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Spectrum Monitoring for Sharing: First Principles SDR Design and Implementation

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16th September 2021

6G: Software Defined Radio and RF Sampling

Overview

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- Spectrum management approaches:
  - Traditional, fixed allocation
  - Shared spectrum with local licensing
  - Dynamic spectrum access
- **The vision for 6G:** fully autonomous Dynamic Spectrum Access combining:
  - Dynamic spectrum licence database
  - Off-the-air, wideband spectrum sensing
  - Cognitive functions and sub-millisecond decision-making
- Introducing… a single-chip, Xilinx RFSoC-based prototype tool that combines:
  - Ofcom UK frequency allocation table
  - Live spectrum monitoring

…. Including a live demonstration!

Radio Spectrum Allocation (fixed)

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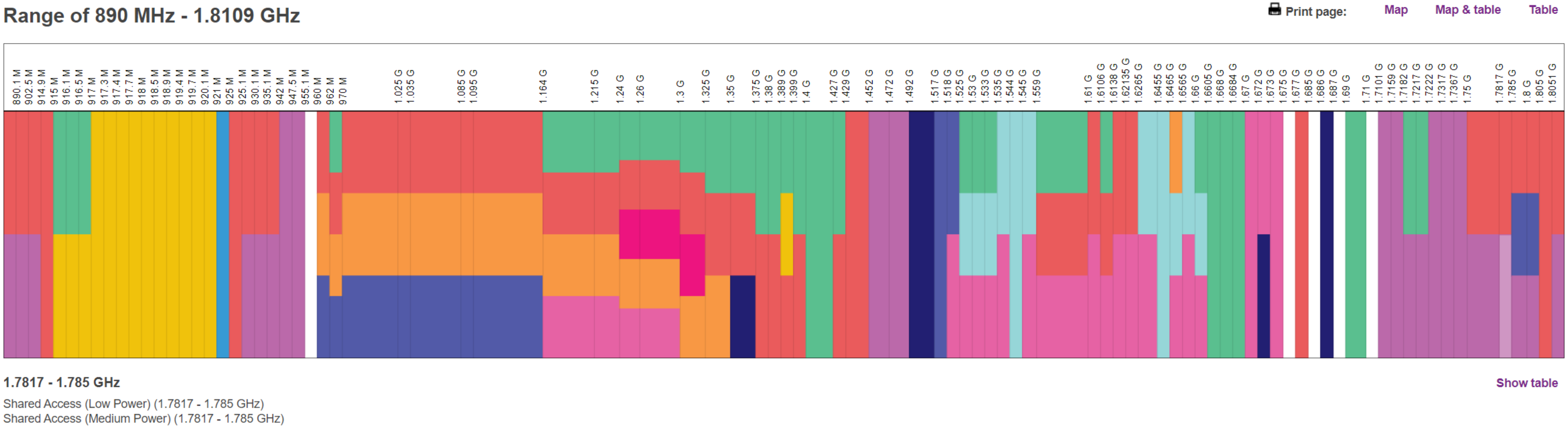
- The longstanding, “traditional” method of managing radio spectrum is to allocate bands of frequencies to particular usage types, and in some cases to licensed users.
- This is done by Ofcom (in the UK), FCC (in the USA) and national regulators around the world.



Extract from Ofcom Spectrum Map: http://static.ofcom.org.uk/static/spectrum/map.html

Radio Spectrum Allocation (fixed example)

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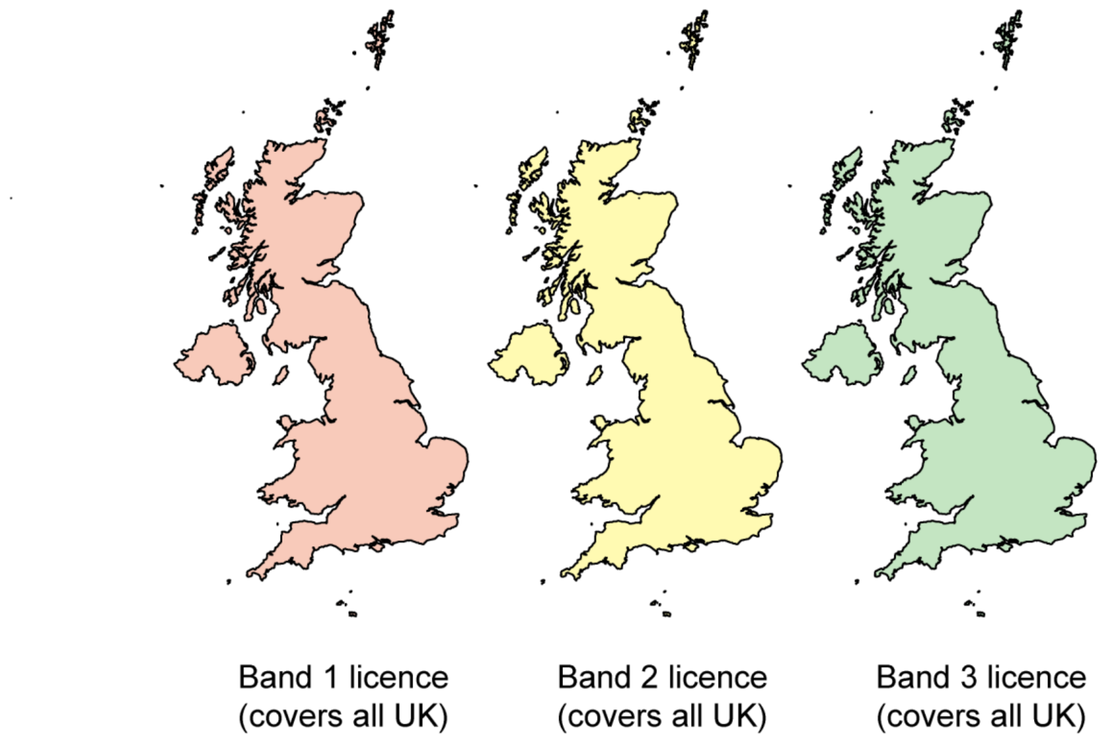
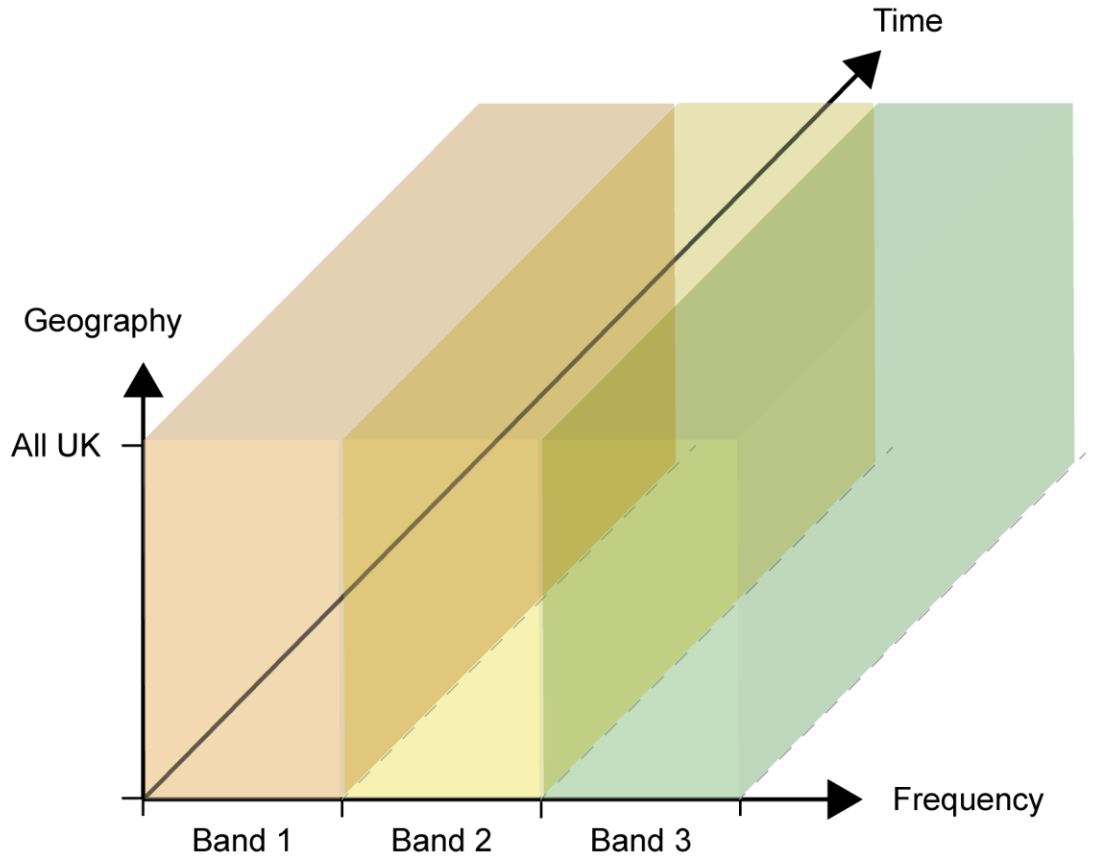
- Frequency bands are licensed for specific uses/users across the UK on a permanent or long-term basis.





Shared Spectrum (local licensing)

- As of 2019, Ofcom has made certain frequency bands available on a “shared spectrum” basis [1].
- These are:

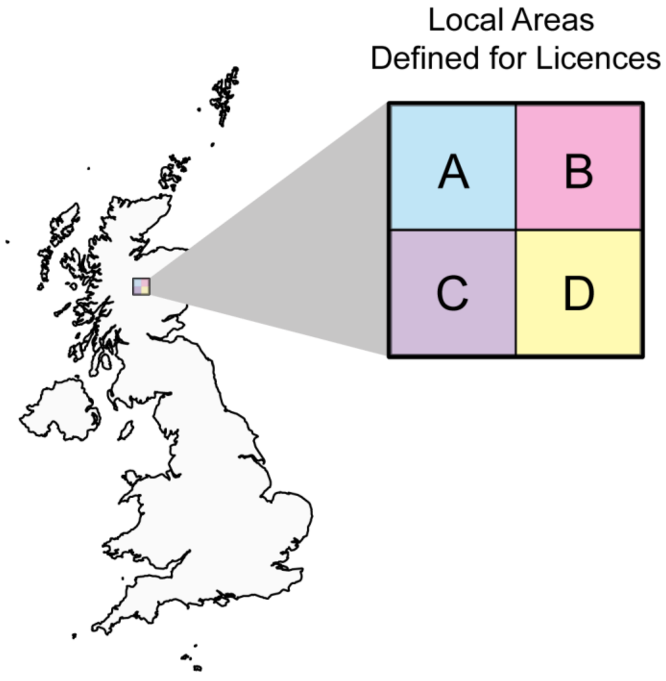
– 1800 MHz band	**1781.7 – 1785 MHz** *paired with* **1876.7 – 1880MHz**	3.3 MHz + 3.3MHz
– 2300 MHz band	**2390 – 2400 MHz**	10 MHz
– 3.8 – 4.2 GHz band	**3.8 – 4.2 GHz**	400 MHz
– Lower 26GHz band	**24.25 – 26.5 GHz** (indoor)	2.25 GHz

- Users apply to Ofcom for a licence in a specific geographical area (time basis: “years”).
- Suitable for private 5G networks, for instance in commercial / industrial facilities.
- Each of these bands is already designated for other uses – new “shared spectrum” users must coexist with existing licensed users.

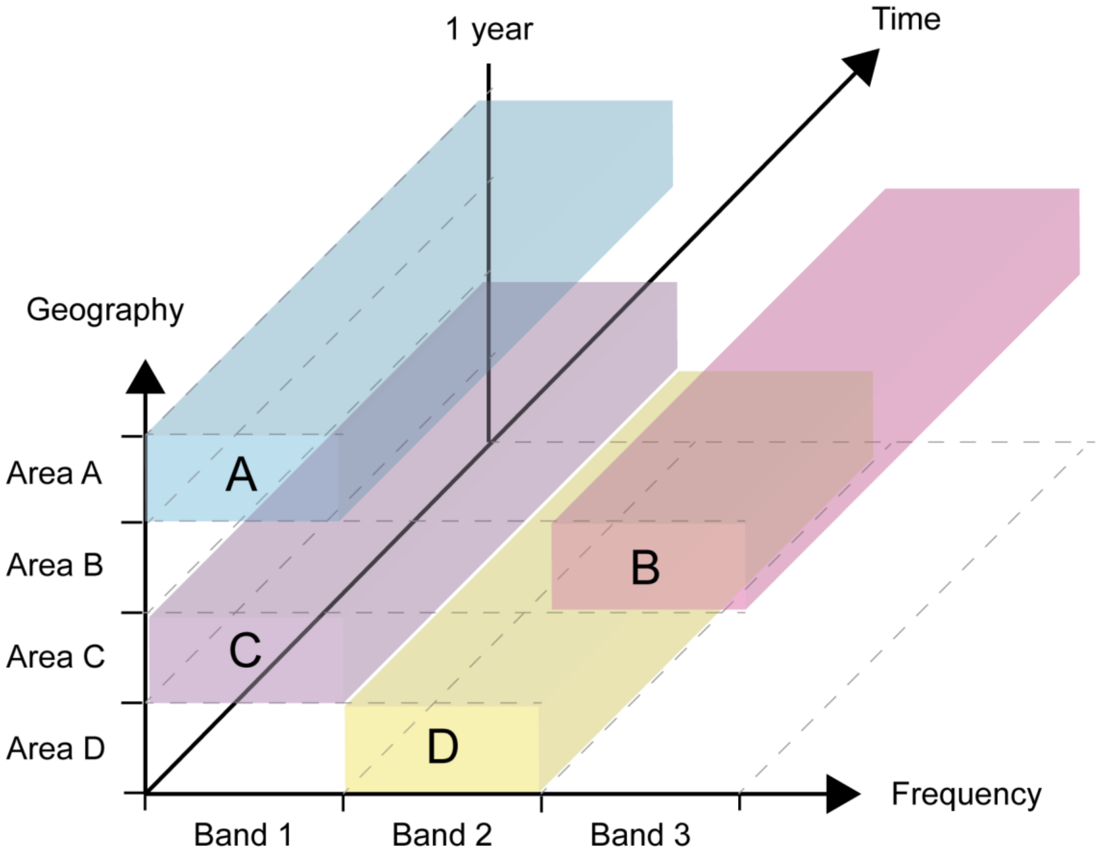
[1] Ofcom, Statement: *Enabling wireless innovation through local licensing*, published 25th July 2019

Shared Spectrum (local licensing example)

- With local licensing, shared frequency bands can be licenced in different geographical locations.
- For instance, Area B (pink) has obtained a licence for Frequency Band 3.

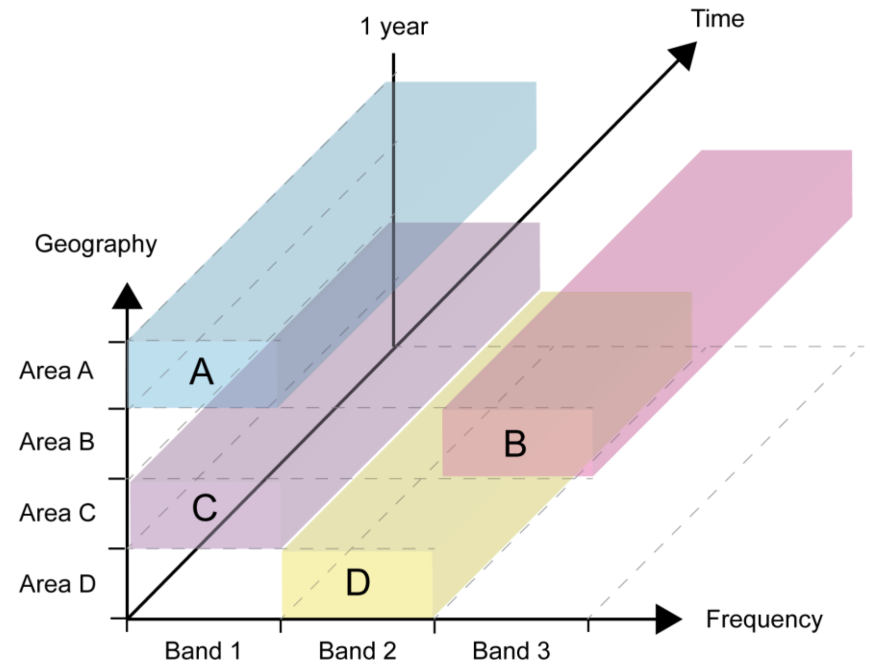


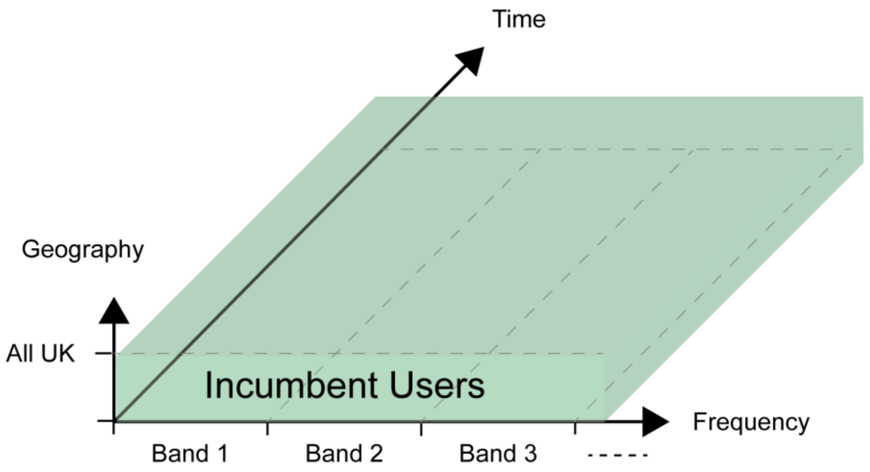
Shared spectrum licence
(based on location)



Shared Spectrum (incumbent users)

- There are also incumbent users of the spectrum, based on the original (fixed) frequency allocations.
- Users of shared spectrum bands must coexist with these incumbent users.
- Coexistence strategies may include spectrum sensing techniques – i.e. a radio observes the ambient radio spectrum before transmitting.
- Links to the idea of **cognitive radio**.





Shared Spectrum (dynamic spectrum access)

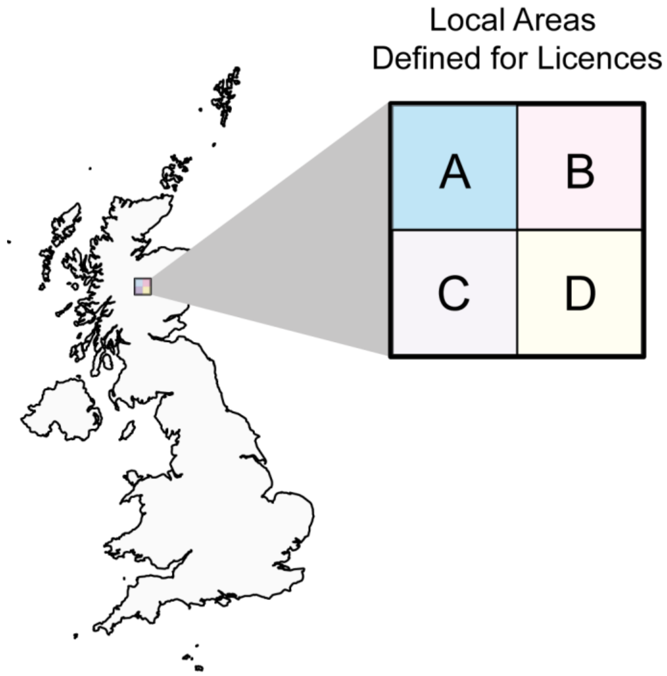
- Also from July 2019 Ofcom statement:

*"We are commencing work to consider whether it would be appropriate in the future to transition towards a **dynamic spectrum access (DSA)** approach supported by a fully automated central database in the bands outlined under our spectrum sharing framework".*

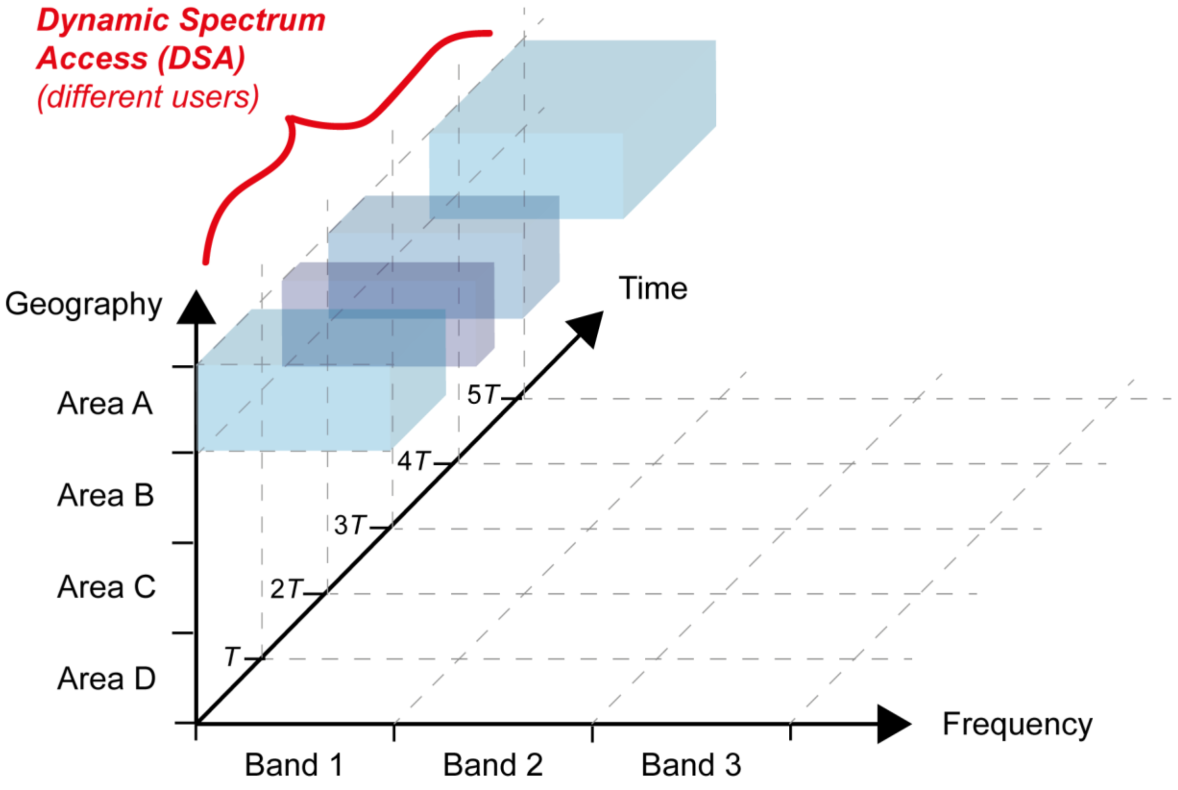
- This type of scheme would enable more agile management of the spectrum, but relies on a robust technical solution. Ideally, a database solution would be augmented with local spectrum awareness at each radio terminal.

Shared Spectrum (a vision for the future?)

- ***The goal:*** optimise spectrum reuse by increasing the temporal resolution (e.g. milliseconds rather than years). This will require a fusion of spectrum allocation information (dynamic database results) and 'live' spectrum monitoring. A key application is for private 5G and 6G networks.



Shared spectrum licence
(based on location)



System concept

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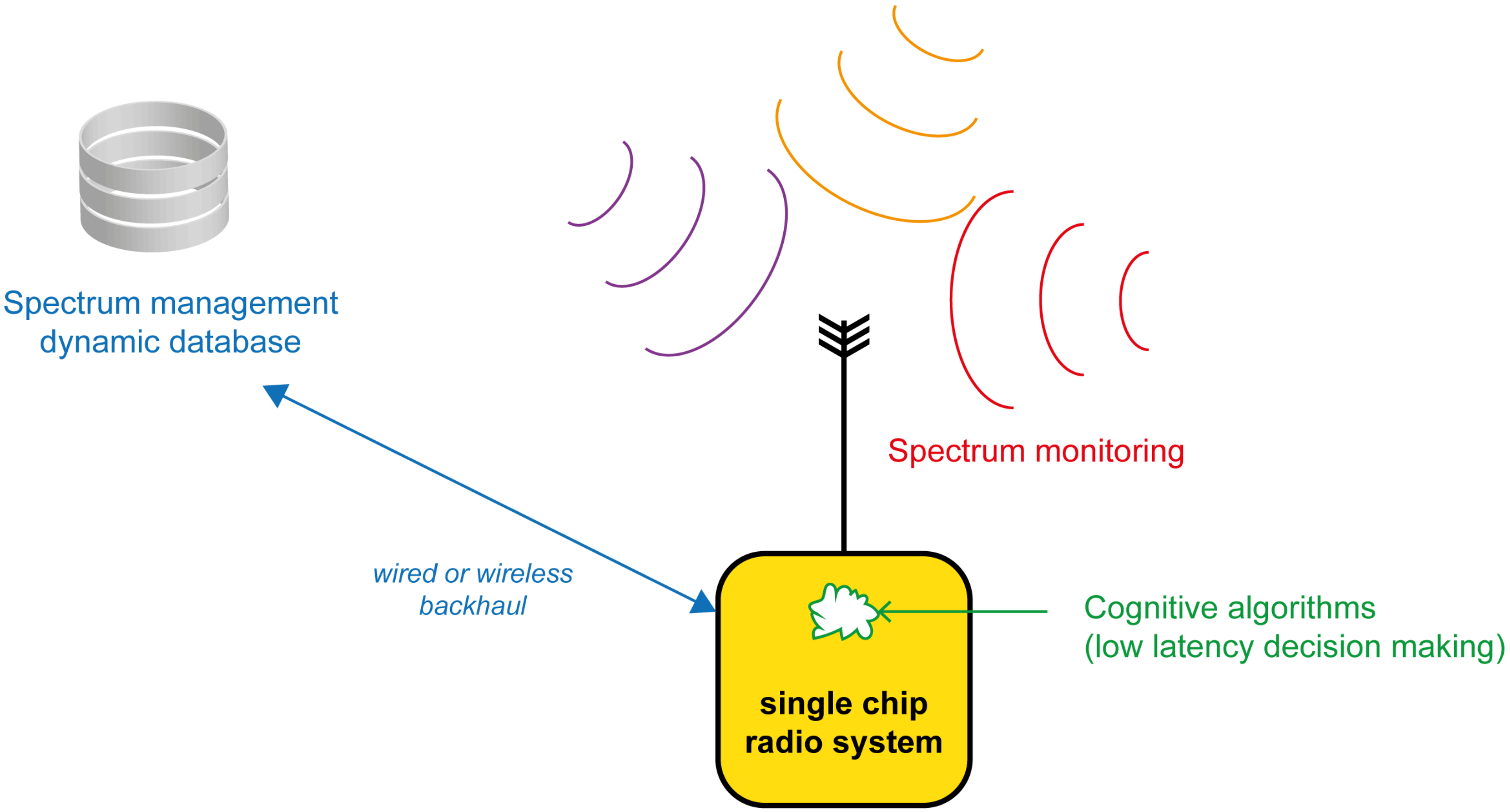
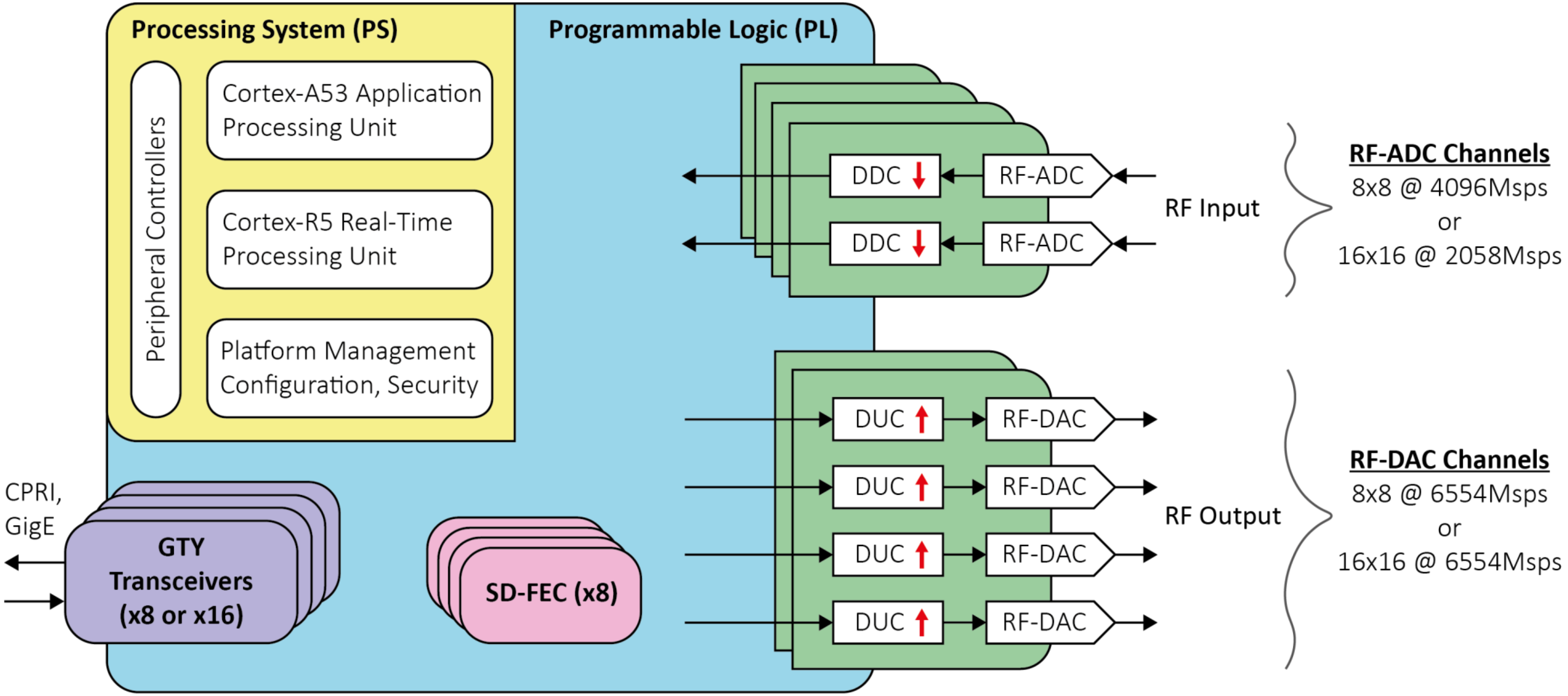
- Autonomous Dynamic Spectrum Access (DSA) management will require a "smart" radio capable of making decisions based on (i) spectrum database information, and (ii) its own spectral observations.



Overview of the Xilinx RFSoC (1^{st} Generation Devices)

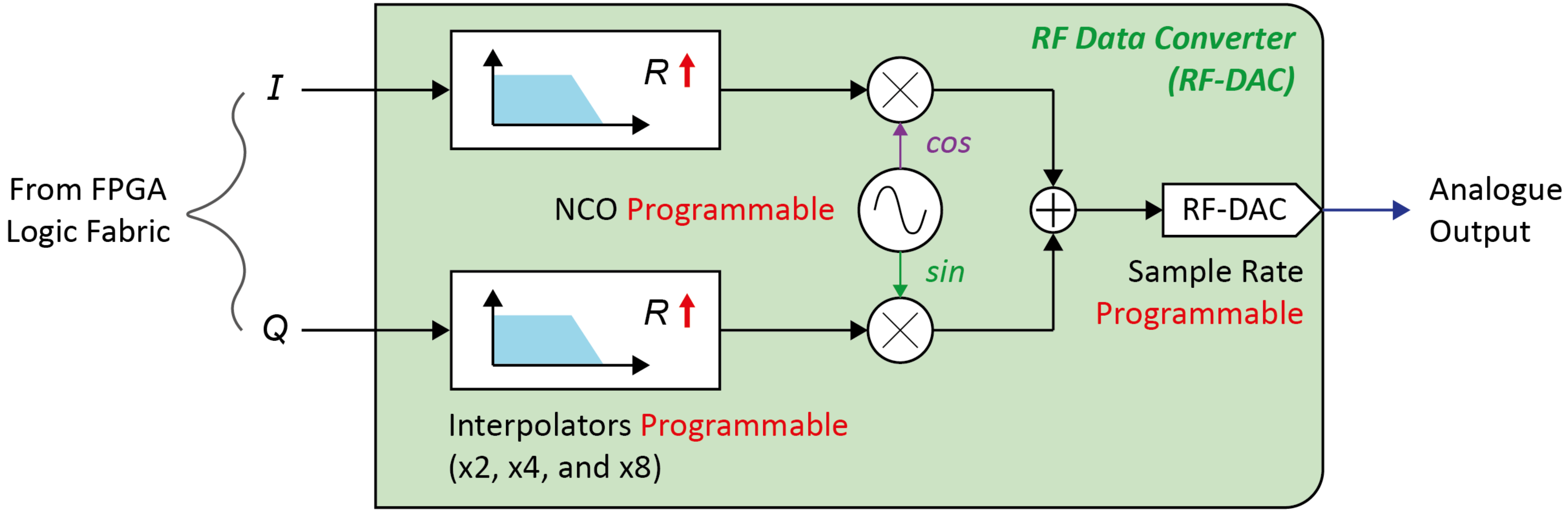
- The Xilinx RFSoC is from the Zynq System on Chip (SoC) family, and is targeted for RF applications.
- It features a ***Processing System (PS)***, ***Programmable Logic (PL)***, and specialist ***RF resources***.



RFSoC Device (1st Generation)

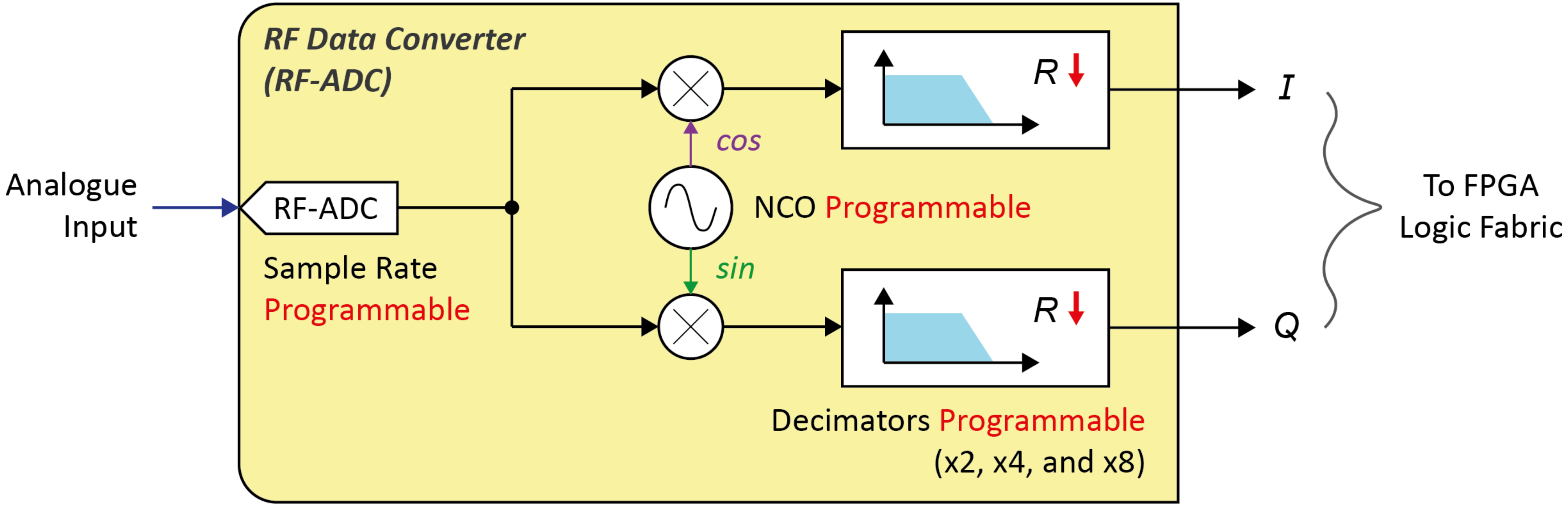
RFSoC Data Converters: The RF-DAC (Simplified)

- **The Transmitter:** An RF-DAC and Digital Up Converter (DUC).
- The interpolators, Numerically Controlled Oscillator (NCO), and sample rate are programmable.



RFSoC Data Converters: The RF-ADC (Simplified)

- **The Receiver:** An RF-ADC and Digital Down Converter (DDC).
- The decimators, Numerically Controlled Oscillator (NCO), and sample rate are programmable.



GHz Sampling & Nyquist Zones (RF-ADC Example)

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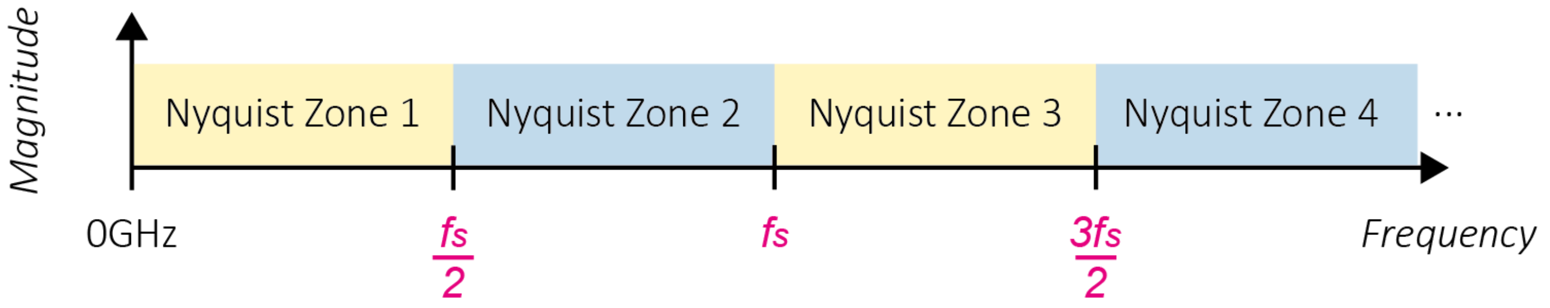
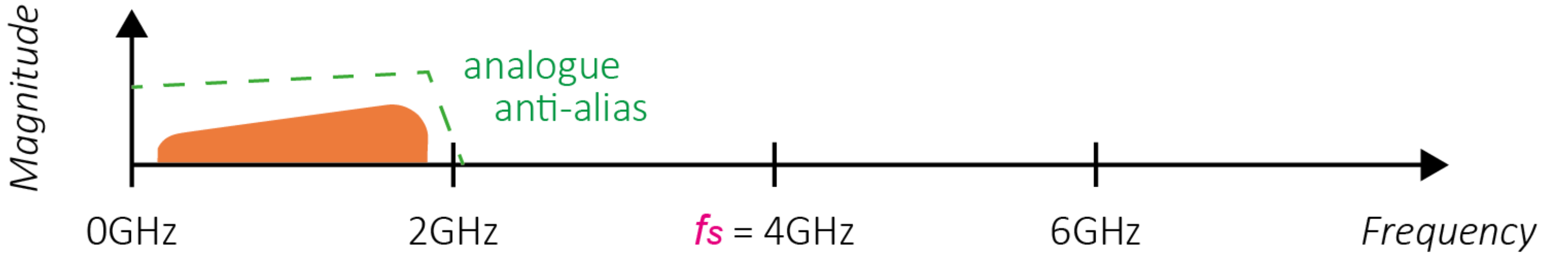
- The RF-ADCs use GHz sampling rates and can directly digitise many wireless bands.
- Signals can be acquired using Nyquist Zones. Only one Nyquist Zone should be used at a time.

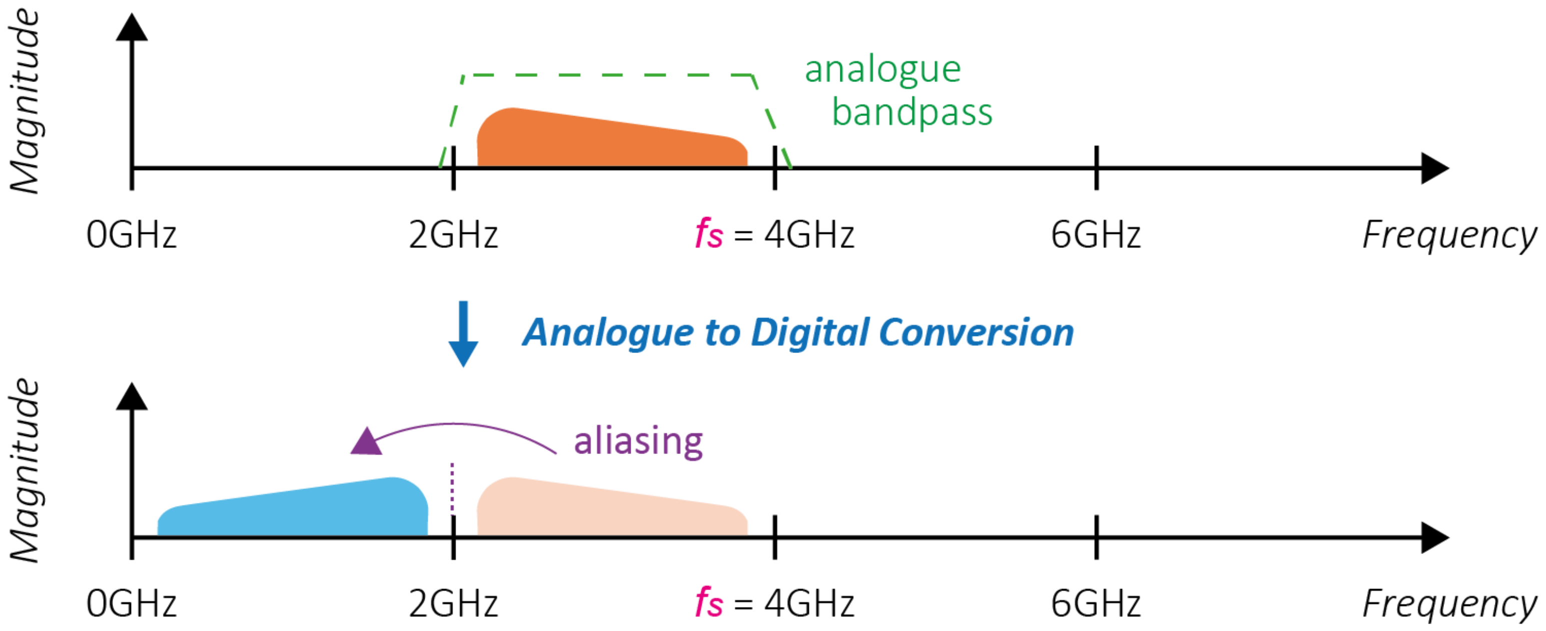


- When using the first Nyquist Zone, apply an analogue anti-alias filter to suppress upper Nyquist Zones.
- When f_s = 4GHz, signals in the first Nyquist Zone can be digitised (i.e. 0 to 2GHz)…



2nd Nyquist Zone Example (RF-ADC Example)

- Aliasing can be exploited as a technique to acquire upper Nyquist Zones.
- A bandpass filter around Nyquist Zone 2, will suppress signals in neighbouring Nyquist Zones.



- After analogue to digital conversion, the signal aliases into the first Nyquist Zone.
- The signal is now acquired and further processing can be performed.

The RFSoC – PYNQ Framework

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- Zynq-based systems can be conceived as a stack of layers.
- PYNQ addresses the complexity of Zynq design by providing a pre-configured stack.
- The ***hardware layer*** contains the FPGA bitstream, or PYNQ overlay.
- The ***software layer*** consists of Python software and the Operating System.
- At the ***applications layer***, user interaction is facilitated by Jupyter/Ipython.
- RFSoC can use PYNQ to enable rapid design and application development.

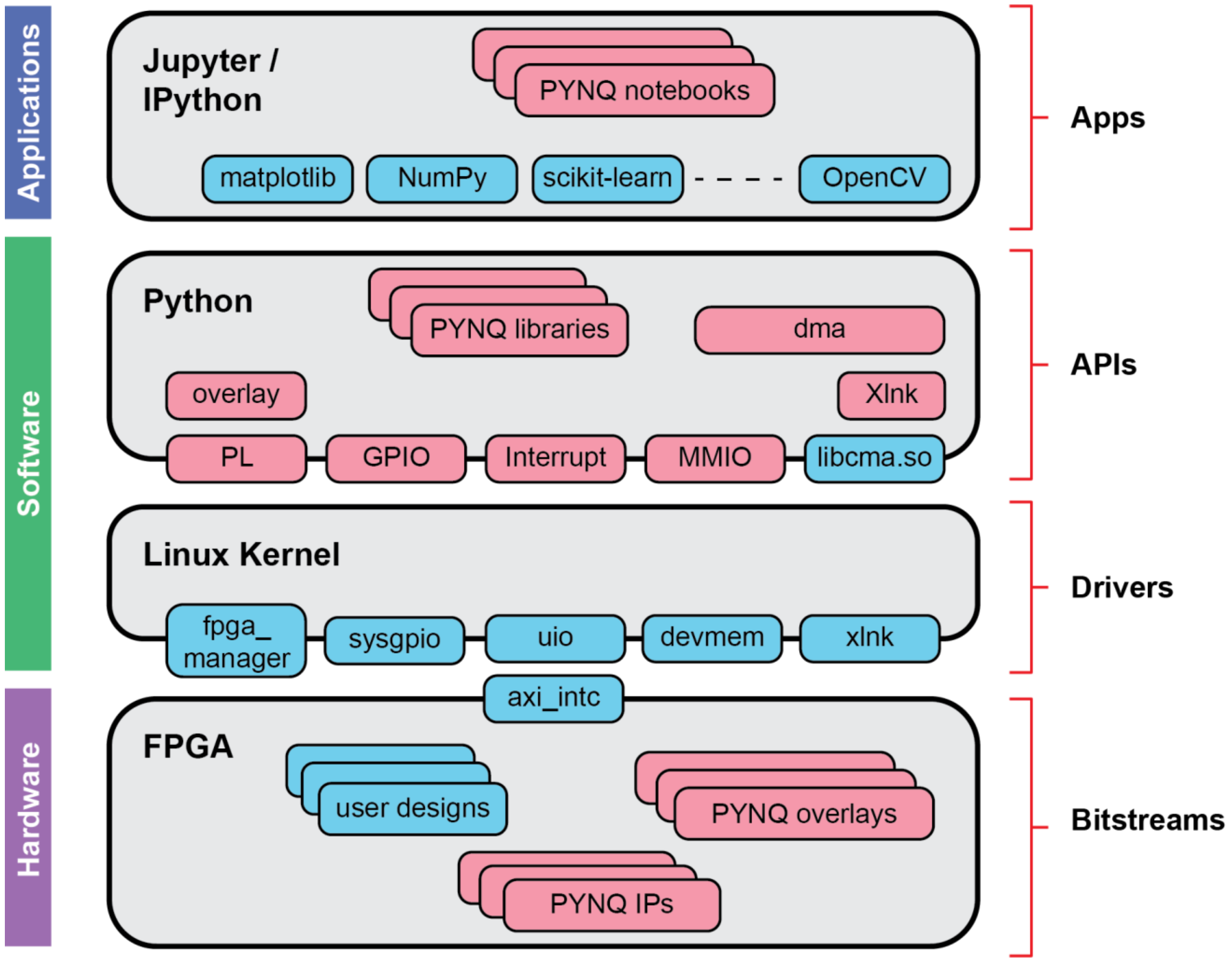

Image from — L. H. Crockett, D. Northcote, C. Ramsay, F. D. Robinson and R. W. Stewart, *Exploring Zynq MPSoC: With PYNQ and Machine Learning Applications,* First Edition, Strathclyde Academic Media, 2019, page 527.

Jupyter Labs Integrated Development Environment

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Access Jupyter with a web browser

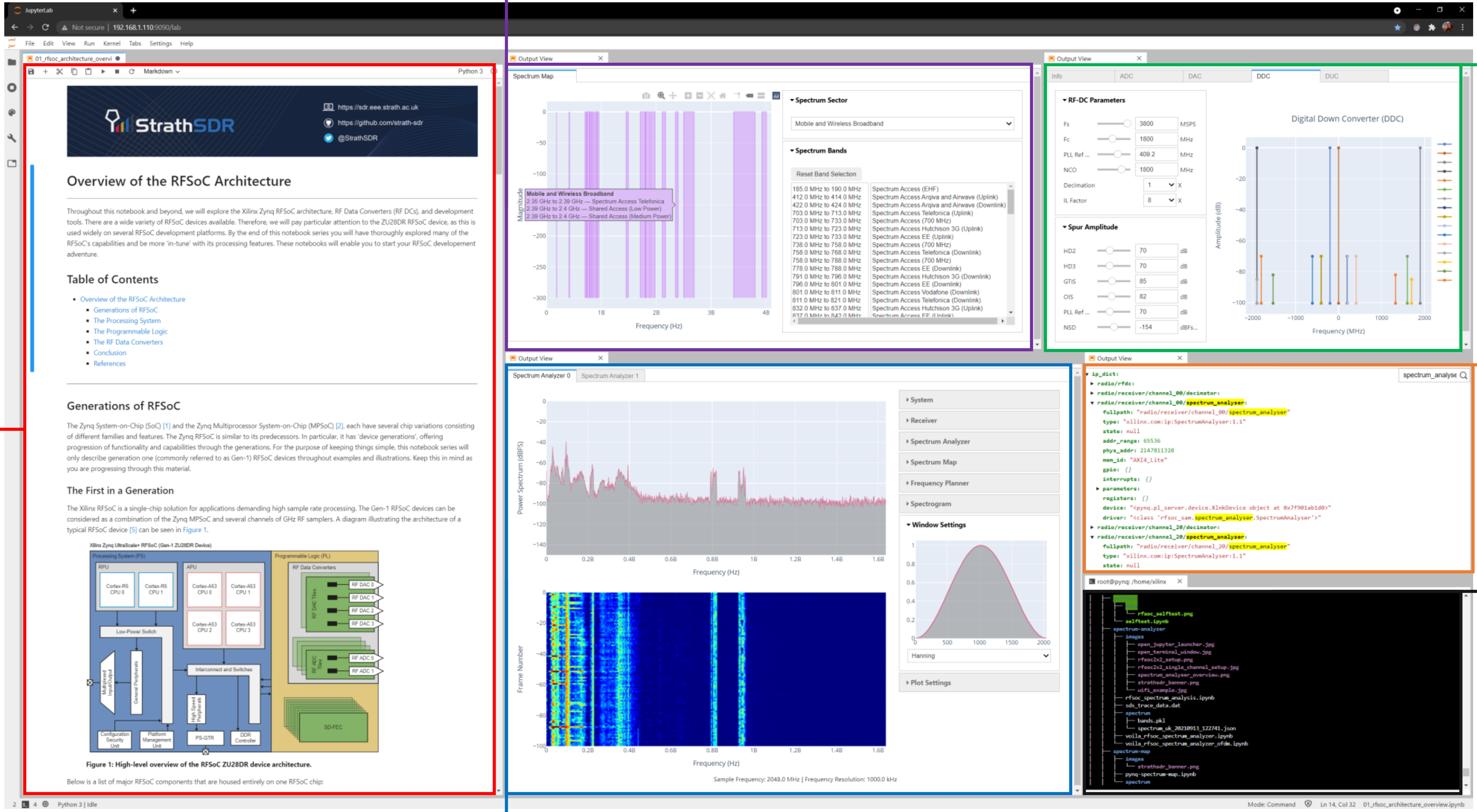
Spectrum Mapping Tool

RFSoC Frequency Planning Tool

Jupyter Notebooks

Hardware Introspection

Linux Terminal Access



RFSoC Spectrum Analyser

Visualisation of Radio Signals using a Single Chip Spectrum Analyser

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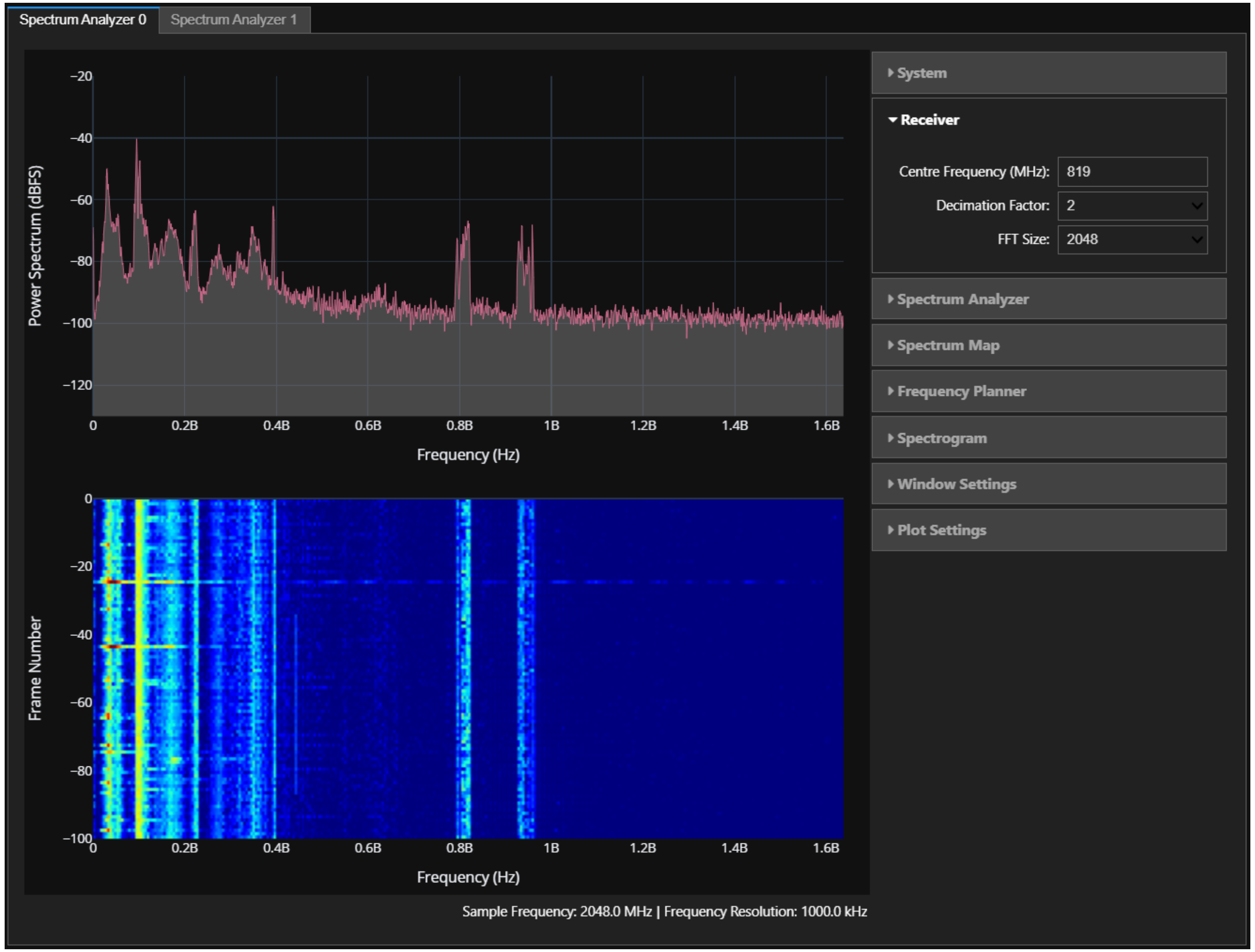
- Accessible using a web browser
- 2.048 GHz instantaneous bandwidth
- Inspection range 0 to 4.096 GHz
- Adaptive bandwidth control and centre frequency selection
- Reprogrammable windowing
- Hardware accelerated processing
- Plotly visualisation of spectrum and spectrogram (waterfall)
- Ipywidgets for dashboard creation and system control.



Spectrum Monitoring: Overview

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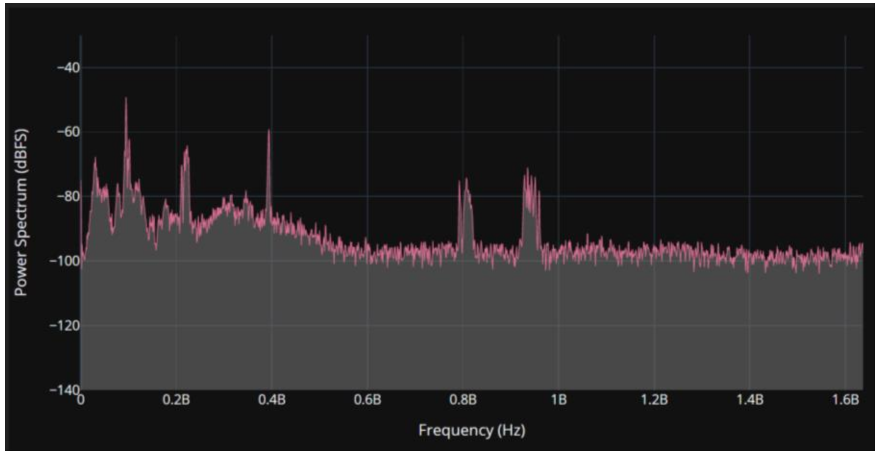
- This demonstration explores radio signals in the environment and is aware of regional radio bands using the Ofcom spectrum map for the UK.



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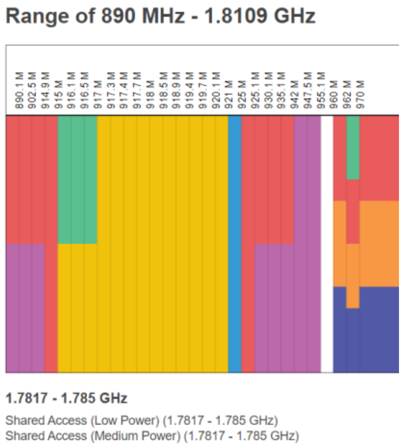

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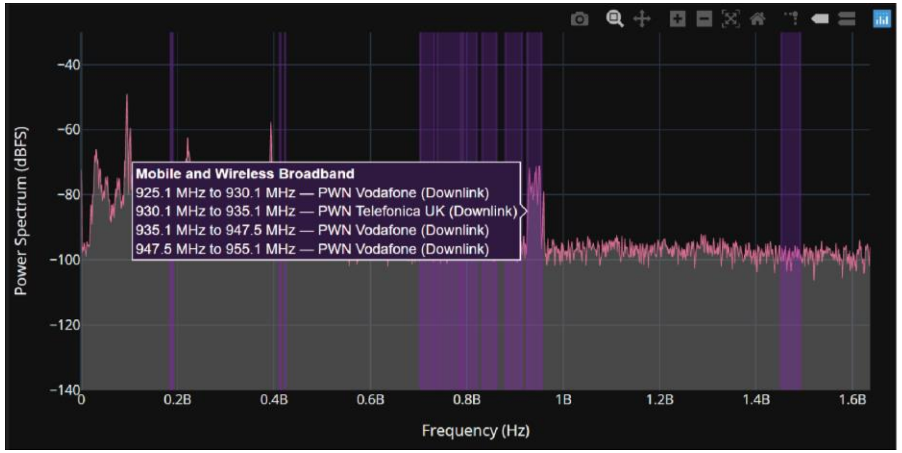
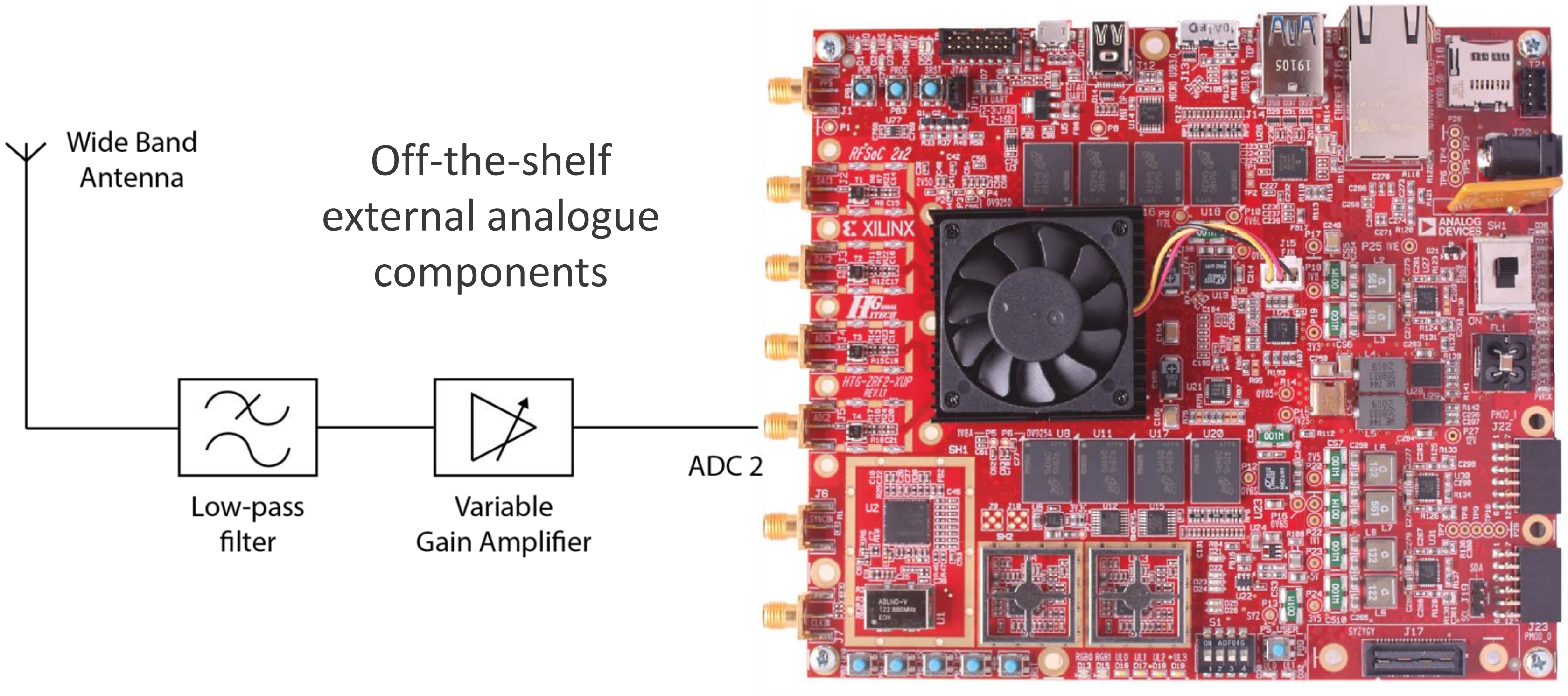


- We will explore the following spectrum:
  - ***Broadcast Sector:*** FM Radio, Digital Audio Broadcast (DAB) Radio
  - ***Public Sector:*** Emergency / Public Broadcasts
  - ***Mobile and Wireless Broadband Sector:*** Mobile Spectrum Access for 4G/5G Communications
- The frequency spectrum will not be decoded or stored in this demonstration.

Spectrum Monitoring: Hardware Setup

- The hardware setup uses a wideband antenna to capture as much RF spectrum as possible.
- The low pass filter is required to filter out the higher order Nyquist Zones and prevent aliasing.
- The variable gain amplifier is useful to adjust the input signal power and improve inspection.



RFSoC2x2 Development Board

The RFSoC2x2 Research and Development Board

Cost: $2,149*

* On 14th September 2021 — Academic customers only!

Spectrum Monitoring (Lets Go Live…)

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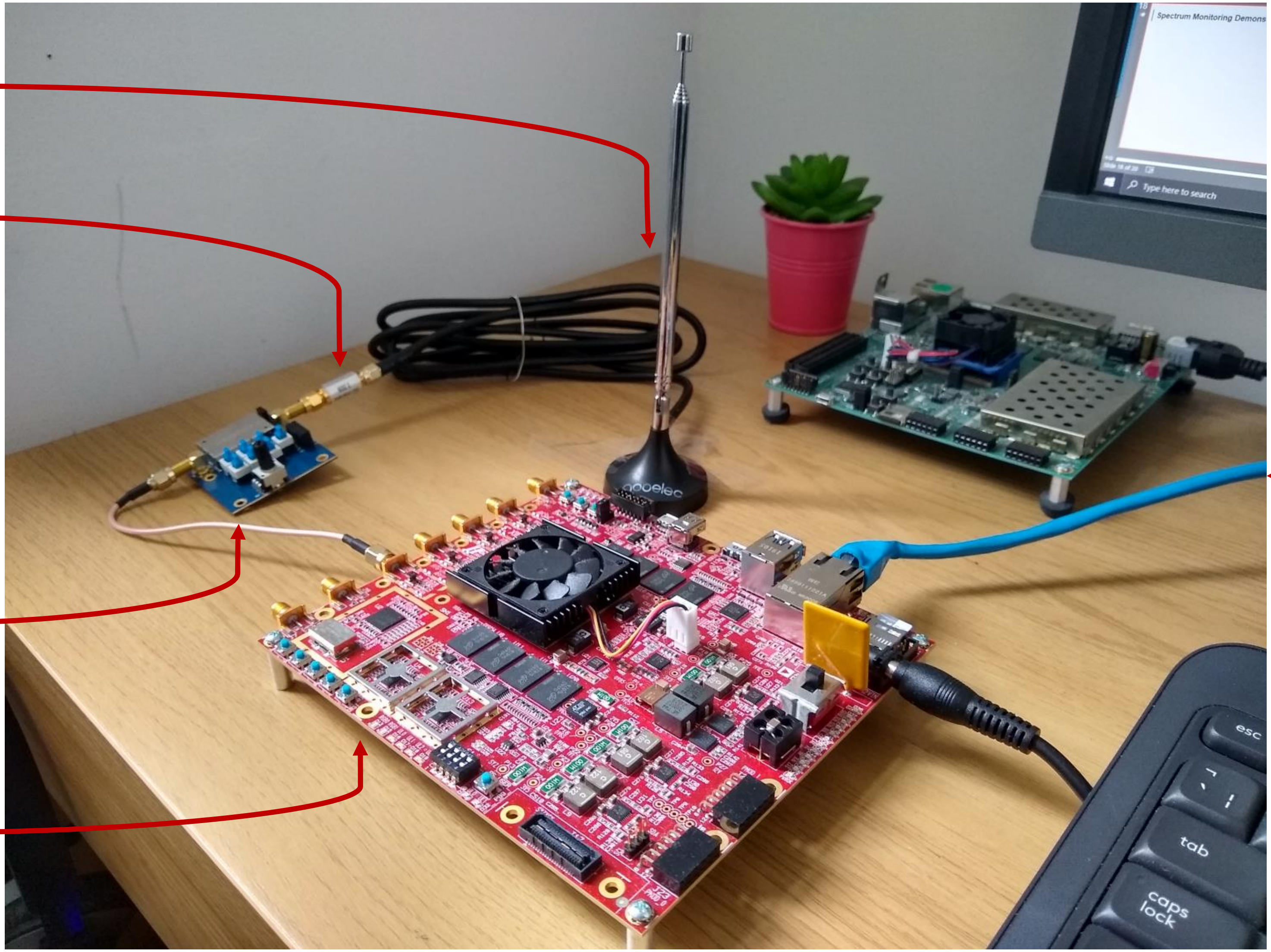
Wide Band Antenna

Low Pass Filter

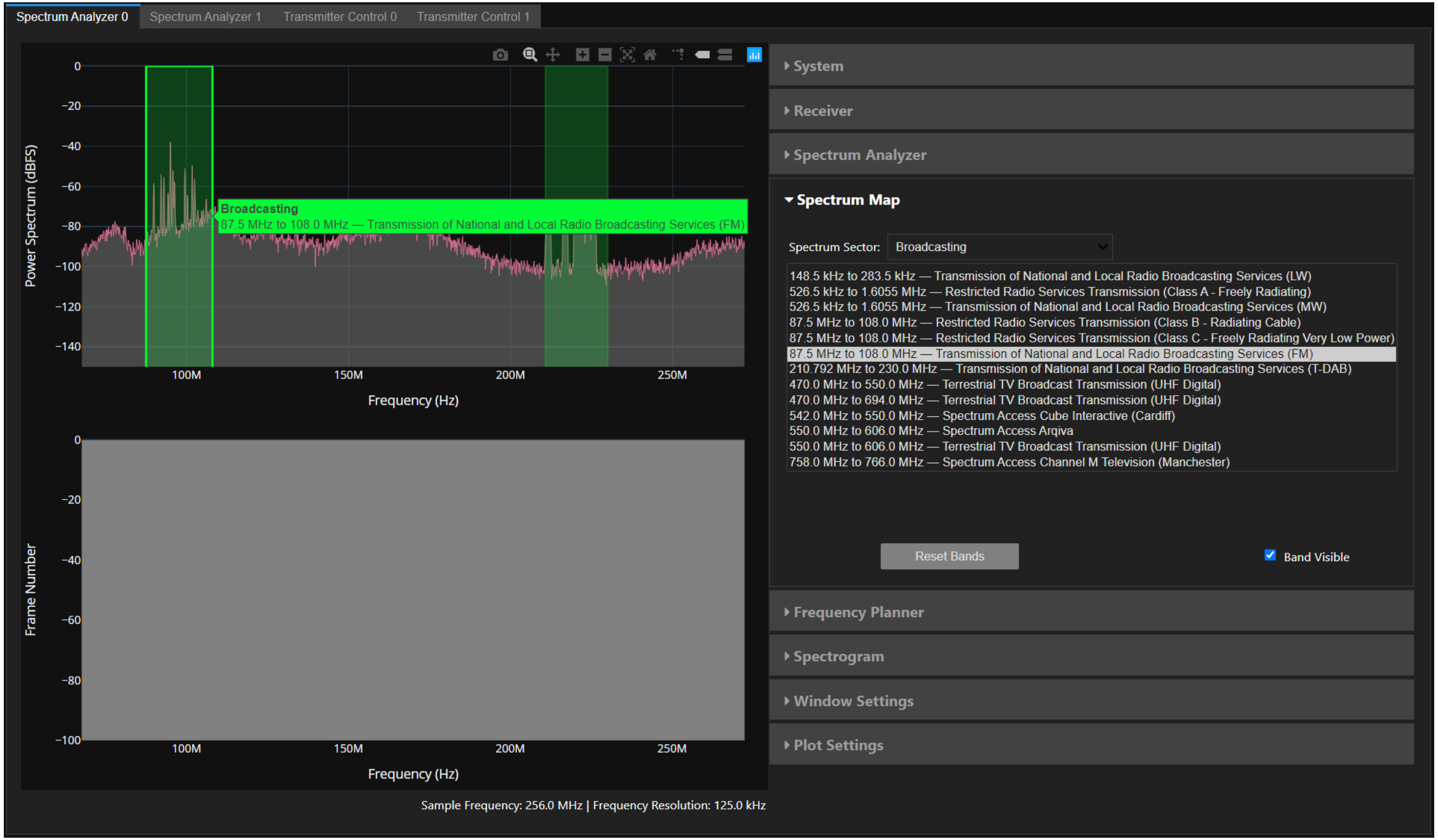
Variable Gain Amplifier

RFSoC2x2 Board with ZCU28DR

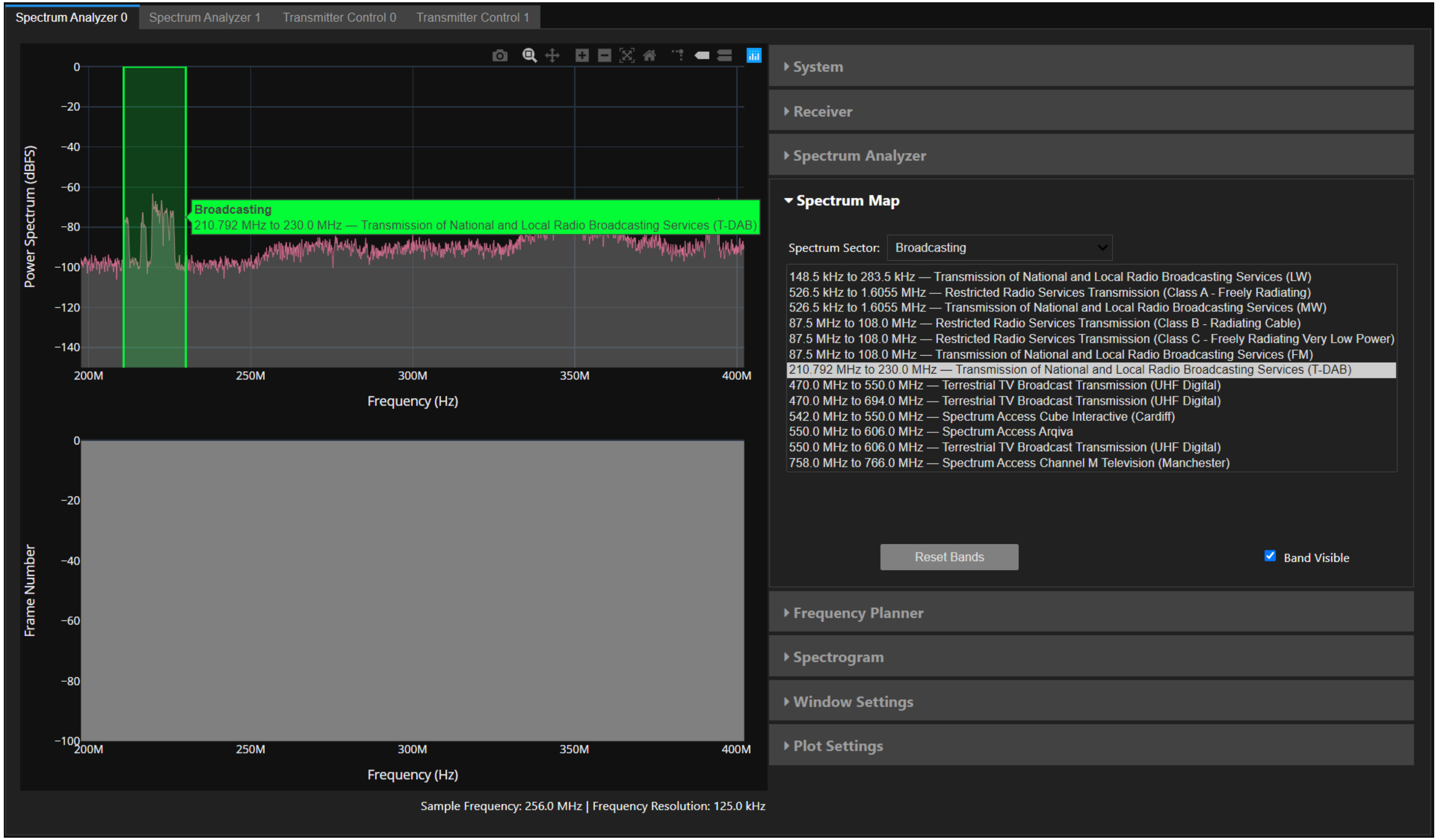
Computer with Ethernet connection



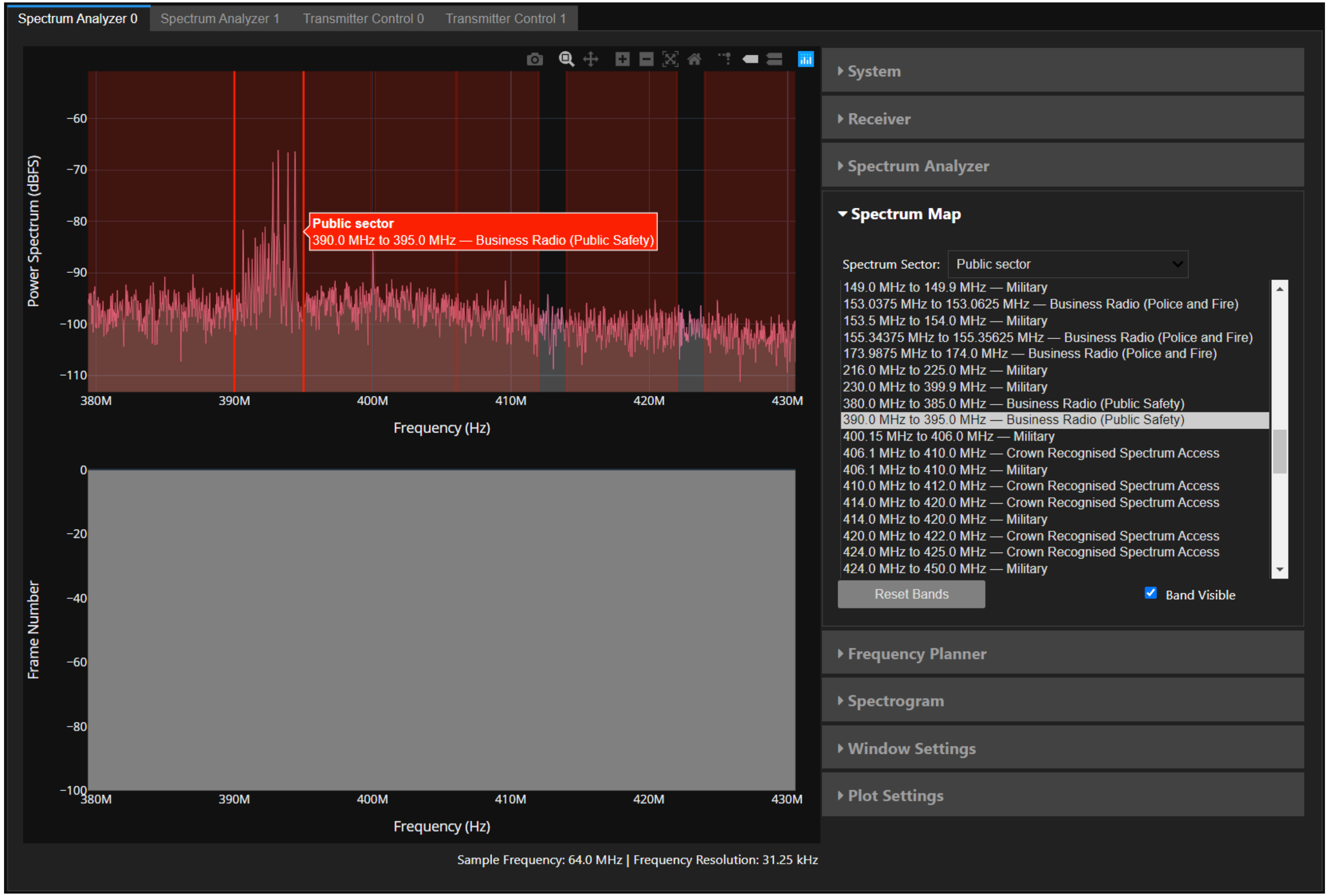
Spectrum Monitoring: FM Radio



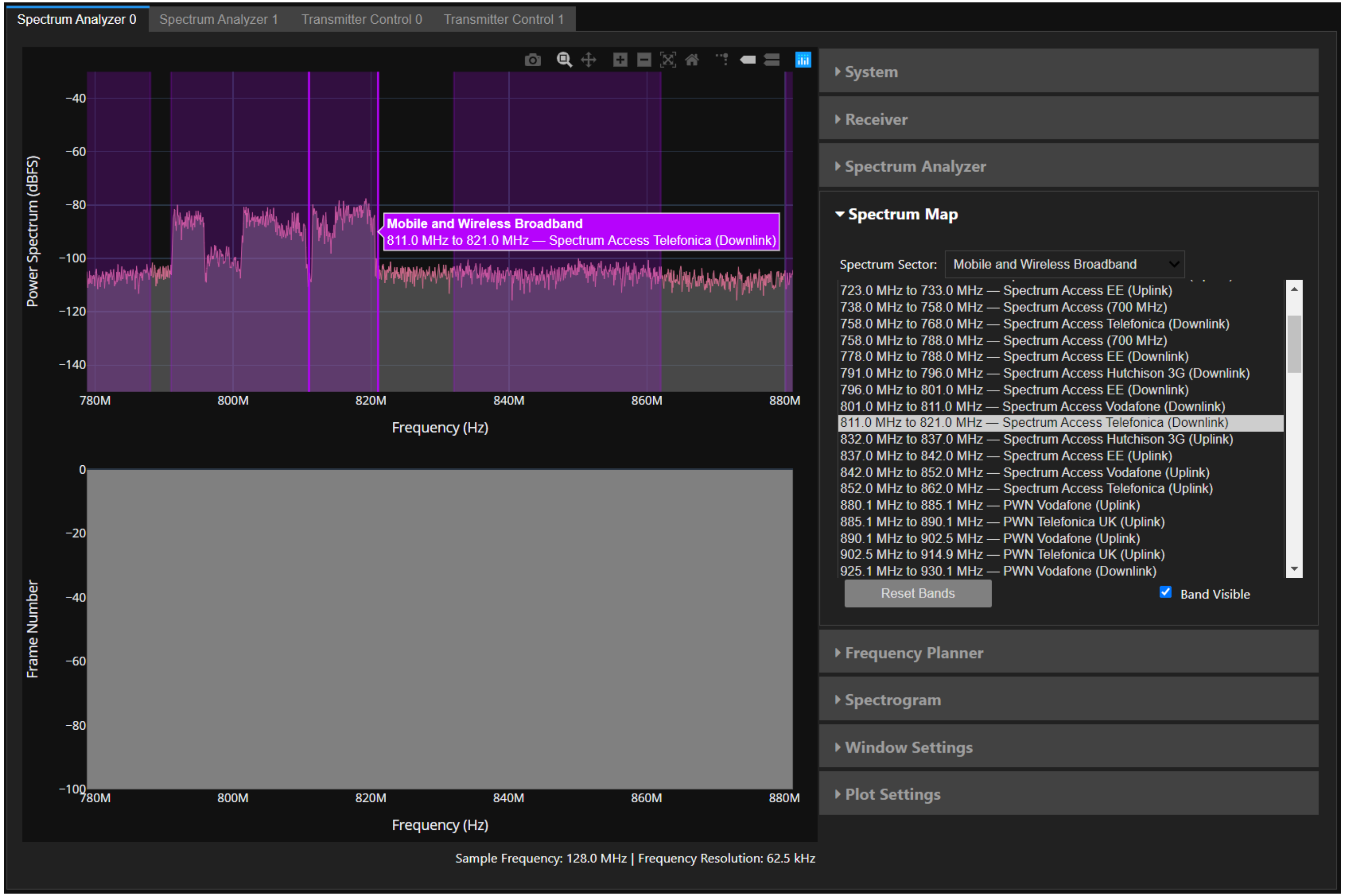
Spectrum Monitoring: DAB Radio



Spectrum Monitoring: Public Radio



Spectrum Monitoring: Spectrum Access (Downlink)



Spectrum Monitoring: Spectrum Access (Uplink)

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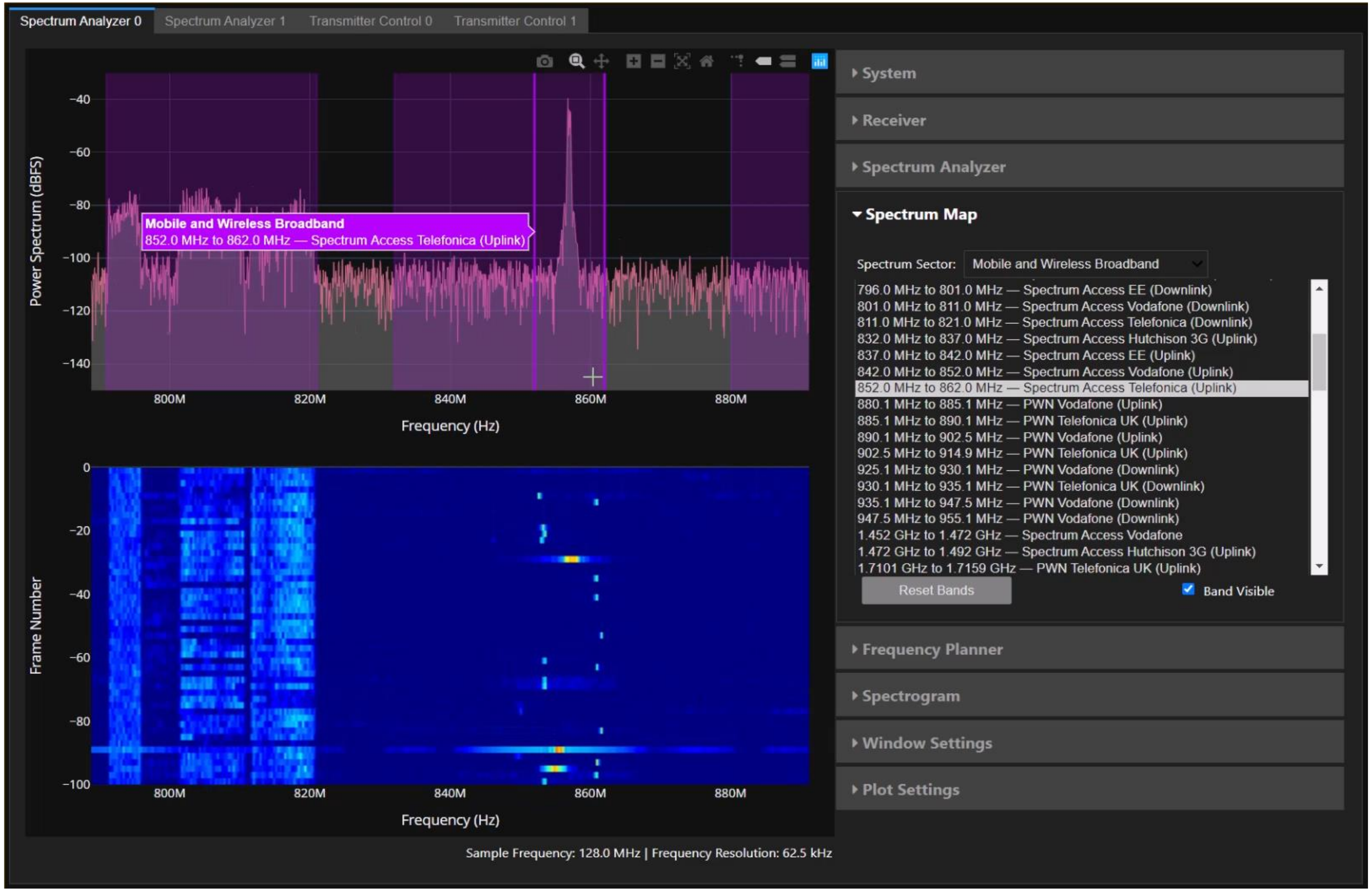

Conclusions

StrathSDR

- Reviewed existing spectrum management approaches:
  - Fixed allocation,
  - Shared spectrum with local licensing,
  - Dynamic spectrum access.
- Explored fully autonomous dynamic spectrum access in 6G networks:
  - Dynamic spectrum licence database,
  - Off-the-air, wideband spectrum sensing,
  - Cognitive functions and sub-millisecond decision-making.
- Introduced the Xilinx RFSoC based prototype:
  - Uses the Ofcom spectrum map for the UK
  - Uses the RFSoC-PYNQ framework and open-source Spectrum Analyser for live spectrum monitoring.
- Demonstrated live spectrum monitoring and spectrum mapping.

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Thanks for listening!

Engage with us:

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github.com/strath-sdr

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