Enabling Efficient Spectrum Usage with Cognitive Software Defined Radio

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Overview

- Background on spectrum under-utilisation, spectrum sharing, Dynamic Spectrum Access (DSA)
- Review of Software Defined Radio (SDR), next gen capabilities
- Cognitive-DSA-SDR Case Study

Presentation Key Terms:

- *Primary User (PU) = licensed radio spectrum user (e.g. cellular, TV, satellite)*
- *Secondary User (SU) = unlicensed radio spectrum user*
- *Dynamic Spectrum Access (DSA) = technique used by SUs to identify + gain access to available spectrum*
- *Software Defined Radio (SDR) = radio with dynamic, software controlled front end*
- *Cognitive Radio (CR) = "intelligence" that can control a SDR*

Background – Spectrum Sharing & DSA

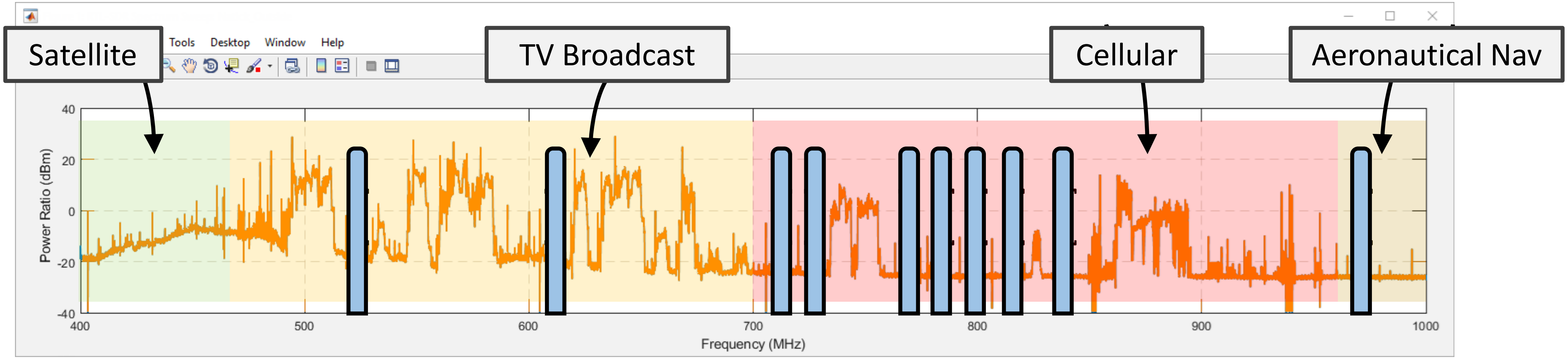
StrathSDR

- The demand for wireless connectivity is exponentially increasing
- Radio Frequency (RF) spectrum resources are used extensively for TV, commercial radio, mobile, WiFi, satellite, military, emergency services etc
- These resources are finite (but non exhaustive)
- Supply and demand issue, result is high cost barriers to obtaining broadcast licences
- Very competitive market – licenses worth £50billion+ to the UK economy

Background – Spectrum Sharing & DSA

StrathSDR

- The radio spectrum is underutilised
- Sharing techniques are being proposed/ enacted to allow **Secondary User (SU)** access to vacant **Primary User (PU)** spectrum



(400 MHz – 1 GHz sweep)

Secondary Users (SUs)

Primary Users (PUs)

Background – Spectrum Sharing & DSA

StrathSDR

- Spectrum Sharing now common all around the world in the TV band with **TV White Space (TVWS)**
  - Unlicenced, zero cost, SUs must contact a database to obtain operating parameters
- Ofcom have recently brought shared spectrum to UK's cellular bands
  - Dedicated shared access bands created / **Shared Access Licence**
  - Route to access all vacant spectrum in MNO-licenced cellular bands / **Local Access Licence**
- **CBRS/ OnGo Alliance** in USA to share military bands
- Gradual regulatory shift towards light licencing, **Spectrum as a Service (SaaS)**

Background – Spectrum Sharing & DSA

StrathSDR

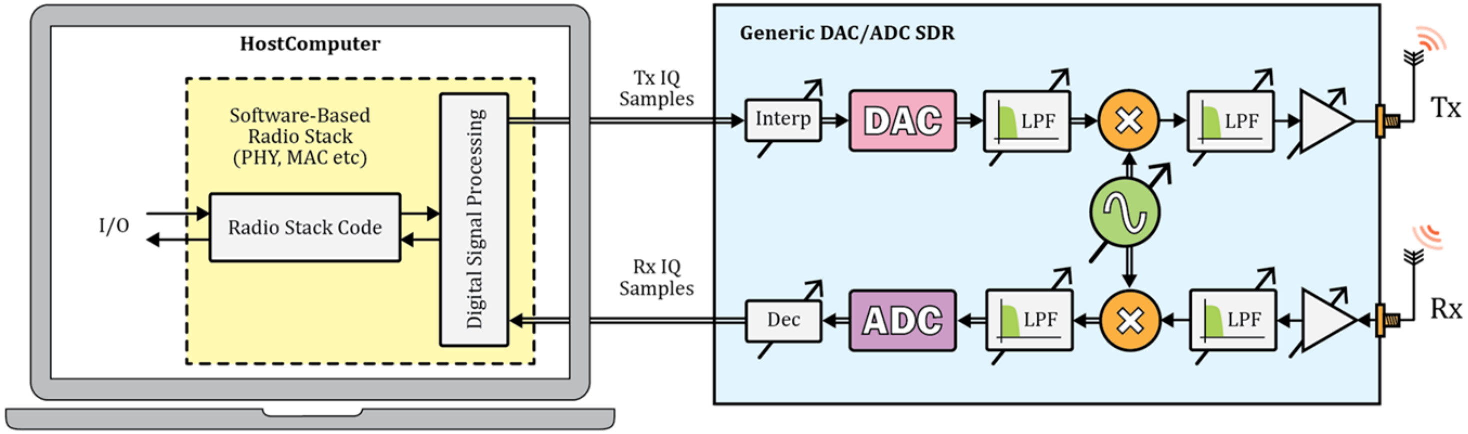
- With **DSA**, radio nodes/networks access the spectrum and establish comms channels "on the fly"
  - operate over **wide range of frequencies** (wideband front end, power amps etc)
  - support **many modulation schemes simultaneously** (implies soft stack/PHY – eg C code, FPGA)
  - **spectrally aware**, able to identify vacant channels (potentially reporting real world spectrum occupancy to a regulator managed database)
  - contain a form of **"intelligence"** (software/ AI to logically reconfigure all operating params in real time)

- Synergy between DSA / CR / SDR >> **Cognitive SDR platform required for DSA**

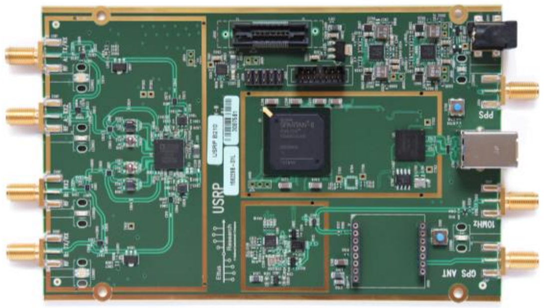
- Spectrum sharing we see now is <u>**not**</u> Dynamic Spectrum Access
  - **DSA not here yet as current regulatory models cannot support it**

Software Defined Radio

- Wide variety of SDRs on the market
- Two broad categories:
  - Digital to Analogue Converter (DAC) + Analogue to Digital Converter (ADC) only



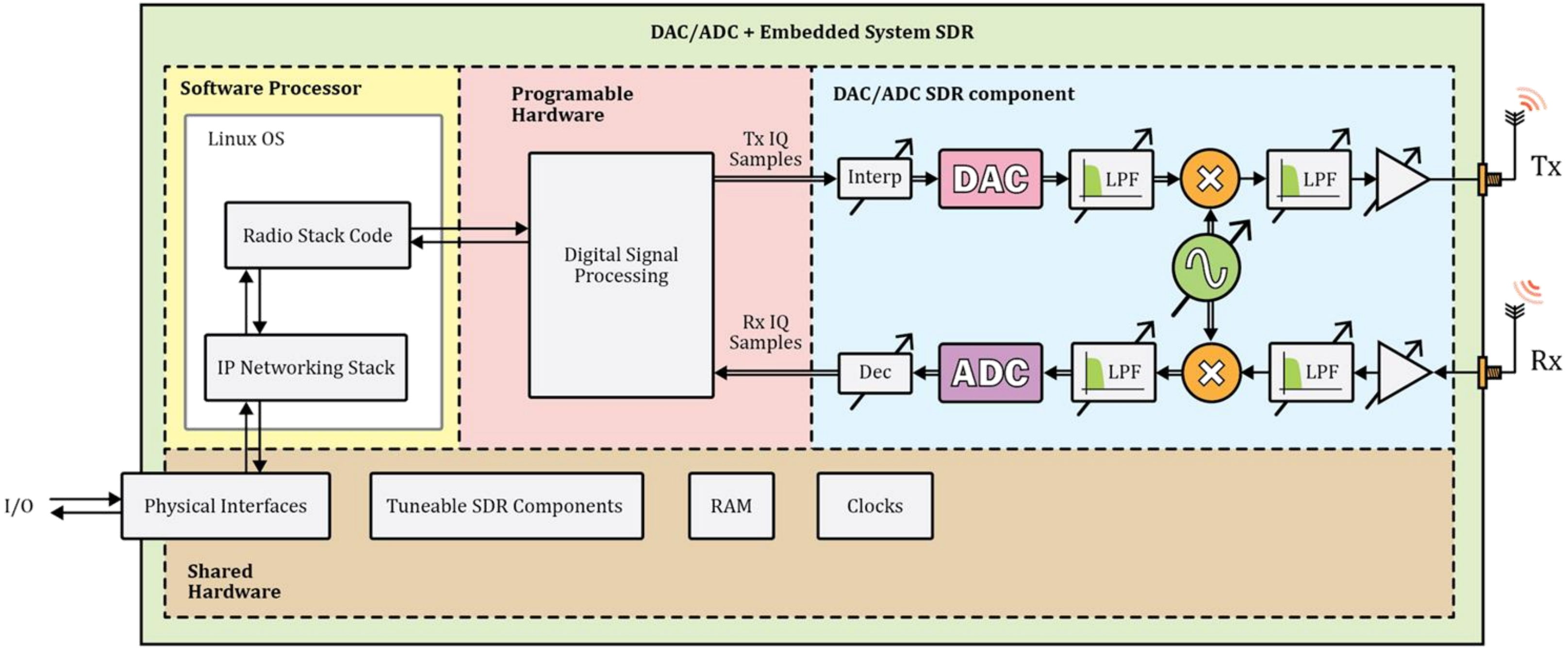
LimeSDR Mini

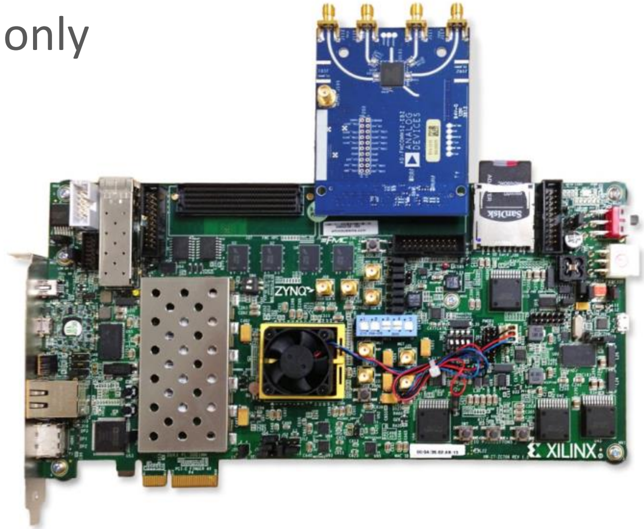


USRP B210

Software Defined Radio

- Wide variety of SDRs on the market
- Two broad categories:
  - Digital to Analogue Converter (DAC) + Analogue to Digital Converter (ADC) only
  - DAC + ADC + embedded system/ programmable hardware





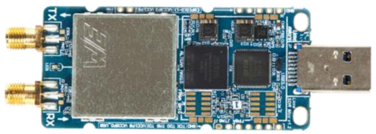
Xilinx Zynq SoC (CPU+FPGA)
[+ addon] Analog Devices SDR
= "ZynqSDR"

Xilinx Zynq ZC706 Dev Board
+ Analog Devices FMCOMMS3

Software Defined Radio – Next Gen

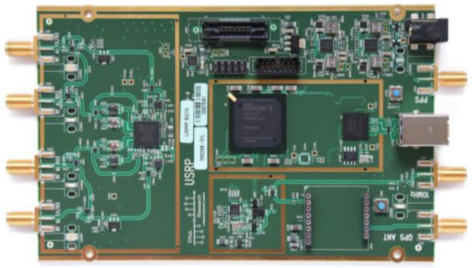
StrathSDR

- Latest Xilinx Zynq Ultrascale+ RFSoC silicon == massive step change in SDR capabilities



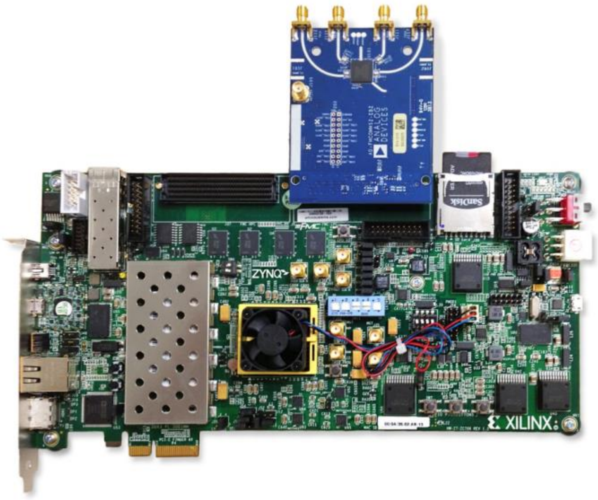
LimeSDR Mini

100kHz -> 3.8GHz range
1Tx 1Rx / 1x1 SISO
61.44MSps (max)
60MHz bandwidth (max)
12-bit
Requires computer host
£



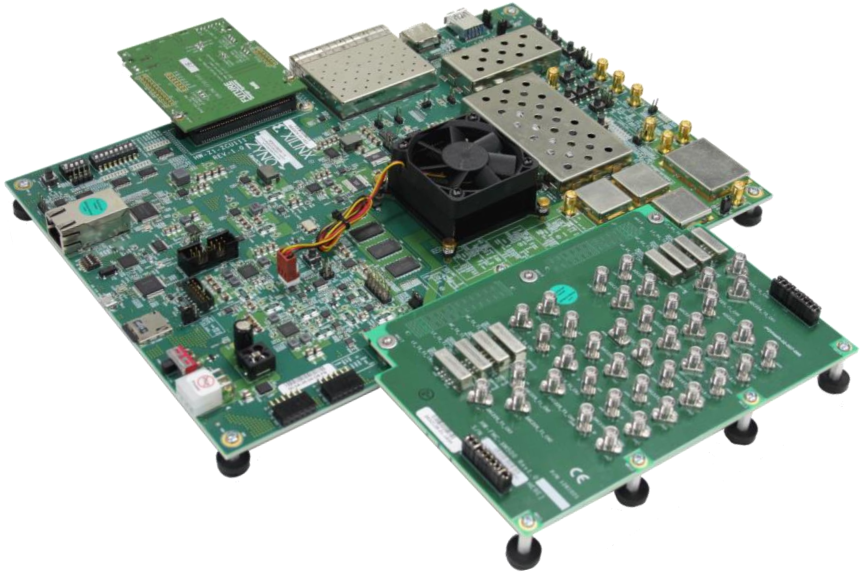
USRP B210

70MHz -> 6GHz
2Tx 2Rx / 2x2 MIMO
61.44MSps (max)
56MHz bandwidth (max)
12-bit
Requires computer host
££



Xilinx Zynq SoC (CPU+FPGA) [+ addon] Analog Devices SDR // ZC706 + FMCOMMS 3

70MHz -> 6GHz
2Tx 2Rx / 2x2 MIMO
61.44MSps (max)
56MHz bandwidth (max)
12-bit
Quad core Arm, mid-size FPGA
£££

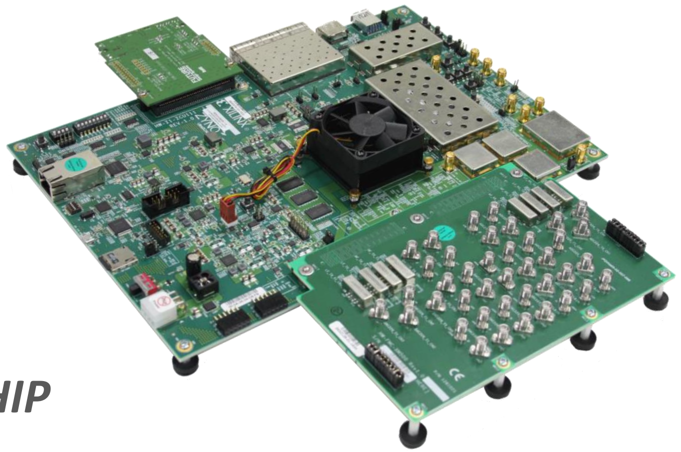


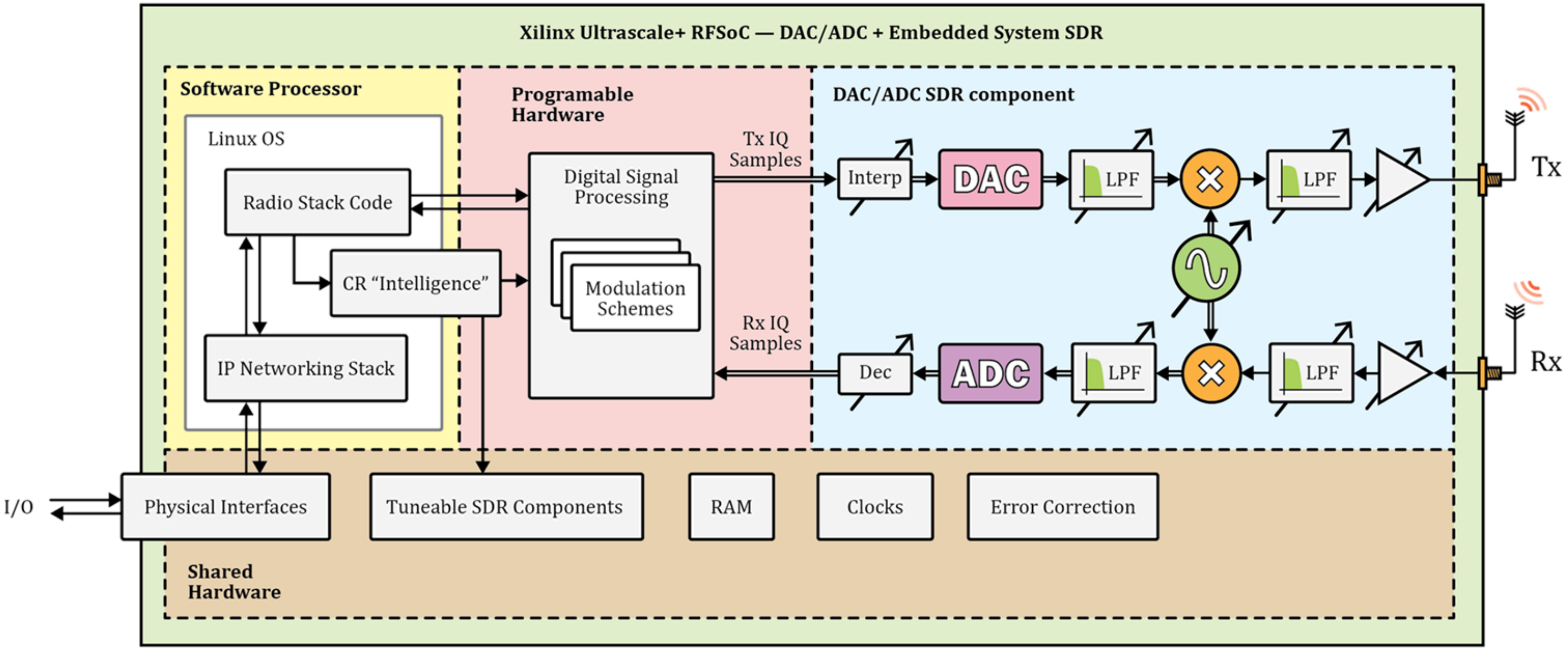
Xilinx Zynq RFSoC ZCU111 (SDR+CPU+FPGA)

0Hz -> 6GHz
16Tx 16Rx / 16x16 MIMO (max)
4GSps ADC, 6GSps DAC (max)
6GHz bandwidth (max)
12/14-bit
Quad core Arm, massive FPGA, error correction
££££

Software Defined Radio – Next Gen

- *Use Case: Shared Spectrum Cellular 5G /6G(!) Basestation*
  - *Integrated spectrum analyser >> use CR "intelligence" + DSA techniques to target vacant cellular spectrum across **ALL sub-6GHz bands***
  - *Dynamic front end selects RF output ports with suitable power amps + filters attached*
  - *Multi-channel SDR supports **multiple MIMO cells simultaneously on SINGLE CHIP***





8x8 MIMO cell
+
4x4 MIMO cell
+
2x2 MIMO cell
+
2 channel spectrum analyser, feeding info to CR engine

Simultaneously...

Case Study –
DSA SDR Targeting FM Radio Band

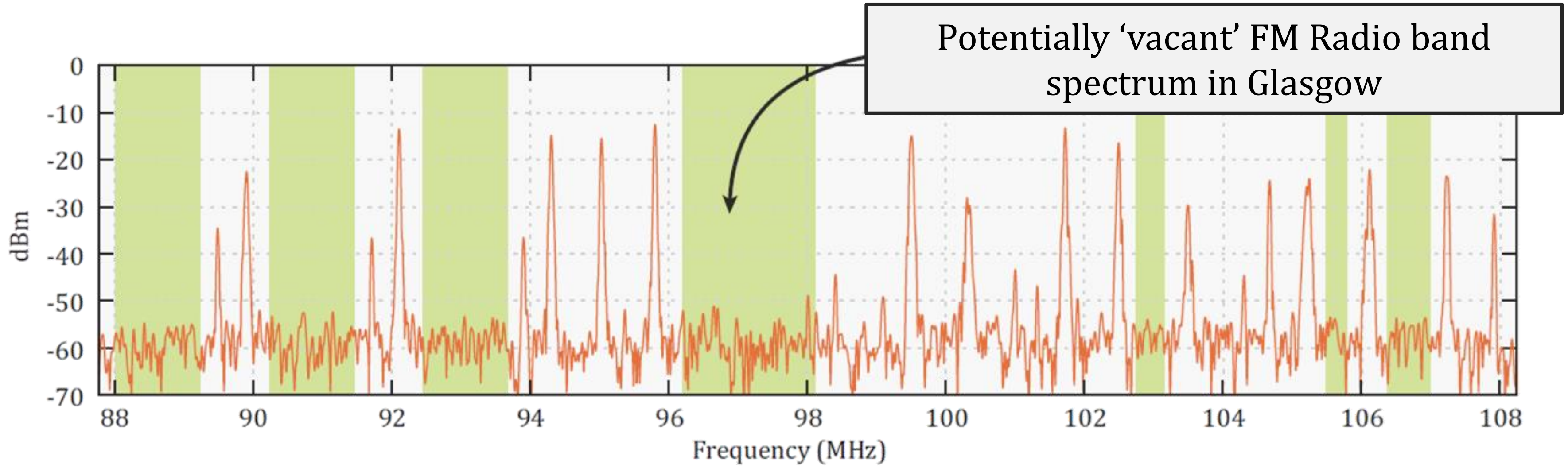
FM Radio Band

- First demonstrated by Armstrong in 1933 …88 year old scheme!
- Used worldwide for commercial (analogue) audio broadcast
- Standard band is **88-108 MHz**, x100 individual 200 kHz wide channels
- Inefficient in terms of transmit energy requirements + spectrum usage
- **Here to stay** for the time being… FM switchoffs being delayed and cancelled around the world

(not my PhD radio…)

FM Radio Band

- FM Radio band is poorly utilised
  - Research in USA shows in urban areas with populations around 1m, only **25% of the band is used**, much less in rural areas [1,2]
  - Carried out a study in Central Scotland, found very similar results [3]

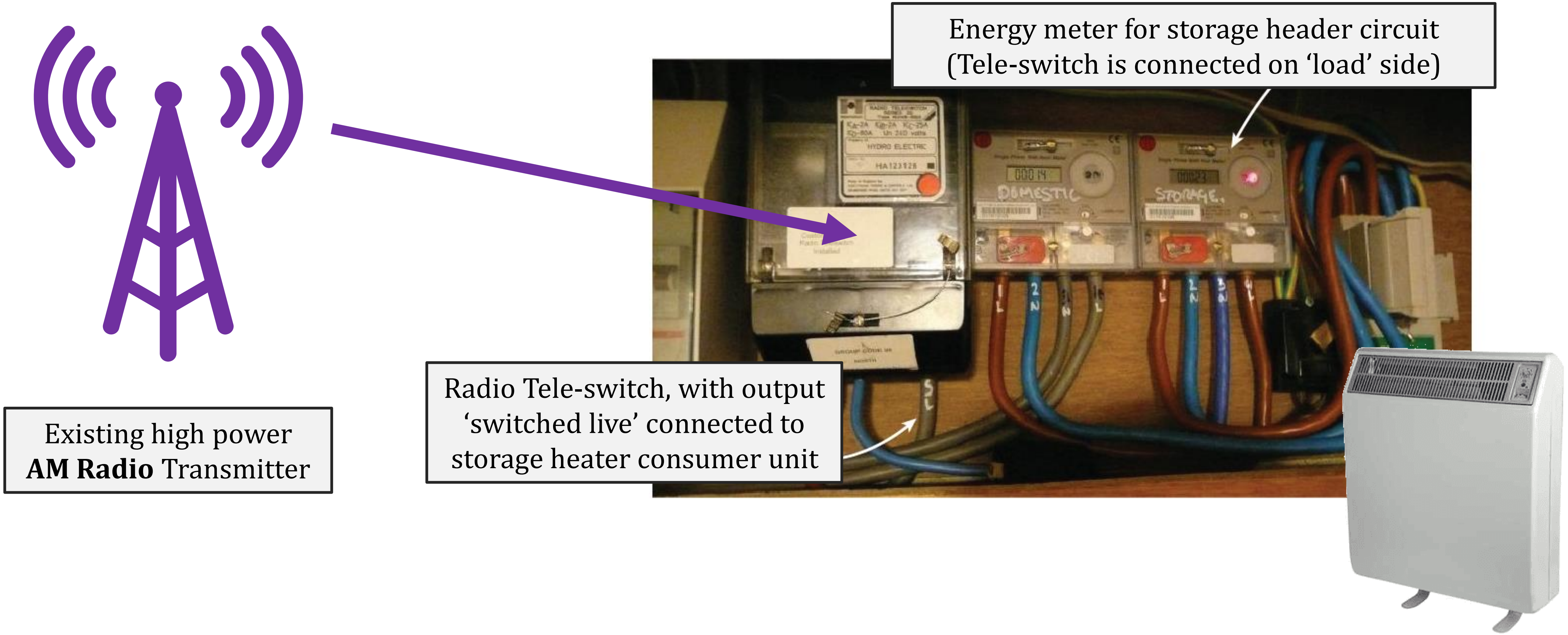


- 1.2 million pop'n
- 22 FM stations (16 unique)
- **15.6 MHz unallocated**

[1] – https://doi.org/10.1109/WF-IoT.2015.7389046
[2] – https://doi.org/10.1109/ACCESS.2016.2616113
[3] – https://doi.org/10.1109/OJCOMS.2020.3039928

FM Radio Band

- Signals broadcast at these freqs have **excellent propagation characteristics**
- FM band is a great candidate for secondary reuse as **smart city wide area network broadcast channel**



FM Radio Band

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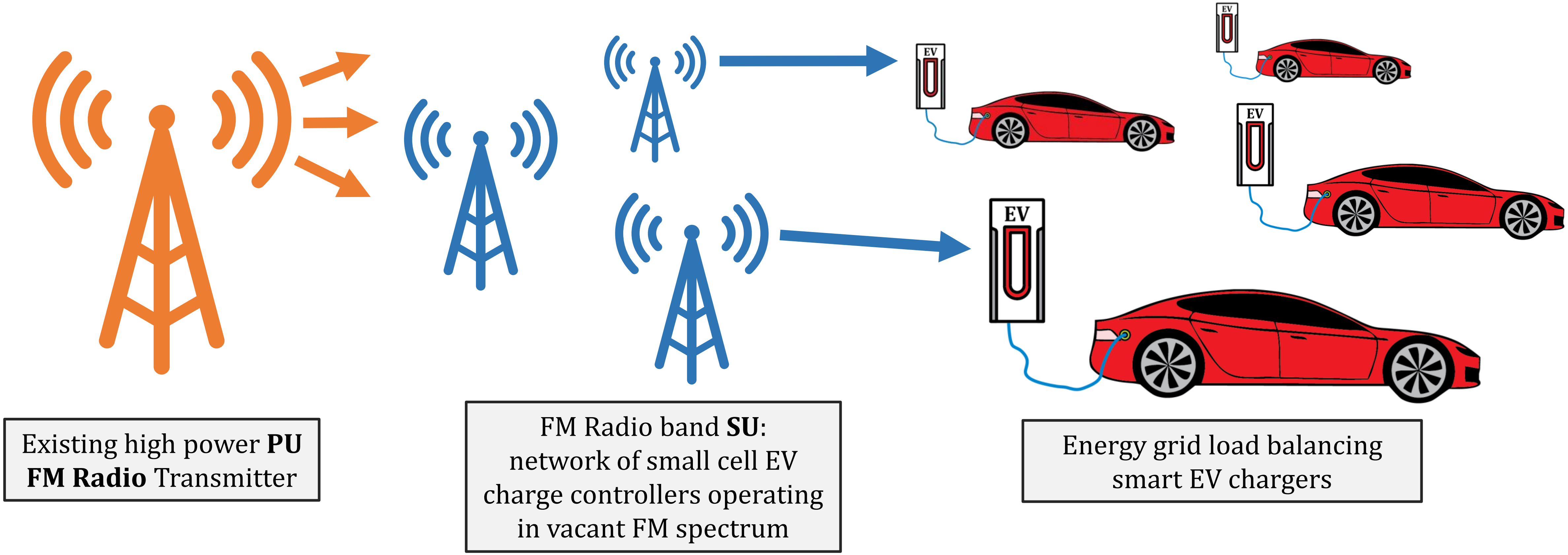
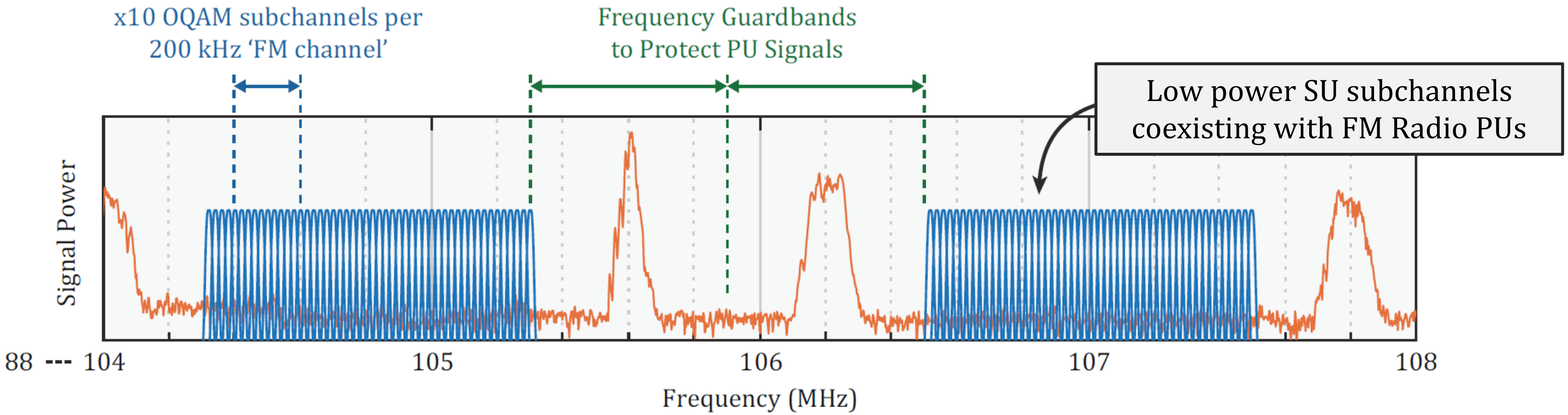


- Currently there is no means to reuse this vacant spectrum – **valuable RF resource laying fallow**

PhD Research Aims

- To design a novel DSA-SU radio capable of operating in gaps in the FM Radio band and use it to explore whether possible to have SU access
  - Radio must cause **minimal (–to no) interference** to FM Station PUs **(IMPORTANT!)**
  - Radio to use an adaptive Non Contiguous (NC) modulation scheme with low Out of Band (OOB) power leakage
  - Should **identify available FM channels by itself** (and build channel mask, complete with guardbands)



DSA Radio – Transmitter Design

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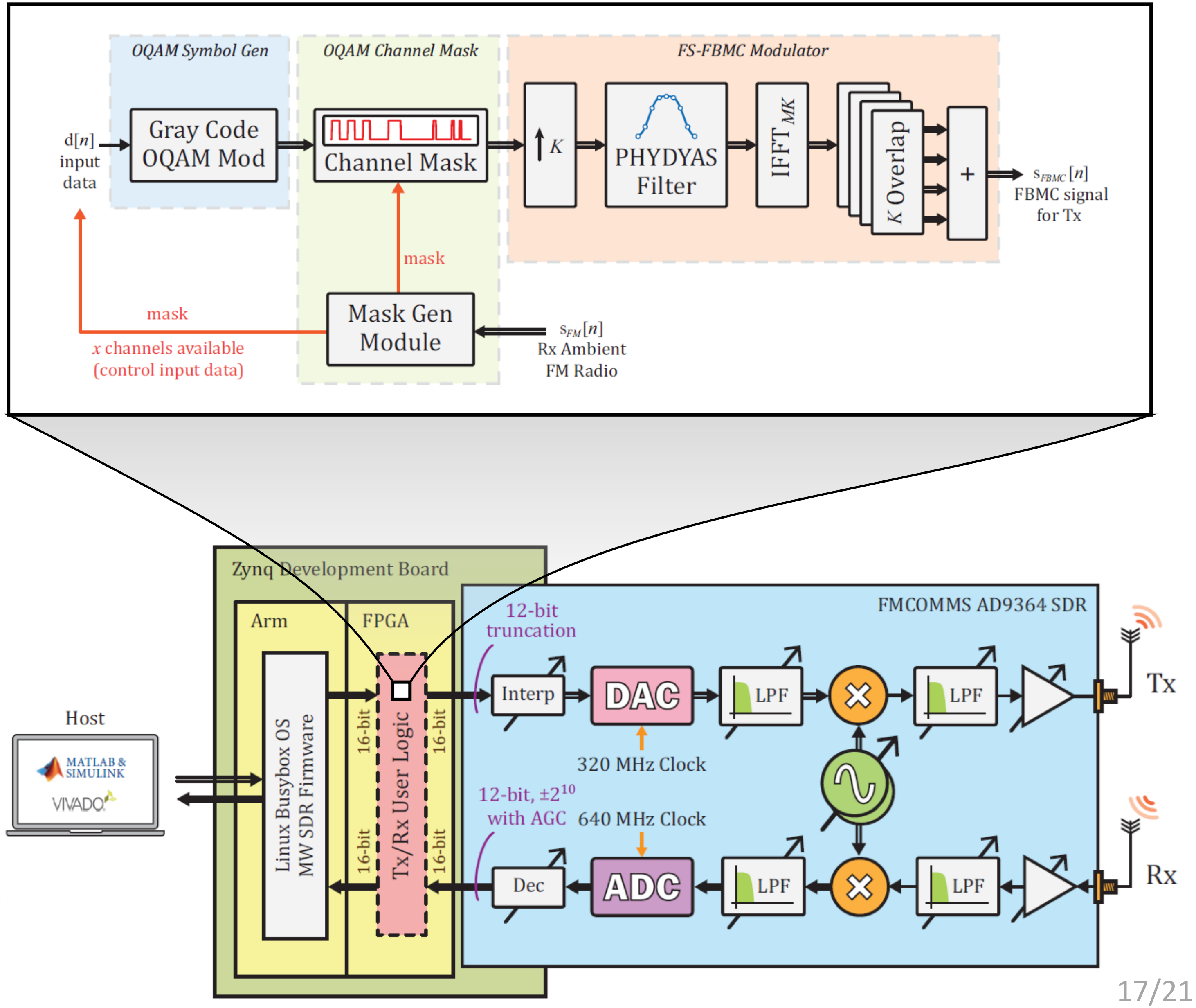
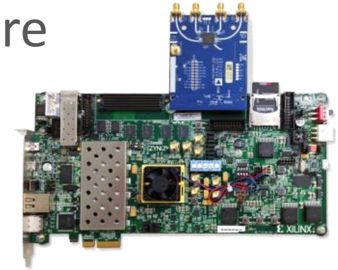
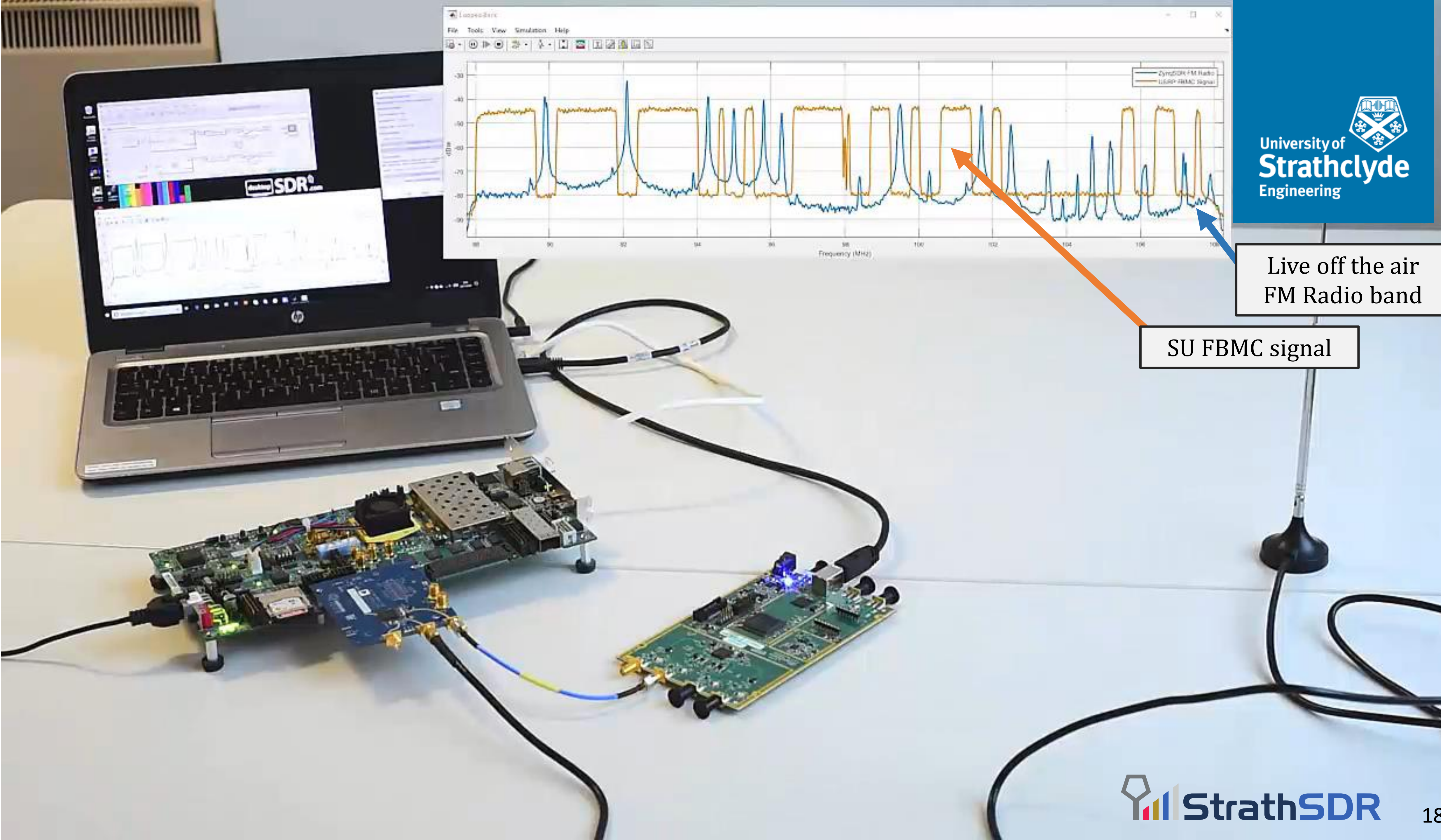
- Developed a Filter Bank Multicarrier (FBMC) PHY that used Offset QAM (OQAM) and the PHYDYAS filter ***(waveform had very desirable SU properties)***
- Built a module that continuously scanned the band, **identified vacant spectrum in real time, dynamically adjusted the spectrum of the output waveform** (aka the "brains" of the transmitter)
- Prototyped + tested the design on Zynq SDR radio hardware

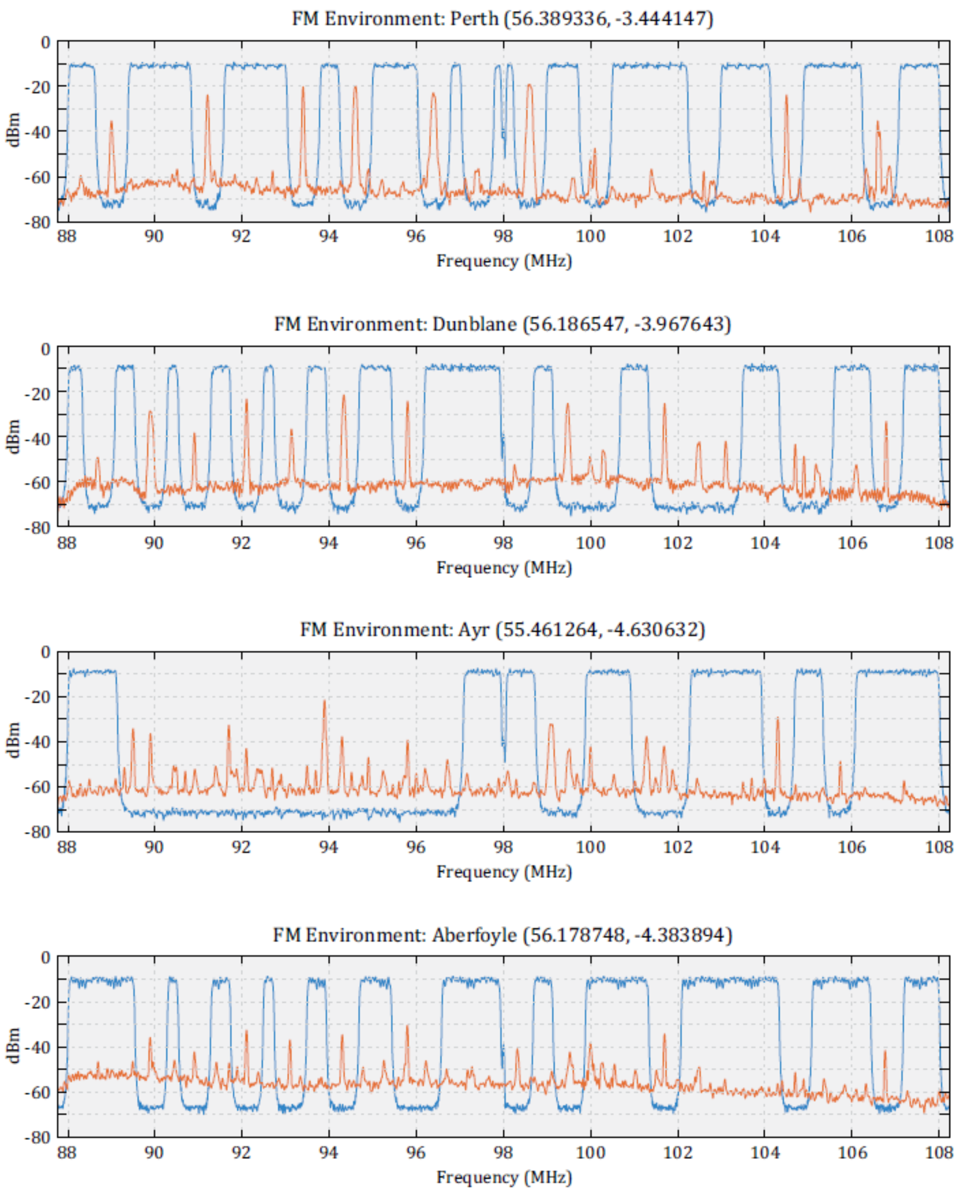





File Tools View Simulation Help
Frequency (MHz)
University of Strathclyde Engineering
Live off the air FM Radio band
SU FBMC signal
StrathSDR

DSA Radio Design – Transmitter Design

StrathSDR



- Papers
  - https://doi.org/10.1109/OJCOMS.2020.3039928
  - https://doi.org/10.1109/5GWF.2018.8517058
- Thesis
  - https://pureportal.strath.ac.uk/en/publications/design-and-implementation-of-real-time-cognitive-dynamic-spectrum
- **YouTube Demo** and design talk-through
  - https://www.youtube.com/watch?v=AZoS_-n-SsY
- (vaguely related) RFSoC paper
  - https://doi.org/10.1109/ACCESS.2020.3008954

Conclusions

Conclusions

- Licenced radio spectrum bands are **underutilised**
- Spectrum sharing techniques can enable **Secondary User** access to vacant licenced spectrum
- Sharing is gaining ground with regulators around the world – **SaaS and DSA likely around the corner**
- Latest advances in **SDR** technology (eg Xilinx RFSoC) are **key enablers** of CR designs

- Case Study provides evidence of underutilisation of the FM Radio band, motive for reuse + use case presented
- Novel DSA radio PHY developed to enable SU access to the FM Band, prototyped on SDR hardware, demonstrated to be capable of live dynamic reconfiguration to protect PU signals

- FM Radio band only **one of many under-utilised bands throughout the RF spectrum**

new thinking + new access solutions + new SDR technology = more efficient spectrum use

Thanks for listening!

Engage with us:

https://sdr.eee.strath.ac.uk

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github.com/strath-sdr

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