personal-data/

