SDR Techniques to Handle Complex and Jam-Packed Spectral Landscapes

Military & Aerospace Electronics Webcast
May 15, 2018

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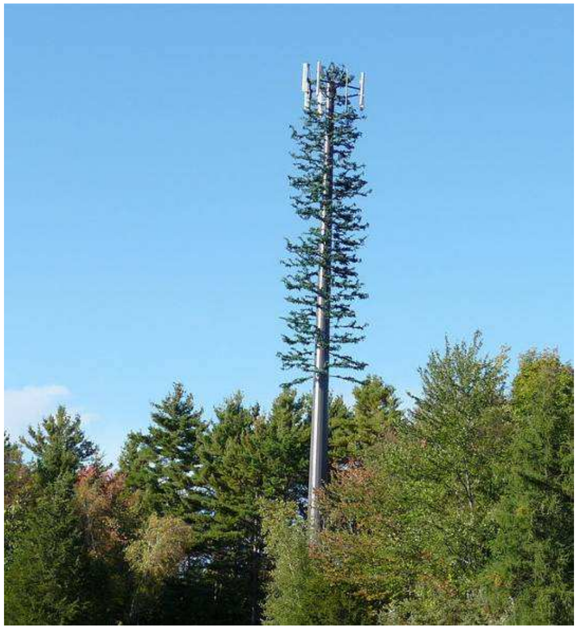
YEARS

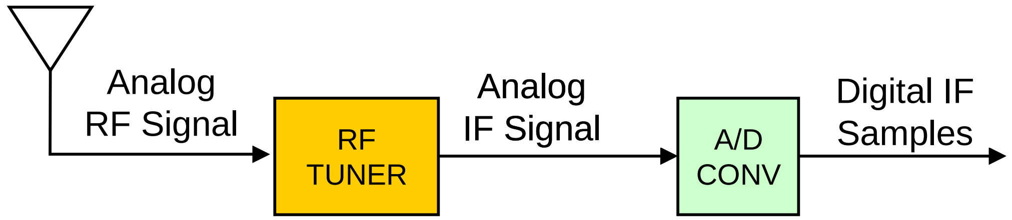
Topics



- SDR Basics and Advantages
- Radio Frequency Spectrum Allocation
- GSM: Classic Technology
- Channelizers Boost Density
- Channelized DDCs
- Multiplexing Techniques
- Sector Beamforming
- RFSoC: Latest Technology

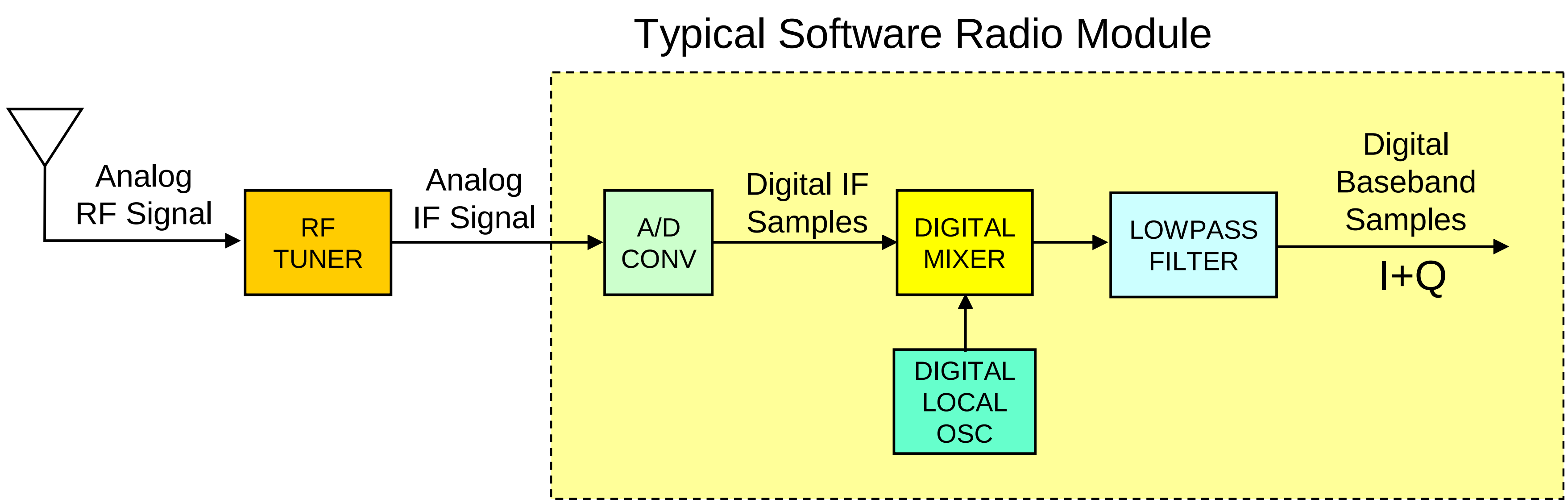
Software Defined Radio Receiver

- RF Tuner down converts analog RF signals to analog IF signals
- Now, the translated IF signal can be digitized by an A/D converter
- A/D converter digitizes the analog IF signal to digital IF samples



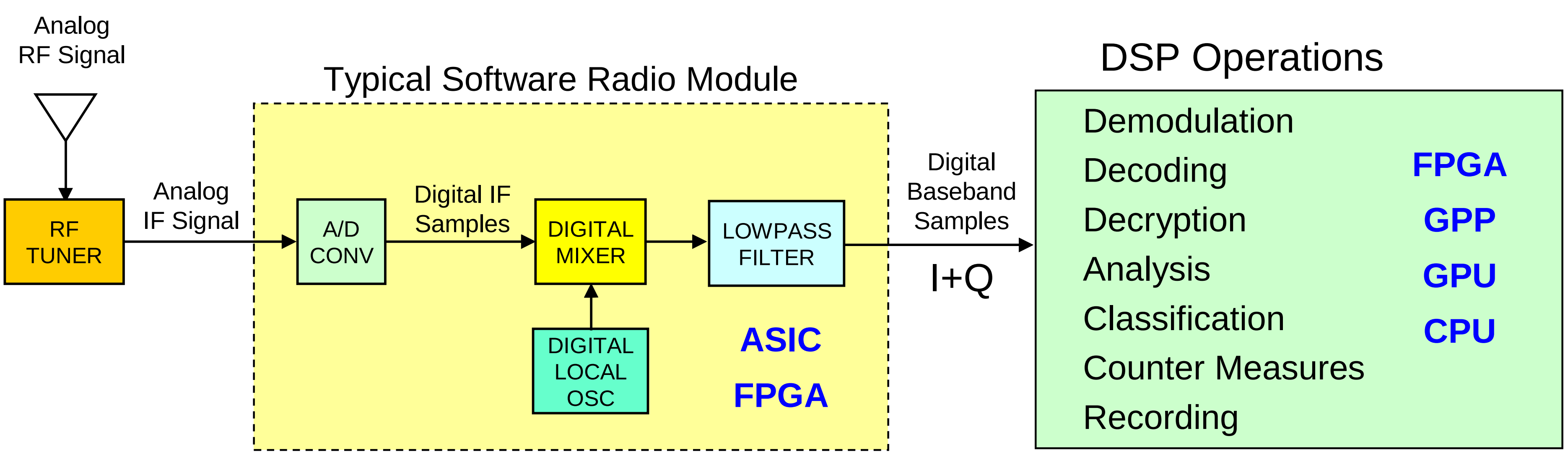
Software Defined Radio Receiver

- Digital Downconverters complete the job
- Digital Mixer and Local Oscillator translate digital IF to baseband
- Digital FIR low pass filter defines the digital IF signal bandwidth
- Output samples are delivered as complex baseband samples (I&Q)
- Local oscillators, mixers, and filters perform the same signal processing tasks as older analog circuitry – just a lot better!



Software Defined Radio Receiver

- Software radio modules use ASICs and FPGAs
- All SDR applications require additional DSP operations
- Most SDR algorithms need complex digital baseband samples
  - Complex signal representation is preferred for efficient processing
  - The signal band is centered at 0 Hz, with positive & negative portions
- DSP operations are tailored to the required application
  - Replaces complicated analog circuitry with extremely precise mathematical operations
  - Performed by FPGA, GPP, GPU or CPU



Scorecard: Analog vs. Digital Receivers

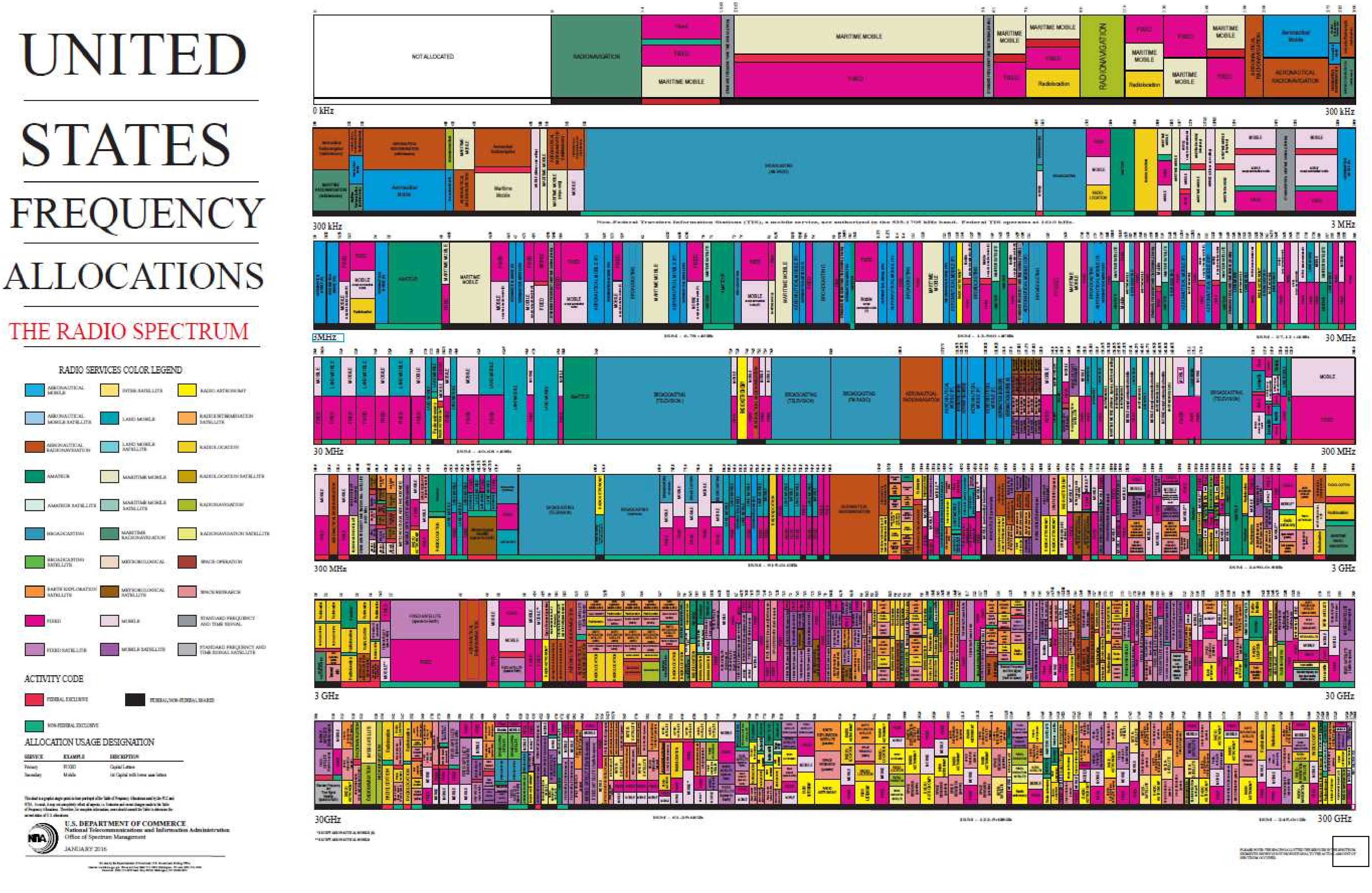
	Analog	**Digital**
High Frequency RF	Excellent	Good
Tuning Speed	Good	Excellent
Frequency Accuracy	Good	Excellent
Complex Modulation	Poor	Excellent
Aging Rate	Poor	Excellent
Filter Characteristics	Poor	Excellent
Mixer Performance	Poor	Excellent
Temperature Stability	Poor	Excellent
Size/Channel	Poor	Excellent
Cost/Channel	Poor	Excellent
Configurability	Poor	Excellent
Adaptabilty	Poor	Excellent

ITU Frequency Bands

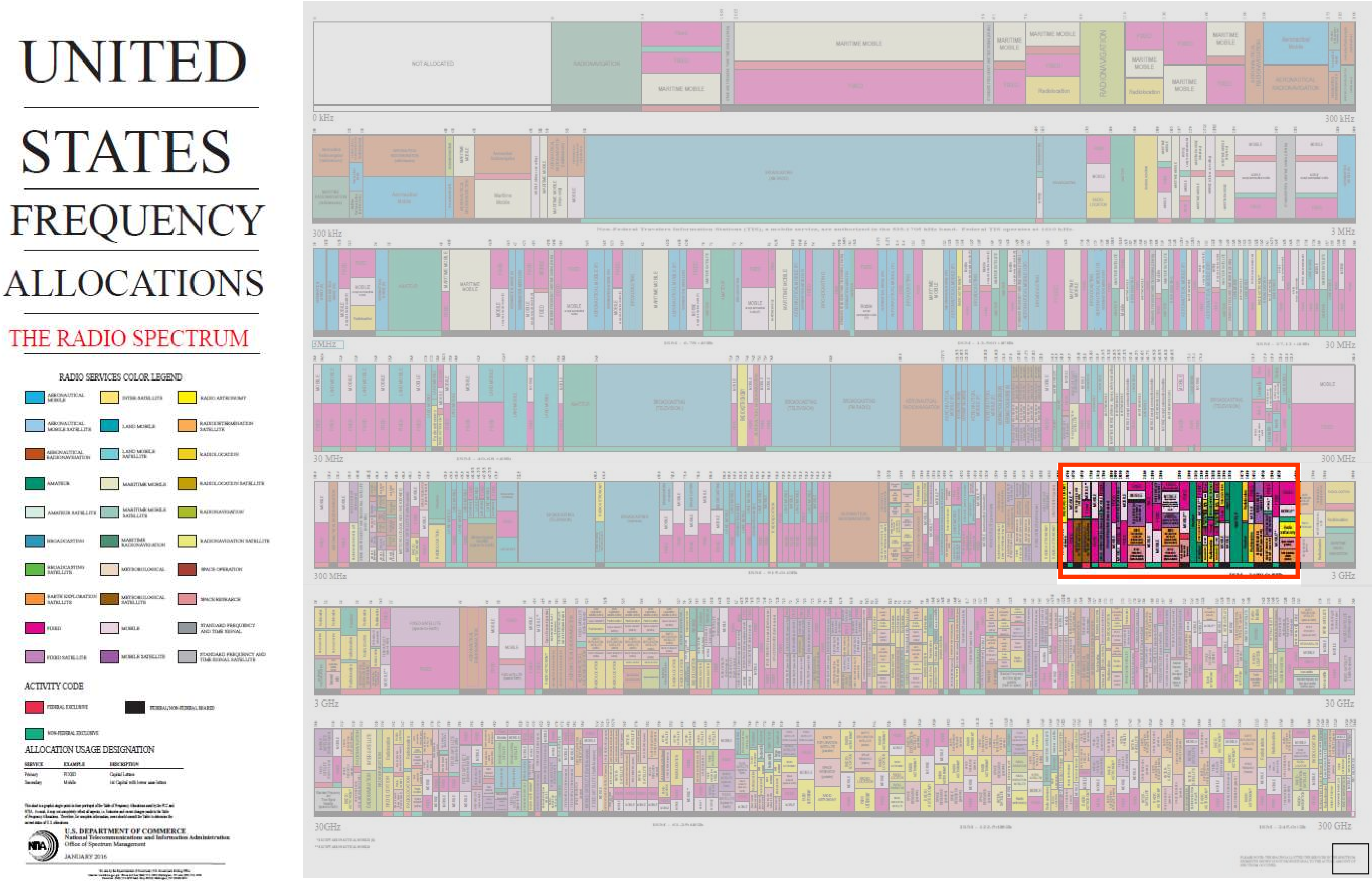
Radio bands established by the International Telecommunications Union

Band name	Abbr	ITU	Frequency	Application Spaces
Extremely low frequency	ELF	1	3–30 Hz	Communication with submarines
Super low frequency	SLF	2	30–300 Hz	Communication with submarines, Mains power (50/60Hz)
Ultra low frequency	ULF	3	300–3000 Hz	Communication within mines
Very low frequency	VLF	4	3–30 kHz	Submarine communication, wireless heart rate monitors, geophysics
Low frequency	LF	5	30–300 kHz	Navigation, time signals, AM long-wave broadcasting (Europe and parts of Asia), RFID, amateur radio
Medium frequency	MF	6	300–3000 kHz	AM (medium-wave) broadcasts, amateur radio, avalanche beacons
High frequency	HF	7	3–30 MHz	Shortwave broadcasts, citizens' band radio, amateur radio, over-the-horizon aviation communications and radar, RFID, Automatic link establishment (ALE)/Near Vertical Incidence Skywave (NVIS) radio communications, Marine and mobile radio telephony
Very high frequency	VHF	8	30–300 MHz	FM, television, line-of-sight ground-to aircraft and aircraft-to-aircraft communications, amateur radio, weather radio, PMR, DVB-T, MRI Land Mobile and Maritime Mobile communications
Ultra high frequency	UHF	9	300–3000 MHz	Television broadcasts, microwave communications, radio astronomy, GPS, mobile phones (GSM, UMTS, 3G, HSDPA), FRS & GMRS radios, wireless LAN (Wi-Fi 802.11 b/g/n), Bluetooth, ZigBee, GPS, Land Mobile, amateur radio, DBS, microwave ovens
Super high frequency	SHF	10	3–30 GHz	Microwave communications, wireless LAN (Wi-Fi 802.11 a/n), most modern radars, communications satellites, amateur radio, DBS satellite television broadcasting, WiMAX
Extremely high frequency	EHF	11	30–300 GHz	Radio astronomy, high-frequency microwave radio relay, microwave remote sensing, amateur radio
Tremendously high frequency	THF	12	300–3,000 GHz	Terahertz medical imaging, ultrafast molecular dynamics, condensed-matter physics, terahertz spectroscopy, computing/communications

U.S. Dept of Commerce Frequency Chart

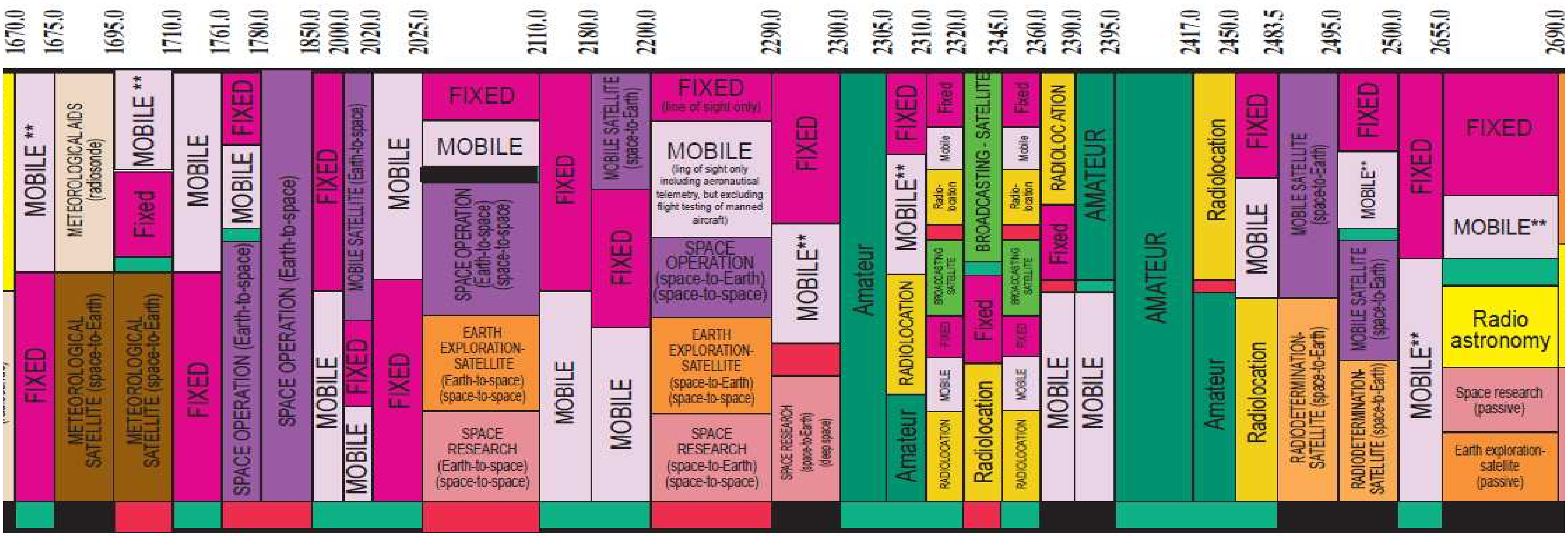


U.S. Dept of Commerce Frequency Chart



High Channel Density and Cost

- March 2016: FCC commenced the first-ever “incentive auction” designed to repurpose spectrum for new uses
- Market forces align broadcast airwaves to 21st century consumer demands for video and broadband services
- Sold 84 megahertz of spectrum – 70 megahertz for licensed use and 14 megahertz for wireless microphones and unlicensed use
- Auction proceeds: $19.8 billion total
  - $10.05 billion to broadcast spectrum sellers
  - $7 billion to the U.S. Treasury for deficit reduction

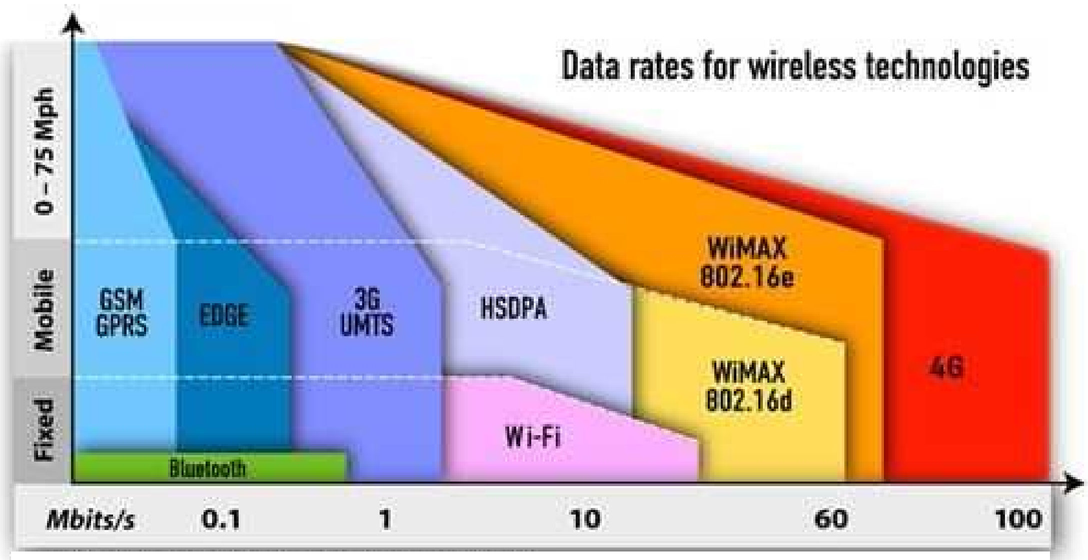


Drivers for Better Spectral Utilization

- High cost of allocated frequency bands
- HD broadcast TV and FM
- Increased data traffic for all services
- Wireless IoT devices and appliances
- Wireless video surveillance
- Enormous appetite for personal wireless data services
- Wireless streaming entertainment and programming
- Mobile Wi-Fi hot spots in autos, planes, trains, & other vehicles
- Unmanned vehicles and drones for personal and military use
- Satellite streaming radios
- Wireless security system components
- Wireless computer connectivity in homes, offices, and industry
- Remote health monitoring devices and mobile medical services
- Broadband wireless replacing wired internet infrastructures

What is GSM?

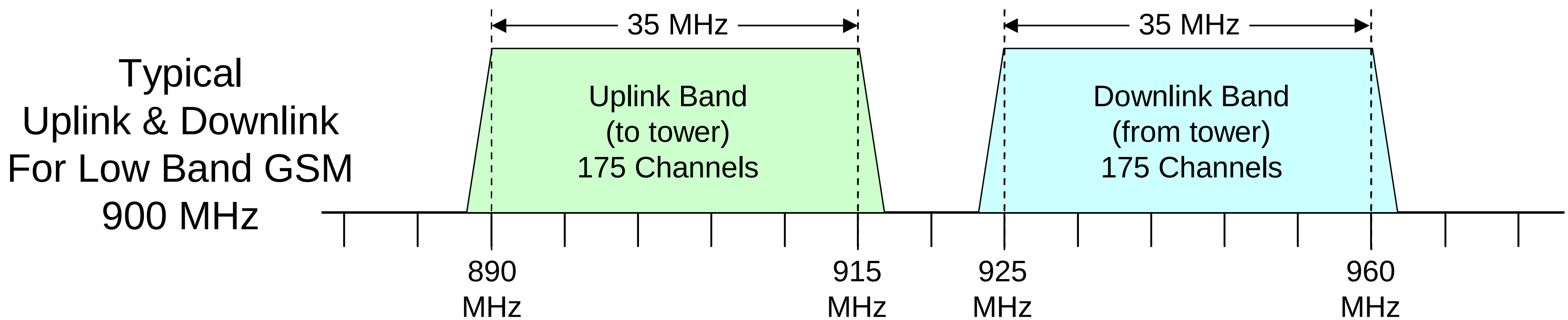
- GSM – Global System for Mobile Communications
  - Protocols were developed for 2G digital networks
  - Voice and data services with flexible roaming capability
  - Tight security & eavesdropping is very difficult
  - SIM cards allow customers to use different phones
- Worldwide standard still with 38% market share in 2017
  - Used in 219 countries and territories
  - Widest selection of handsets compared to any other standard
  - Low operational costs due to equipment vendor competition
- Although new standards are emerging, GSM will be around for a **very** long time



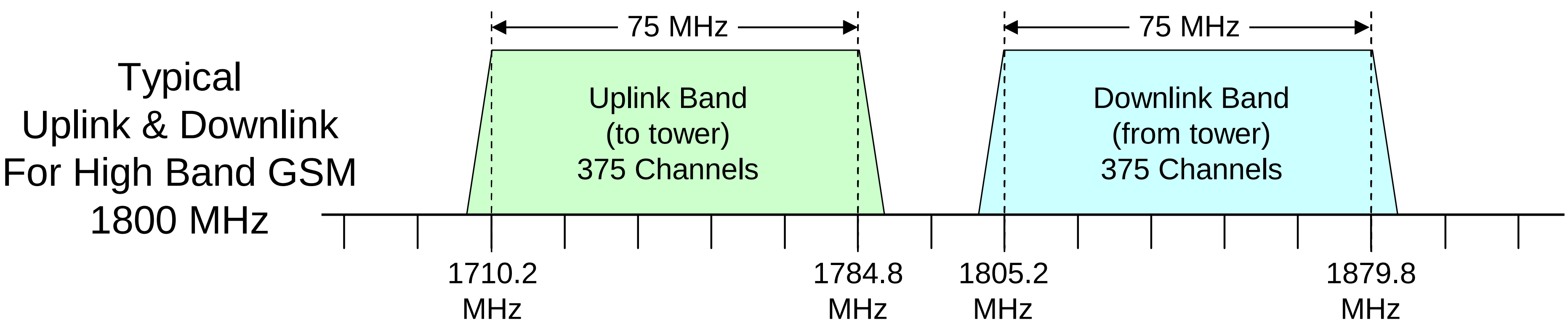
Sources: WiSOA, Abm, Siemens, Intel, Maravedix, Samsung, UMTS Forum, Nokia

What Frequencies Does GSM Use?

- Different countries use different popular GSM carrier frequencies
  - Low Bands: Centered approximately at 810, 850, or 900 MHz

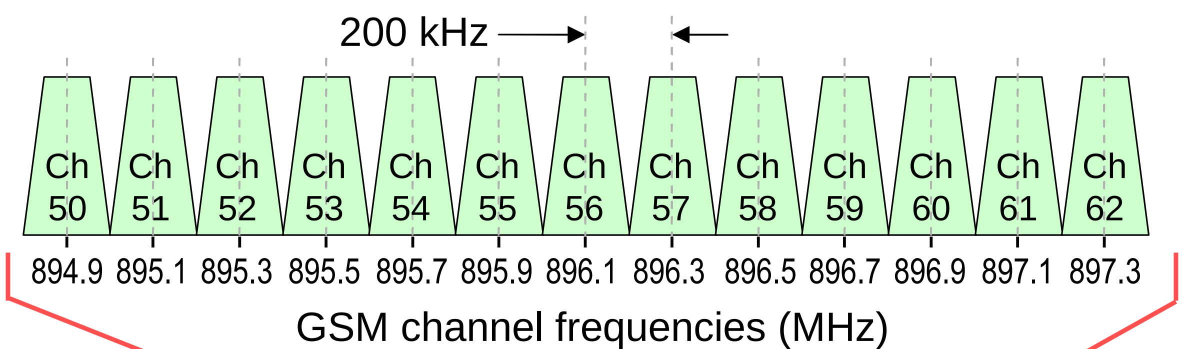


  - High Bands: Centered approximately at 1800 or 1900 MHz

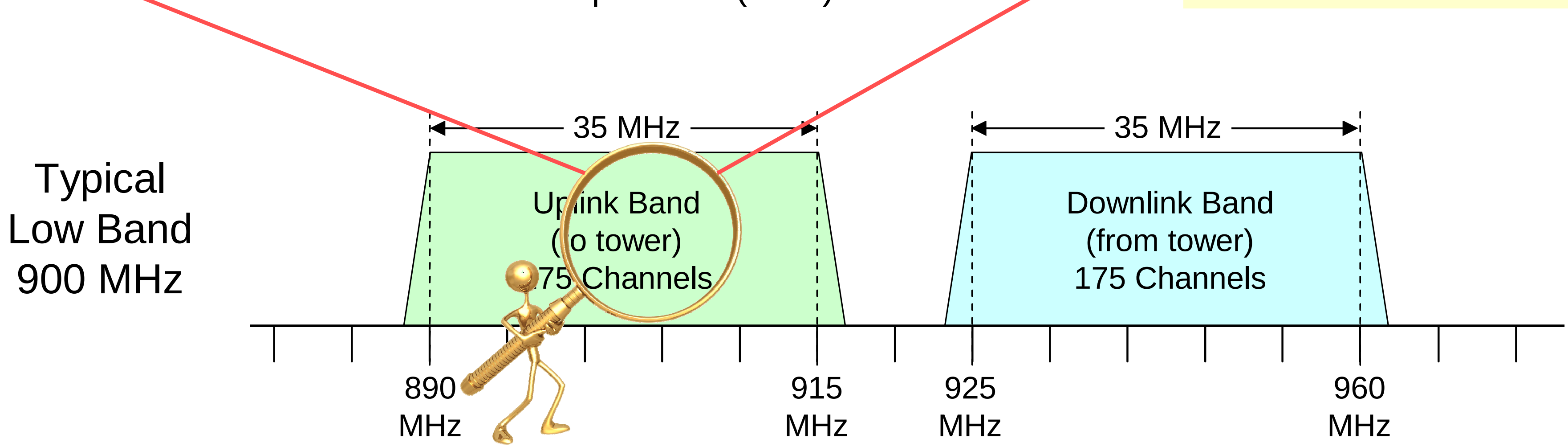


What's Inside Each GSM band?

- Uplink and downlink bands
  - GSM channels are equally spaced in frequency at 200 kHz intervals
  - Each channel carries a voice or data signal for one subscriber
  - For low up/down bands: 35 MHz bandwidth / 200 kHz = 175 channels each
  - For high up/down bands: 75 MHz bandwidth / 200 kHz = 375 channels each

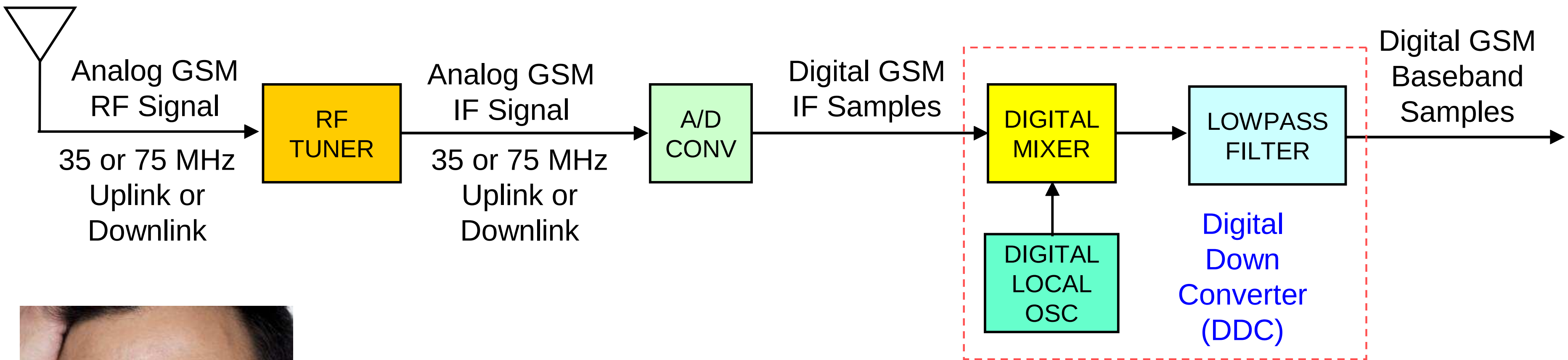


Low Band Uplink	175 Ch
Low Band Downlink	175 Ch
High Band Uplink	375 Ch
High Band Downlink	375 Ch
GSM Total Channels	**1100 Ch**



How do we capture a GSM signal?

- One DDC can down-convert one GSM channel to baseband (0 Hz)
- But first we need an A/D to digitize the GSM uplink or downlink bands
- GSM antenna signals are high frequency, so we need to use an RF Tuner
- RF Tuner translates the RF signals down to a lower IF frequency

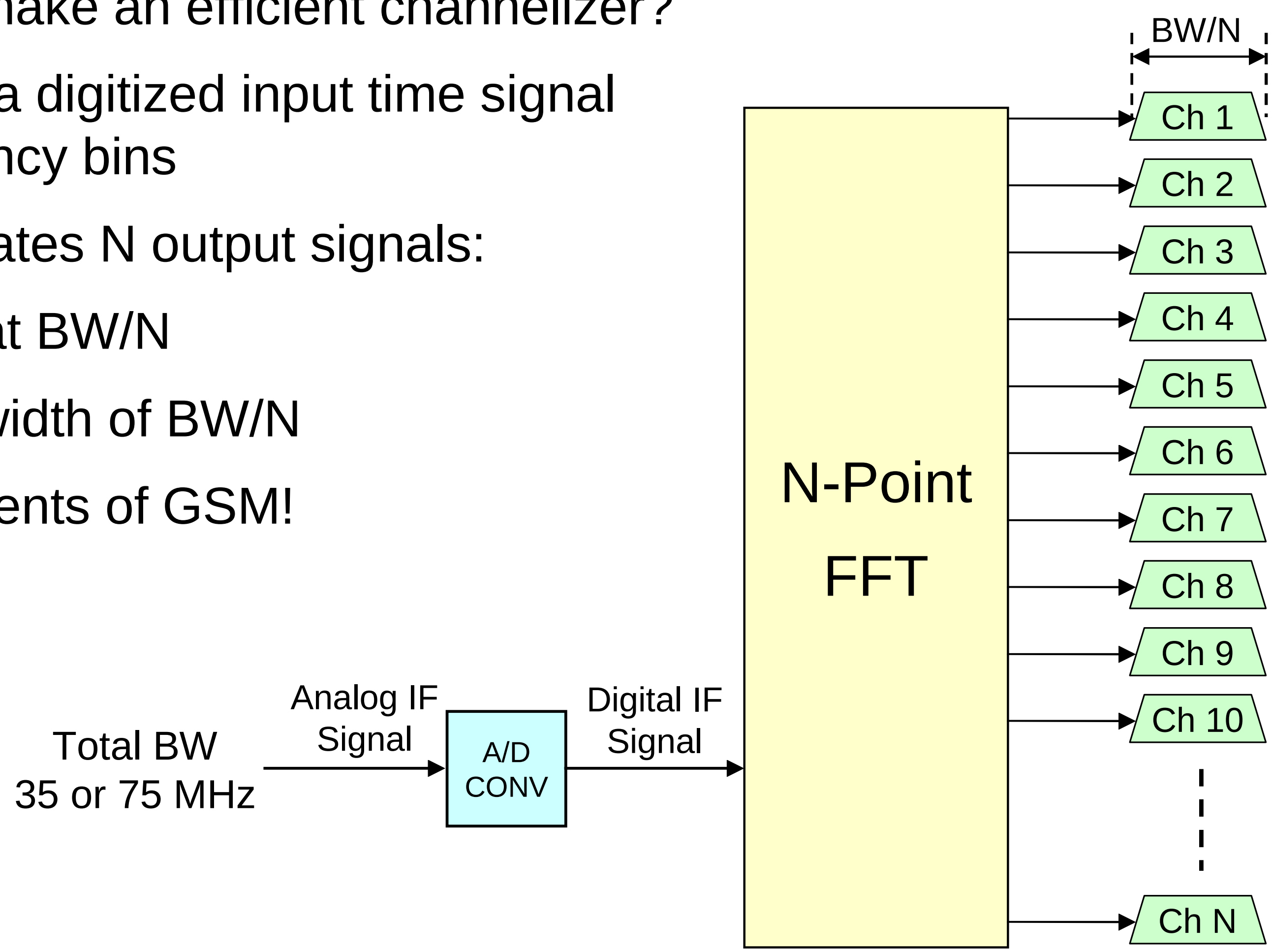


But ……

How can I capture all 1100 GSM signals simultaneously ??

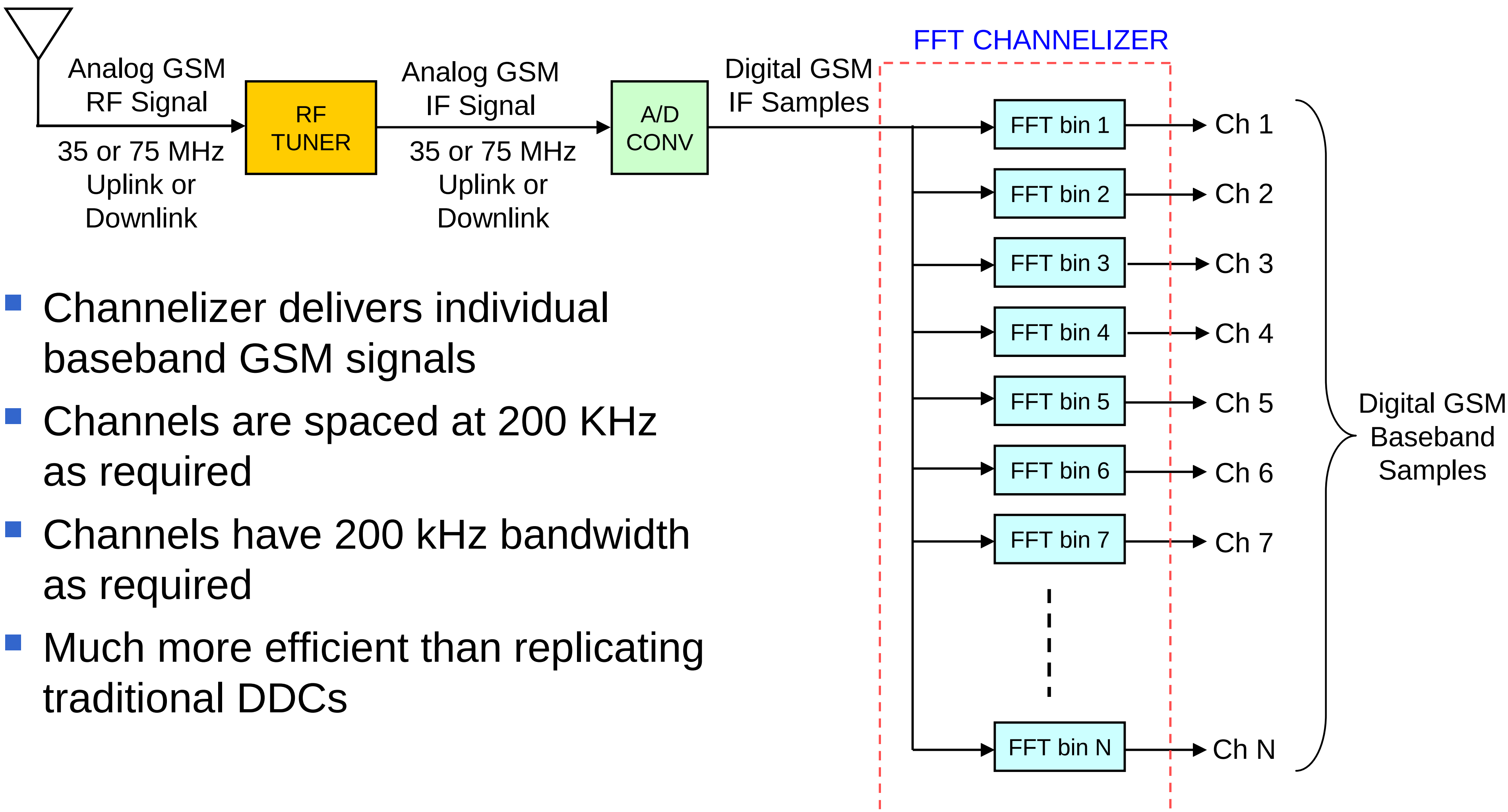
What Is a Channelizer?

- A channelizer is a bank of parallel frequency downconverters
- All output channels have a fixed bandwidth
- All output channels have a fixed frequency spacing
- Why does an FFT make an efficient channelizer?
- An FFT transforms a digitized input time signal into discrete frequency bins
- An N-point FFT creates N output signals:
  - Equally spaced at BW/N
  - Filtered to bandwidth of BW/N
- Meets the requirements of GSM!



Using a Channelizer for GSM

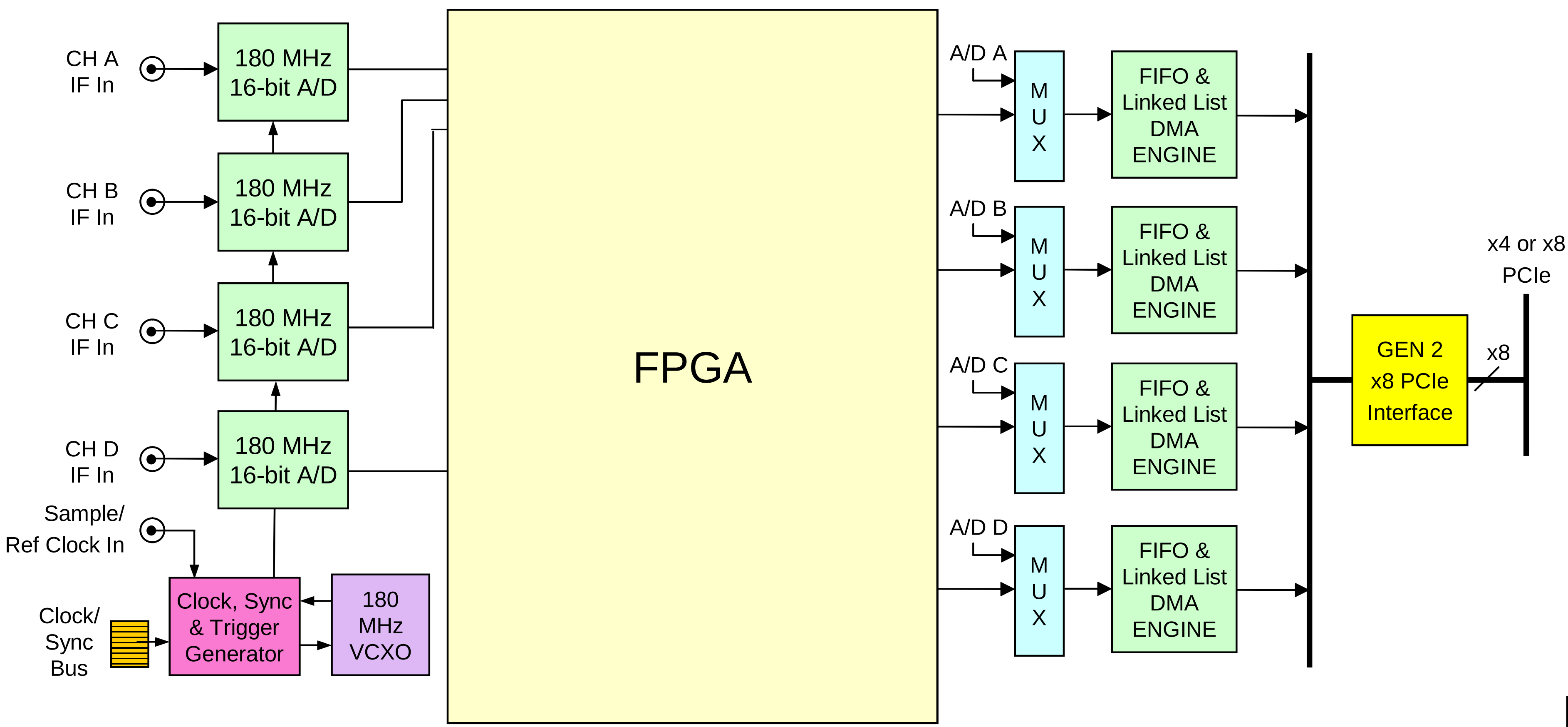
- An FFT channelizer implements a DDC bank with fixed spacing and bandwidth
- Accepts a digitized uplink or downlink GSM band containing multiple channels



- Channelizer delivers individual baseband GSM signals
- Channels are spaced at 200 KHz as required
- Channels have 200 kHz bandwidth as required
- Much more efficient than replicating traditional DDCs

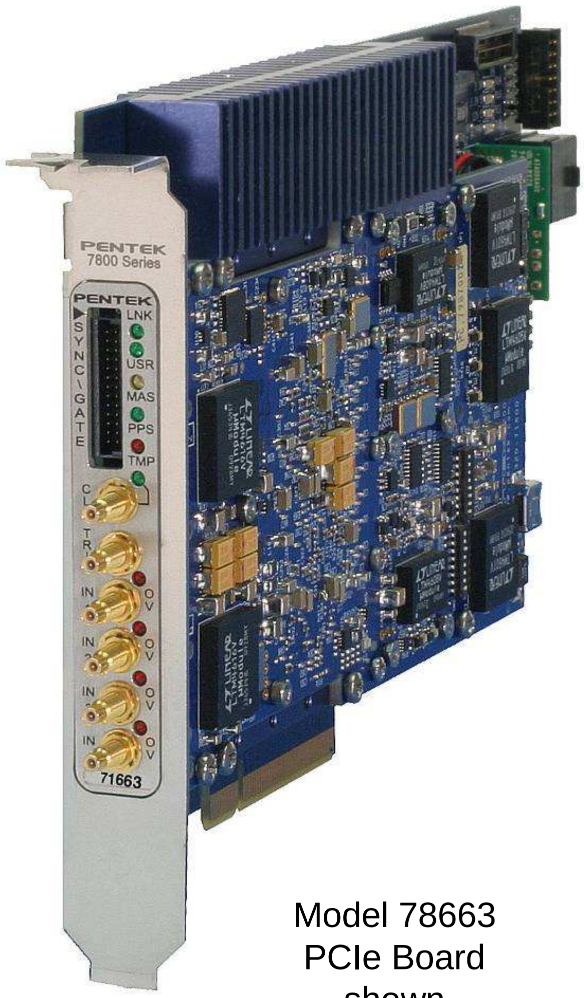
Model 71663 GSM Channelizer XMC

- 1100 GSM Channels FPGA IP Core – Captures <u>every</u> GSM signal!
  - Two channelizers of 175 channels for low band GSM up & down links
  - Two channelizers of 375 channels for high band GSM up & down links



Model 71663 Opens New Applications

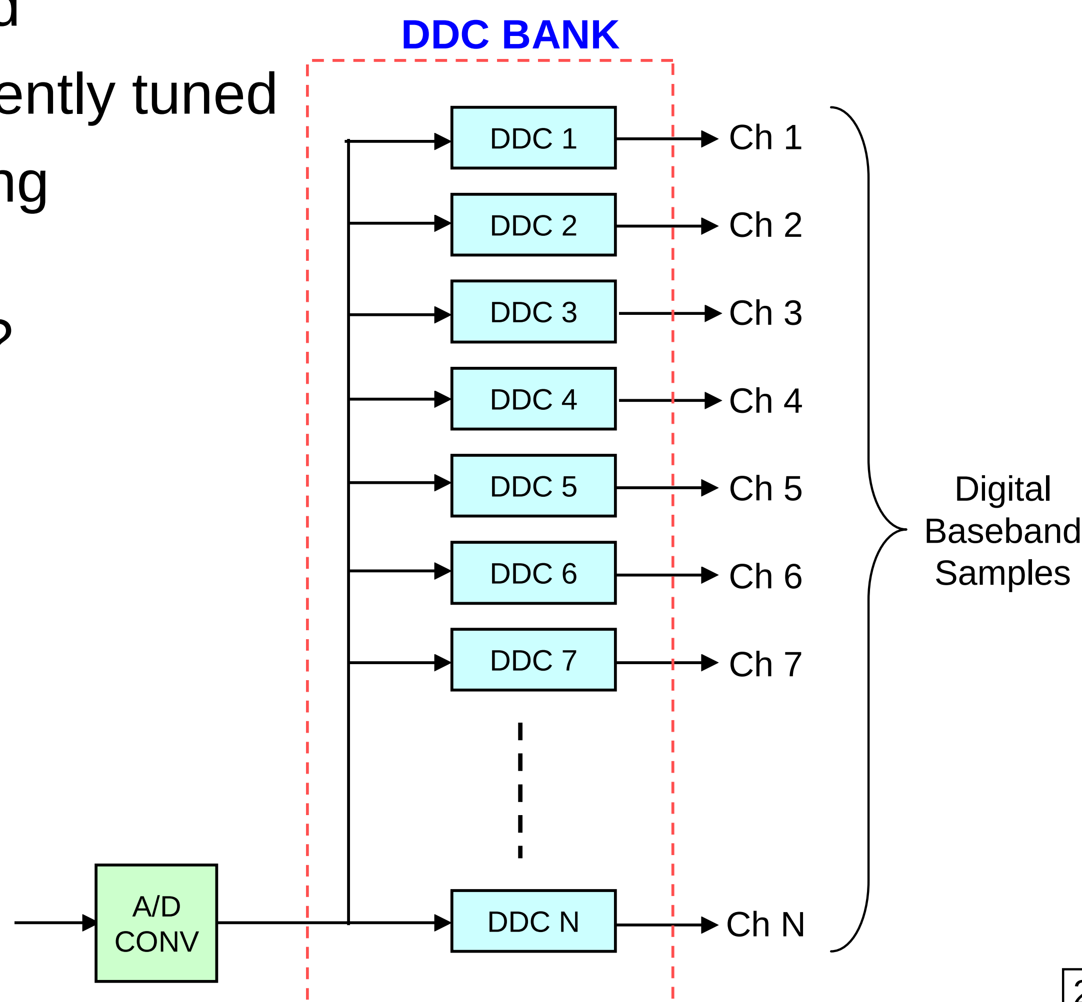
- Extremely effective in size, weight, power and cost
- Can be used in portable or field monitoring systems
- GSM Service Providers
  - Signal quality monitoring and trouble shooting
  - Mobile mapping of cell tower coverage
- Government intelligence monitoring and security
  - Domestic anti-terrorism, foreign intelligence
- Drug Traffic Interdiction
  - Monitor transactions and deliveries
- Municipal, State, and Government Police
  - Crime detection and prevention
  - Emergency and crisis management
- Military Applications
  - Detect GSM phone traffic for detonating IEDs
  - Call interception for war fighter tactical intelligence



Model 78663
PCIe Board
shown

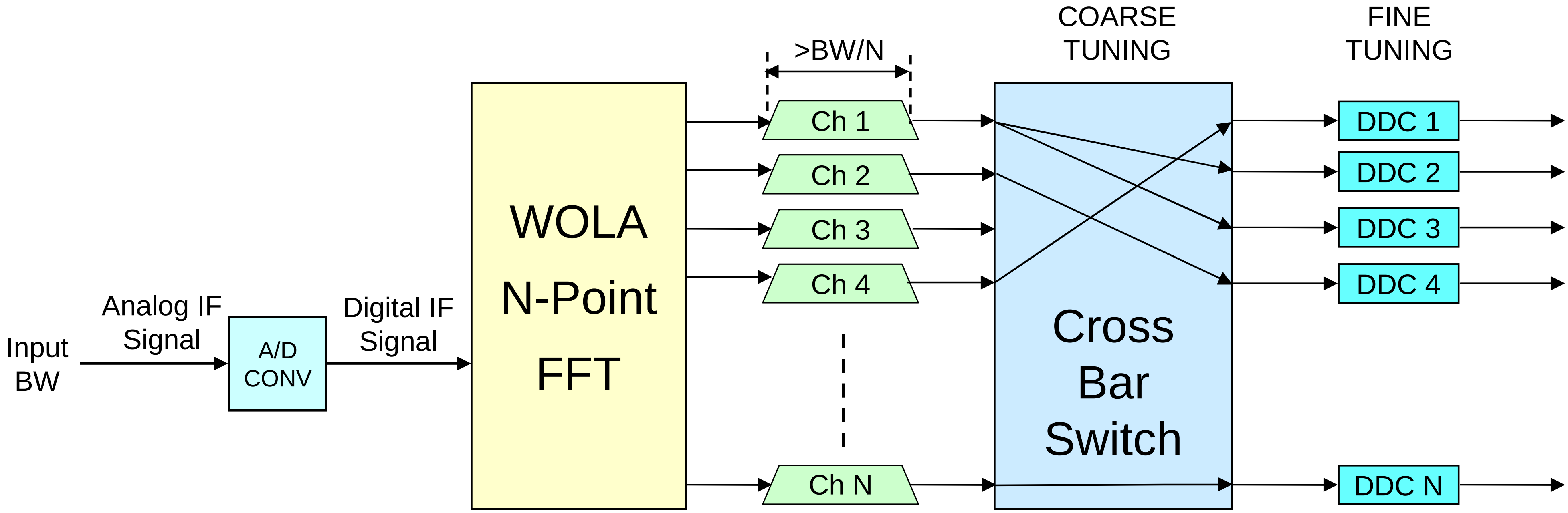
High Density DDC Designs

- FFT Channelizers offer fixed spacing and bandwidth
- But, many signal bands require arbitrary frequency spacing
- A bank of N DDCs would provide free tuning across entire input band
- Each DDC could be independently tuned
- Much more flexible for acquiring arbitrary or unknown signals!
- But how can this be achieved?



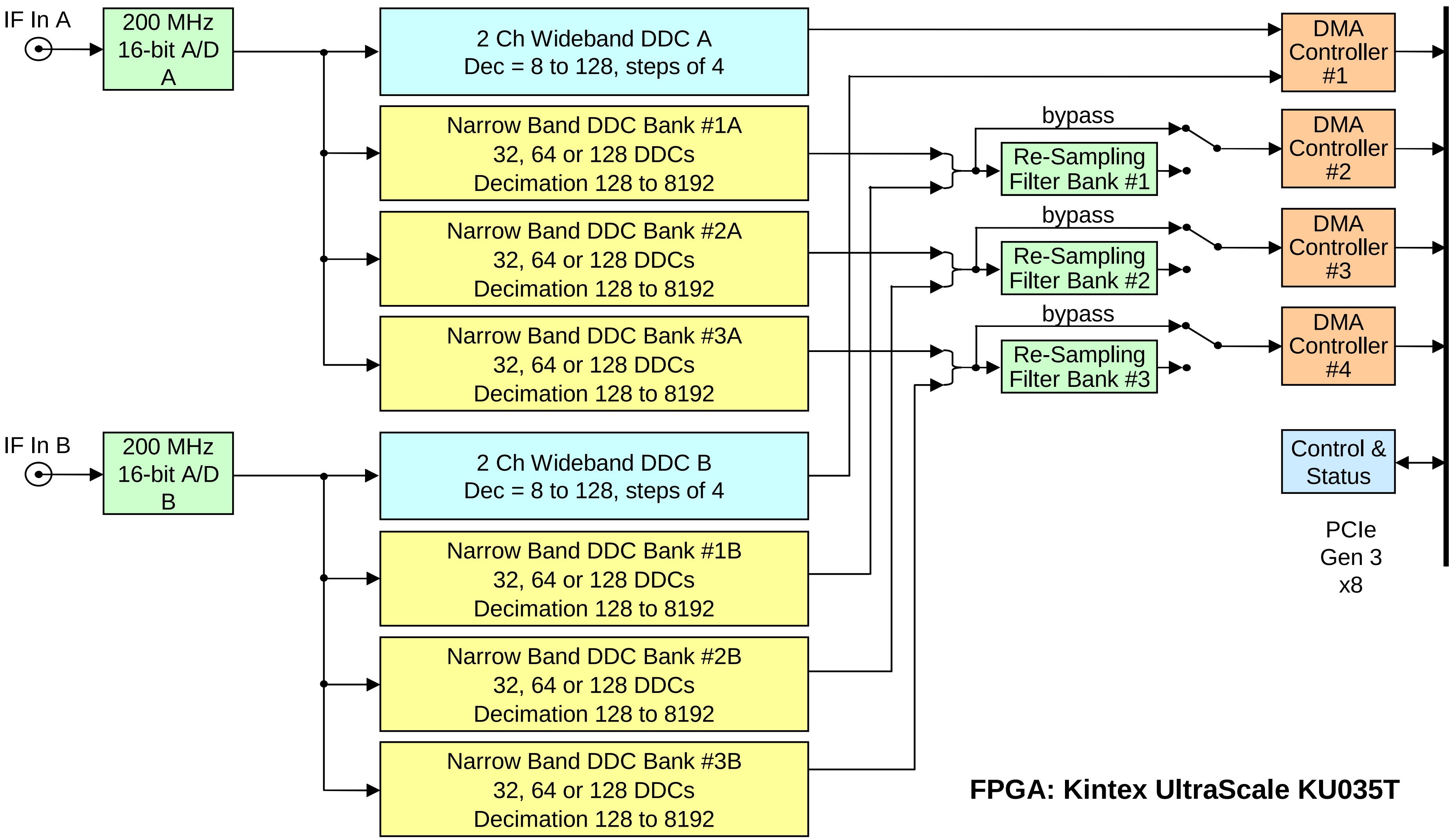
DDC Enhanced Channelizer

- WOLA (weighted overlap & add) FFT techniques create wider, overlapping bin output bandwidths
- Each bin frequency bandwidth overlaps the two adjacent bins so that any signal frequency is available in at least one bin
- Cross Bar Switch performs coarse tuning by selecting the desired bin
- Fine tuning DDCs perform final center frequency tuning
- DDC hardware can be multiplexed because of very low sample rates
- Much more efficient for high channel-count DDCs



Model 71865 768-Channel DDC

- 4 Wideband DDCs – Bandwidths 1.25 MHz to 20 MHz
- Up to 768 Narrowband DDCs – Bandwidths 20 kHz to 1.25 MHz
- Free independent tuning for each DDC: 0 to 200 MHz



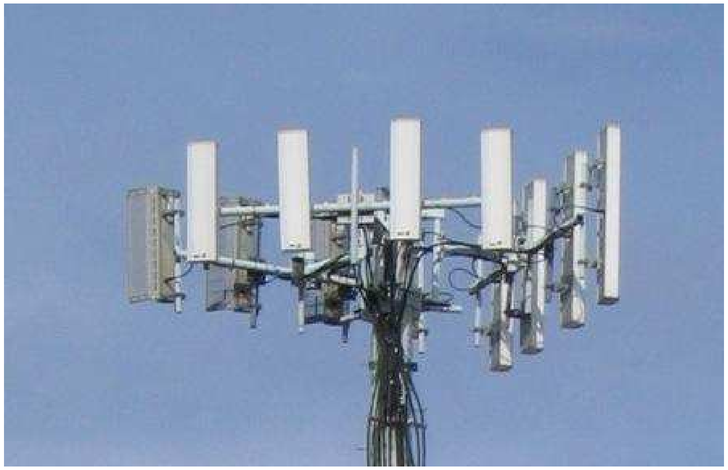
FPGA: Kintex UltraScale KU035T

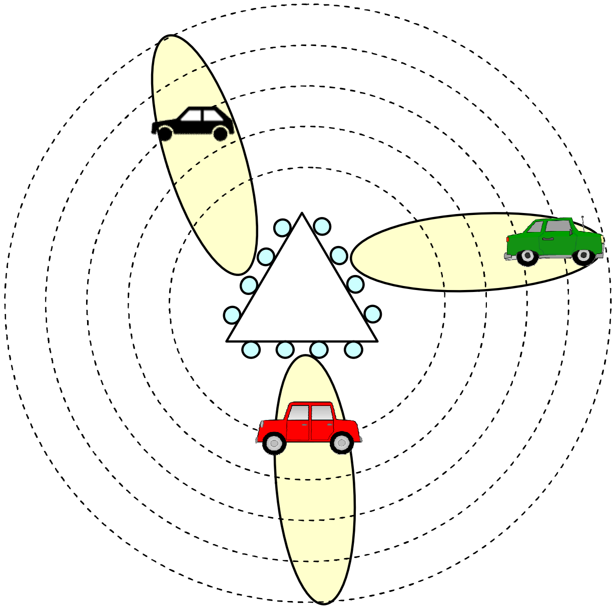
Multiplexing Boosts Utilization

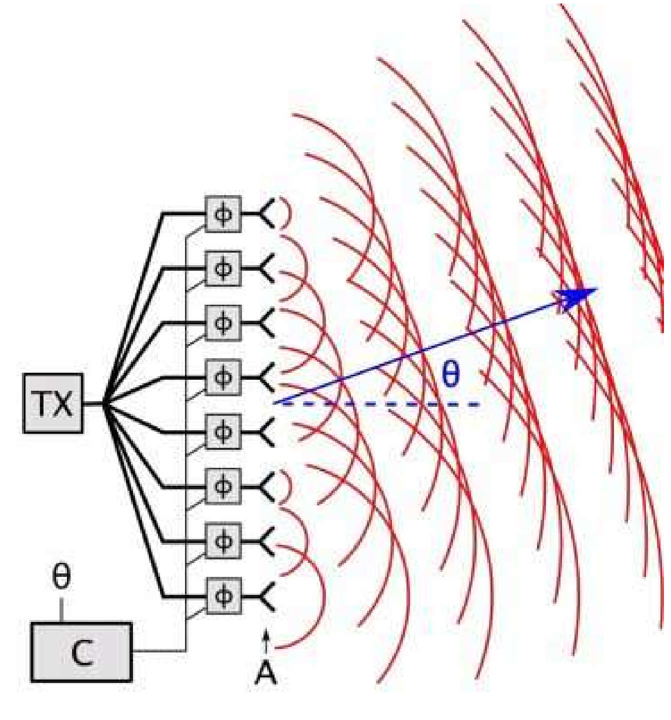
- FDMA – Frequency Division Multiplexing
  - Used in 1G and 2G Wireless
  - GSM packs 175 or 375 frequency channels in each GSM band
  - High precision of digital filters permit tight spacing between channels
- TDMA – Time Division Multiplexing
  - Used in 2G GSM
  - Times slots in each frame are allocated to different users
  - Average data rate per user supports service requirements
- CDMA – Code Division Multiplexing
  - Used in 2G and 3G Wireless
  - Pseudo Random modulation spreads spectral bandwidth of each channel
  - Multiple channels can share same band
  - Demodulation with same pseudo random code extracts each channel
- Spatial Multiplexing……

Sector Beamsteering

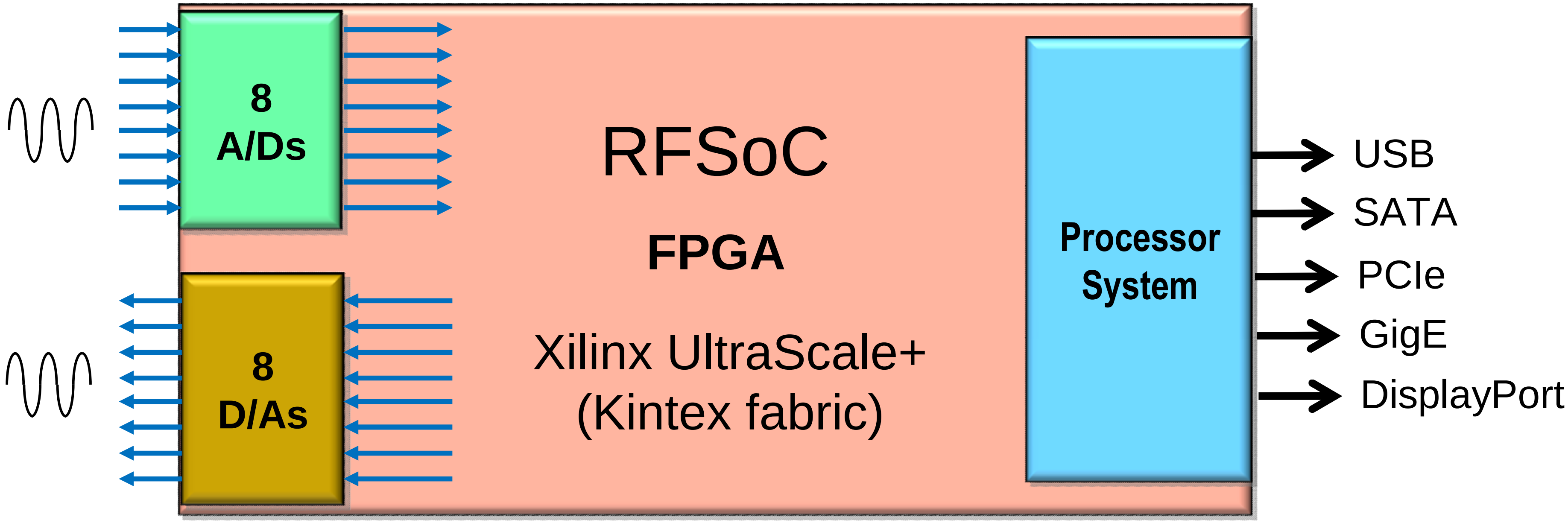
- Cell towers can steer the direction of reception and transmission by using antenna elements in phased arrays
- Each element in the array is precisely offset in phase to direct transmit and receive signals along specific angles
- A frequency band in one directional lobe can be reused in other lobes without interfering
- Increases the number of customers for each cell tower







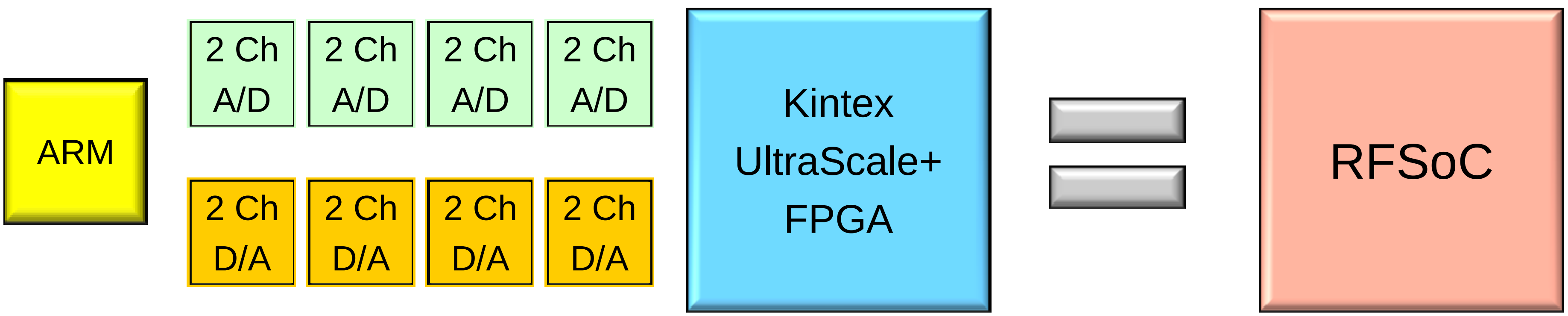
Xilinx RFSoC – System on Chip



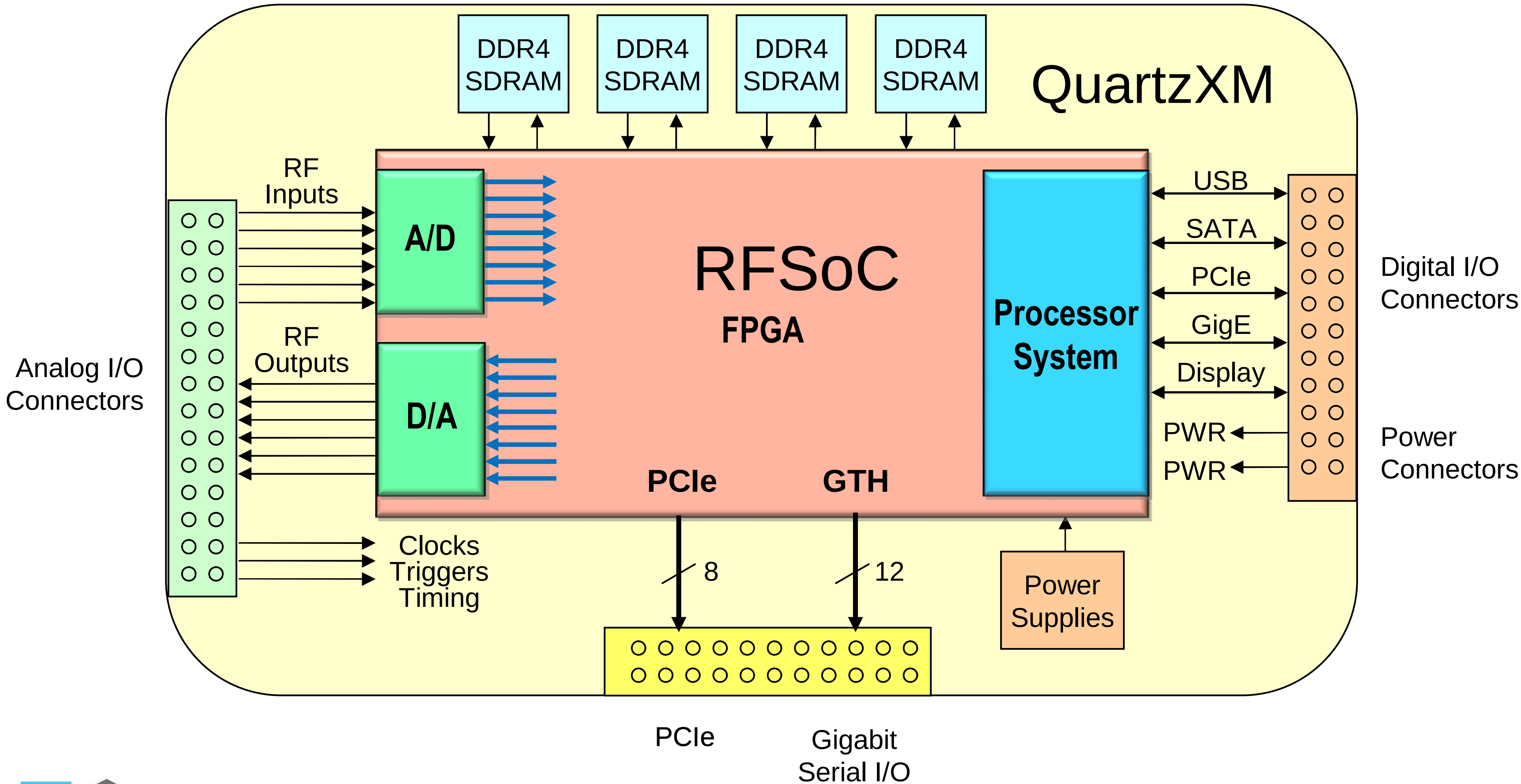
- Kintex UltraScale+ FPGA Fabric
  - Latest 16 nm technology
- 8 A/Ds 12-bit 4 GS/sec with integrated DDCs
- 8 D/As: 14-bit 6 GS/sec with integrated DUCs
- Processor System
  - Quad 64-bit ARM Cortex-A53 cores
  - Dual ARM Cortex-R5 real time cores
  - GPU (Graphics Processing Unit)

How Does RFSoC Change the Market?

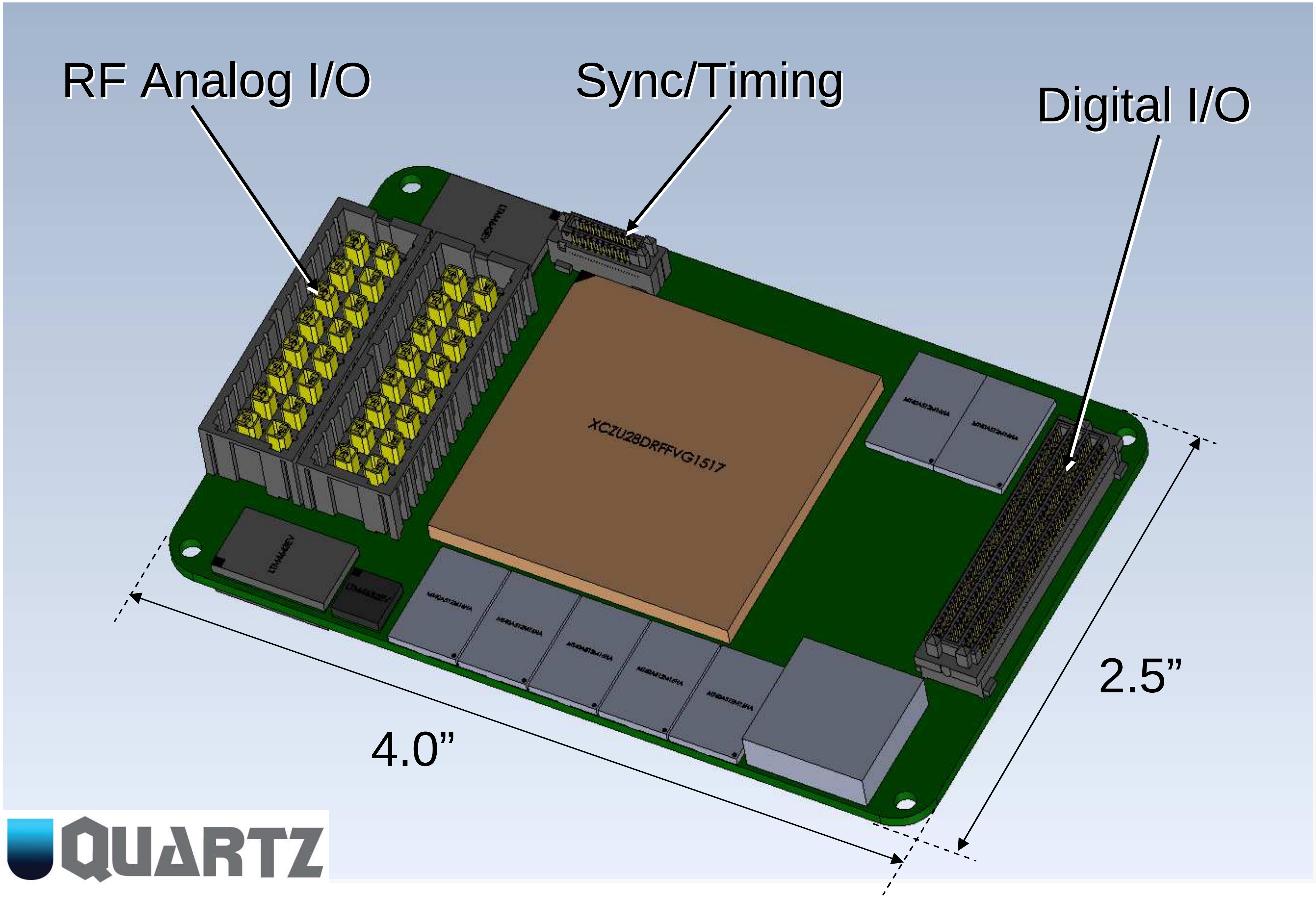
- Reduced footprint
  - Data converters, FPGA and processor system in a single chip
- Reduced power
  - About 40-65% total power savings
- Reduced cost
  - About 35-60% total cost savings
- Lowest Latency Solution
  - Fast direct path from A/D to FPGA to D/A
  - Essential for critical military EW applications



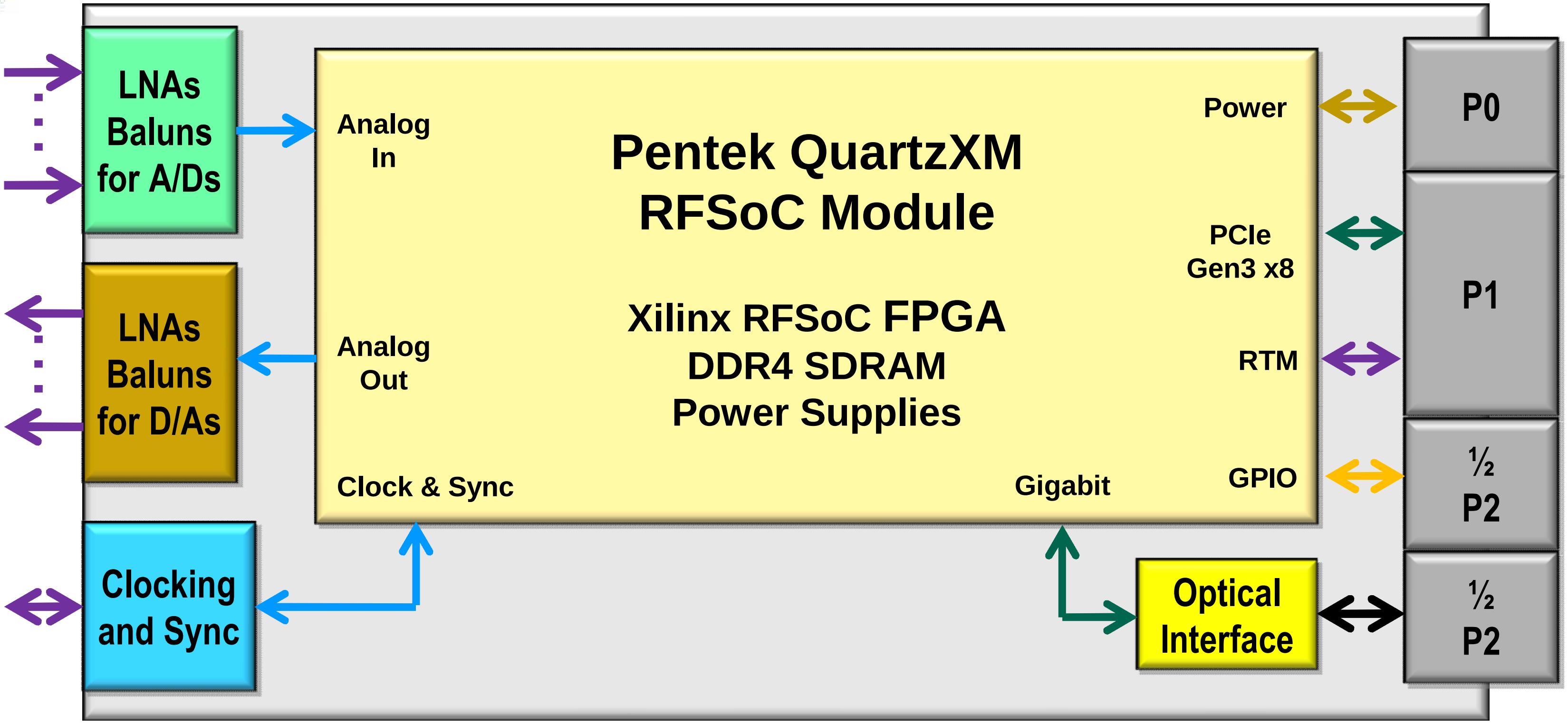
Pentek QuartzXM RFSoC Module



Pentek QuartzXM RFSoC Module



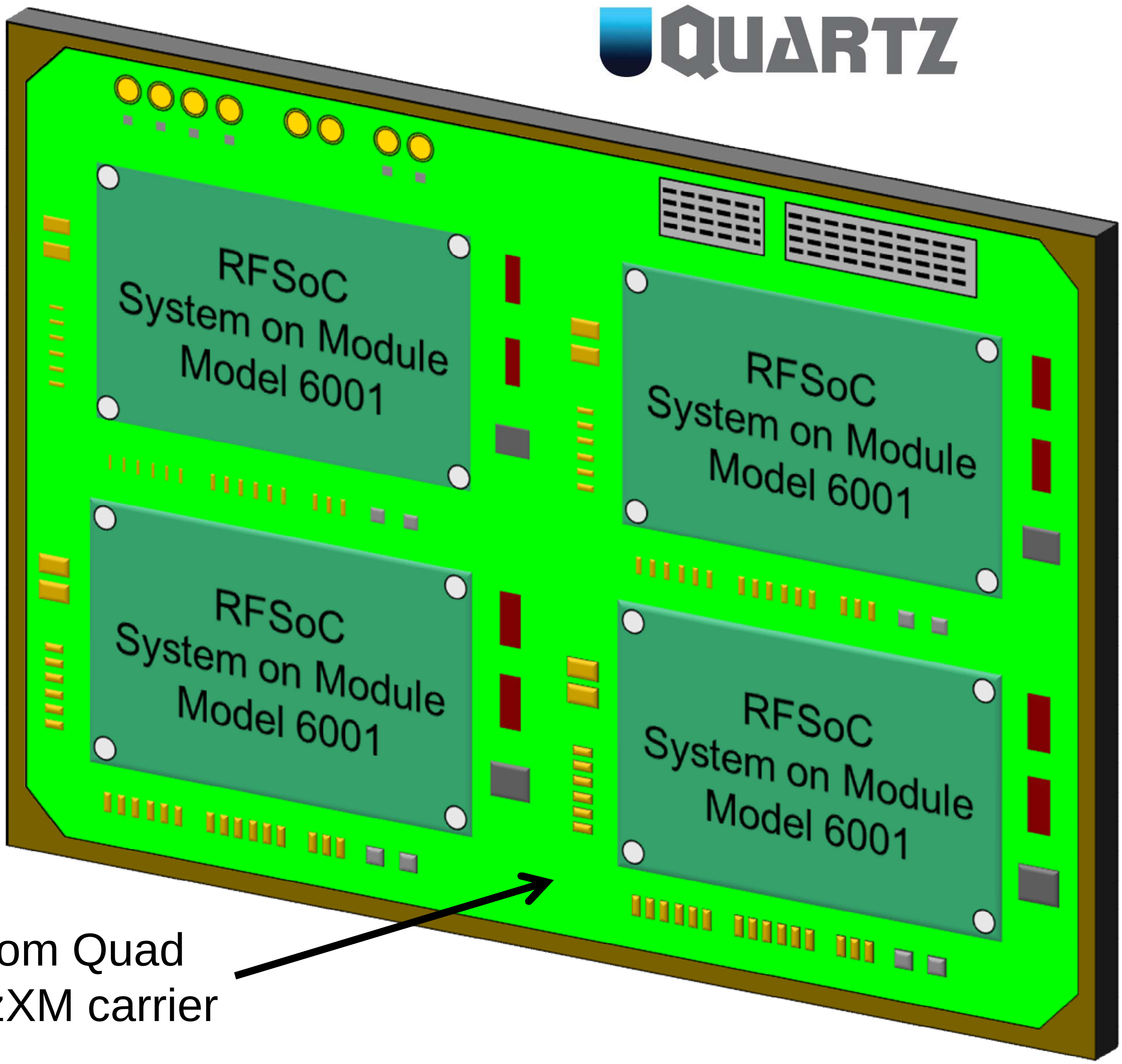
Pentek QuartzXM on a 3U VPX Carrier



3U VPX

Model
5950

QuartzXM Application Specific Solutions



Custom
8 x 4 antenna
array

Custom Quad
QuartzXM carrier

Summary – Take Aways

- SDR techniques have revolutionized radios in just 25 years!
- All modern radio traffic requires the use of SDR techniques
- Licensing costs for spectral space is extremely high
- Enormous commercial markets drive new technology
- Complex SDR techniques boost efficiency of spectrum use
- FPGAs provide leading edge development platforms for SDR
- High volume production requires ASICs for reduced cost
- SDRs are flexible enough to cover different modes and bands
- SDR functions are moving closer to the antenna
- New technologies like RFSoC are changing SDR landscapes
- SDR is just getting started!

Questions?

- Email: rodger@pentek.com
- Visit www.pentek.com