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Akademie der Wissenschaften

1759

Next Generation Radios Communication Networks

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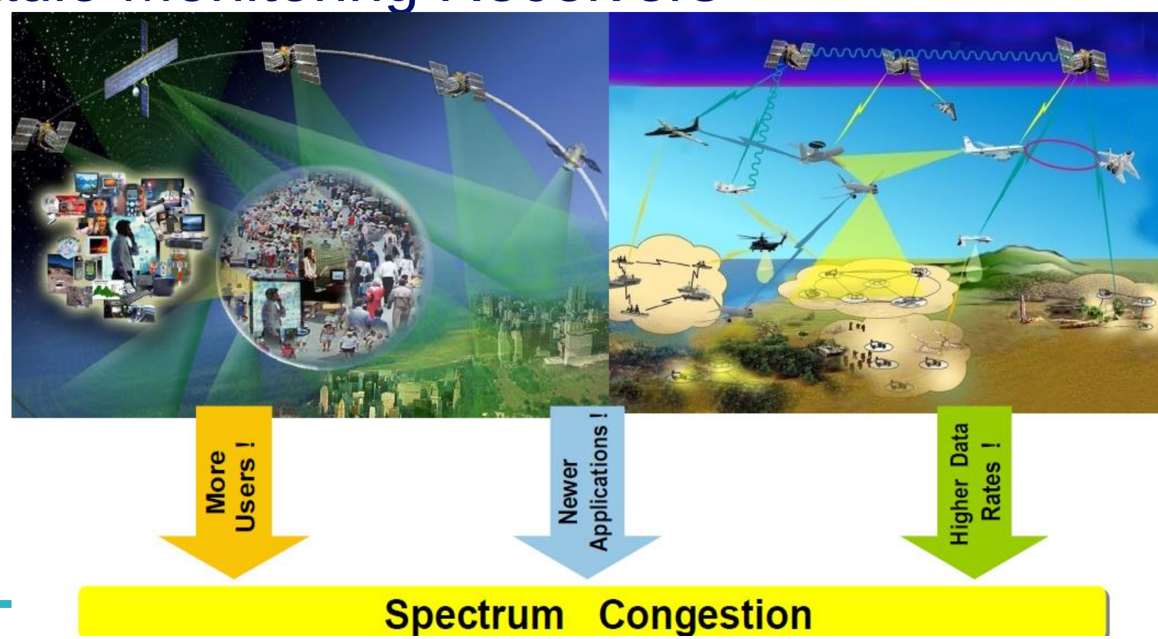
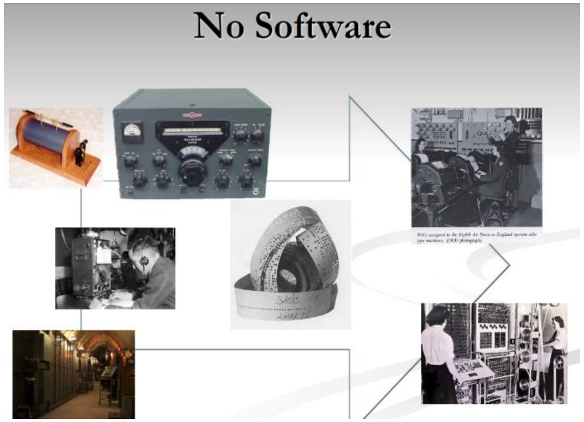
Outline

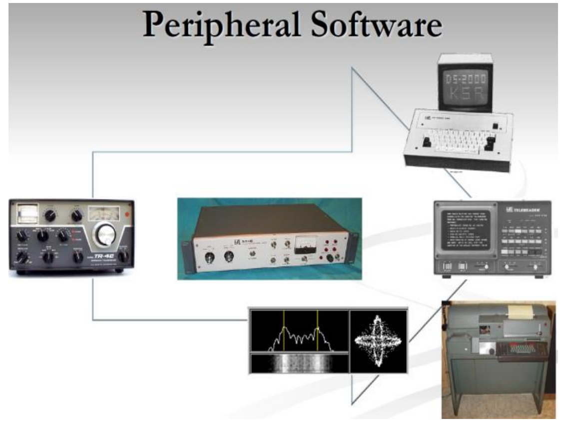
- Radio Communication
- Radio Communication Standards
- Software Radio Classifications
- Software Defined Radio (SDR)
- Cognitive Radio
- 5G (5th Generation) Cellular Network
- Next Generation Radio Monitoring Receivers
- Conclusion

High Performance Radio Needed Everywhere !



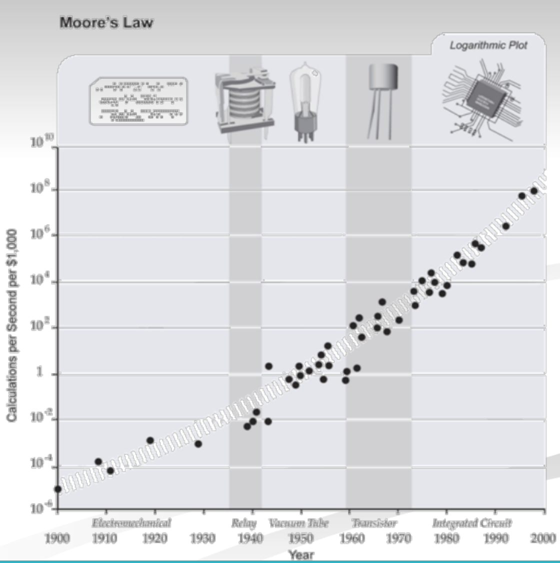
Radio Follow Moore's Law



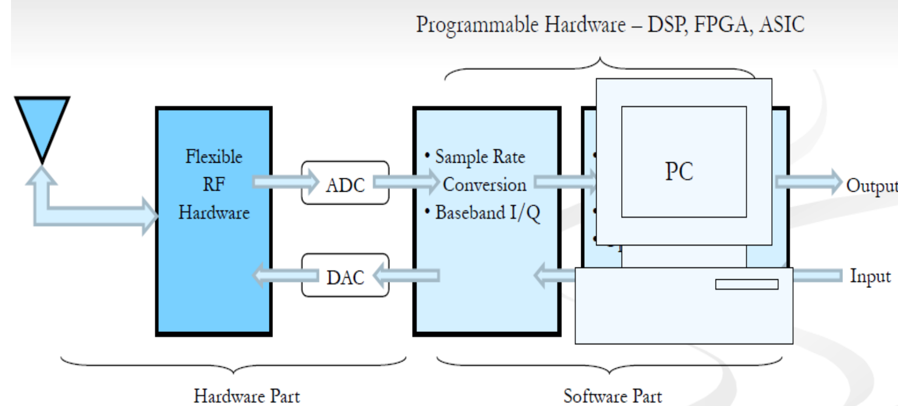


Radio Follows Moore's Law Too

- First 50 Years
  - Electro Mechanical
  - Vacuum Tube
- Second 50
  - Transistor
  - IC
- Next… ?



SDR Architecture



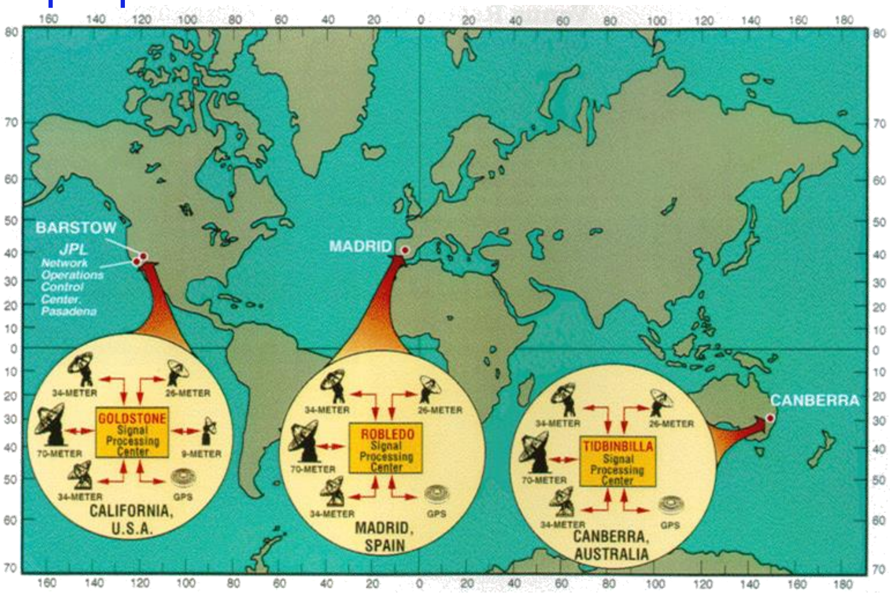
Why SDR ?

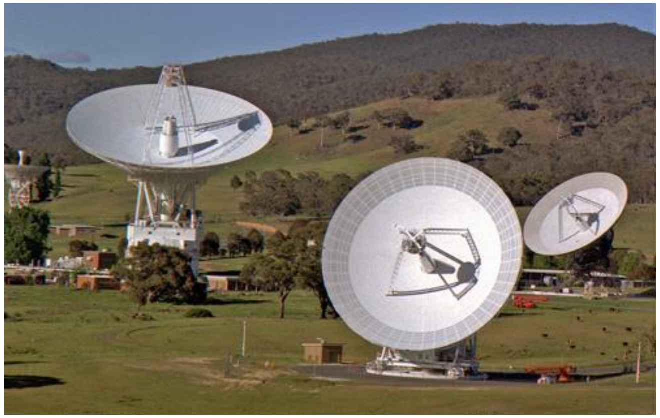
First-Responder Communications Failures

- SDR will facilitate radio interoperability

Why SDR?

Deep Space Communications

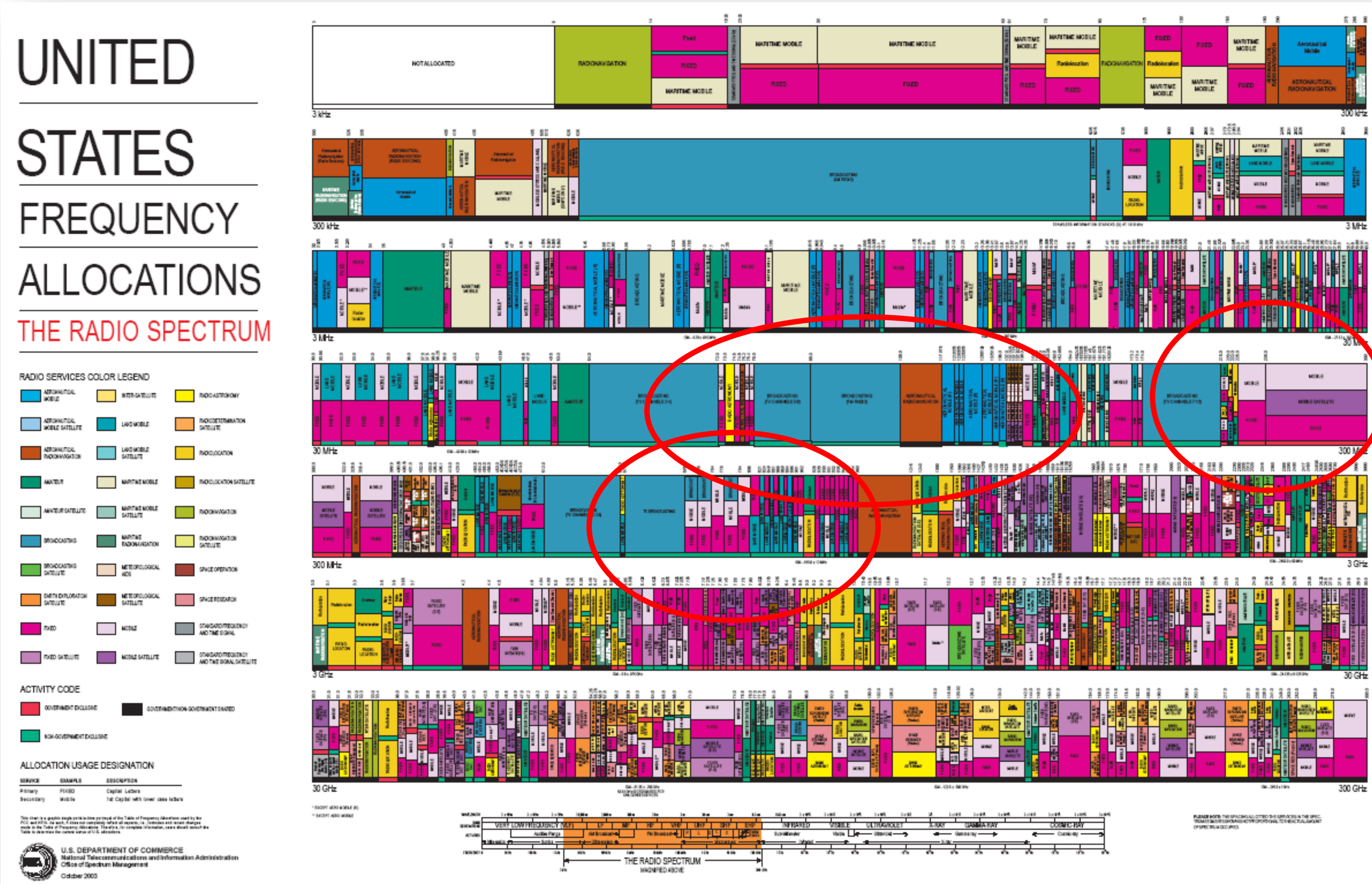




- SDR allows old and new protocols

Why SDR?

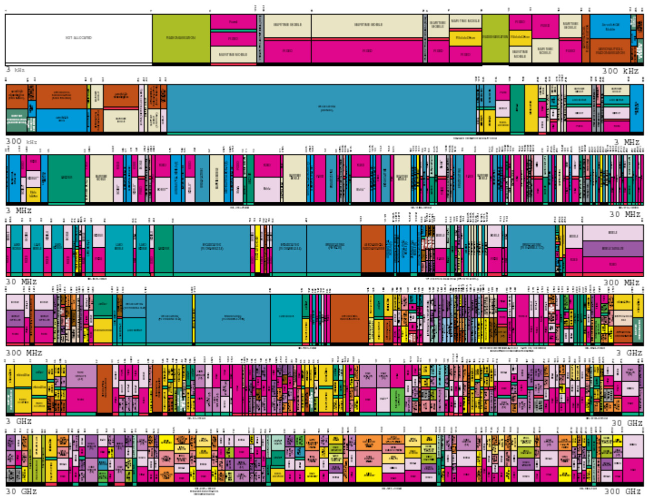
Spectrum space as a scarce resource



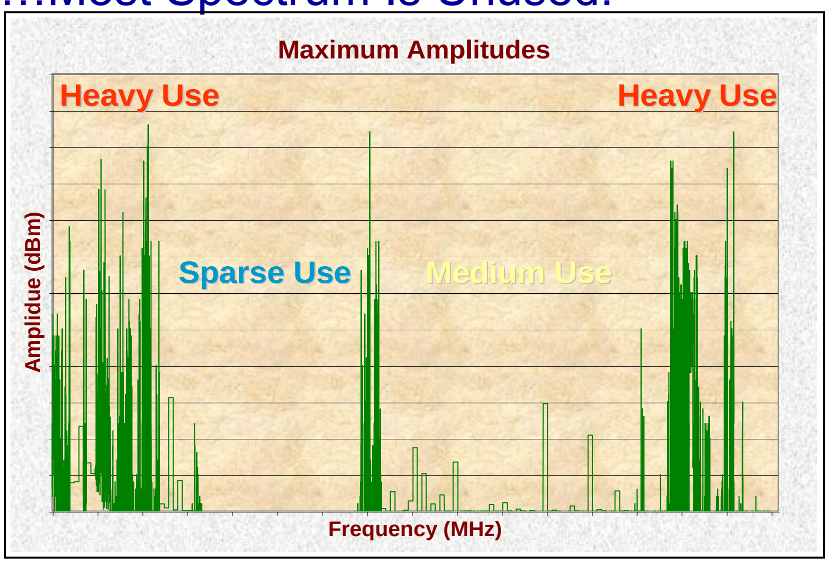
- SDR will enable spectrum reuse

SDR will Dynamically Access Available Spectrum

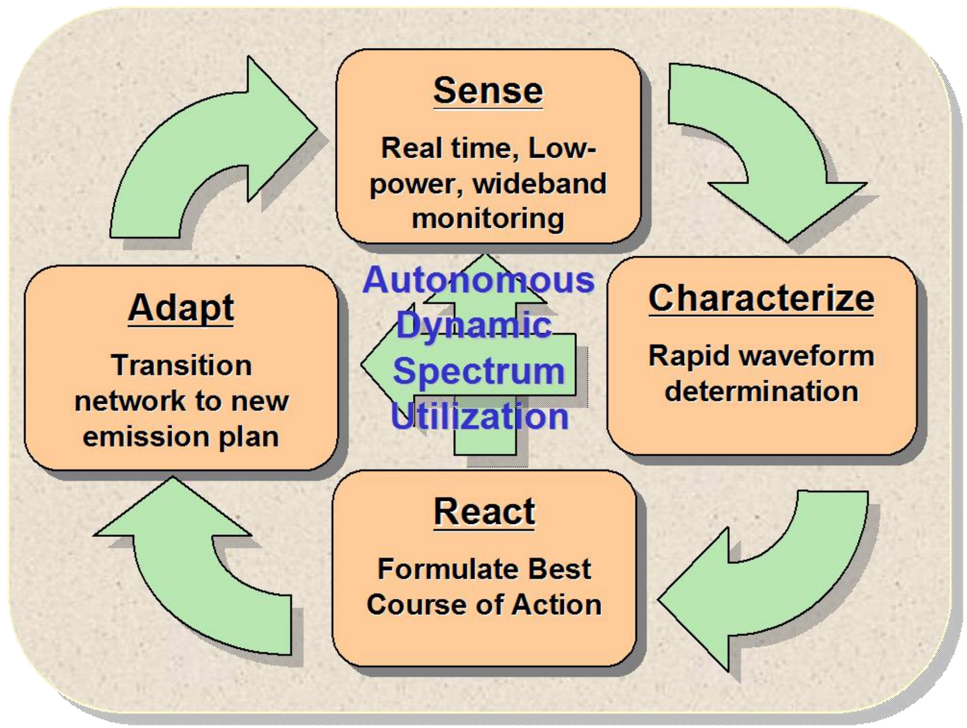
All Spectrum May Be Assigned, But…



…Most Spectrum Is Unused!



Next Generation Radios: Enable Technology and System Concepts for Dynamically Access Available Spectrum



Goal: 10 Folds increase in spectrum access

SDR (Software Defined Radio)

- Definition:

  A Software Defined Radio (SDR) is a communicaton system, where the major part of signal processing components, typically realized in hardware are instead replaced by digital algorithms, written in software (FPGA).

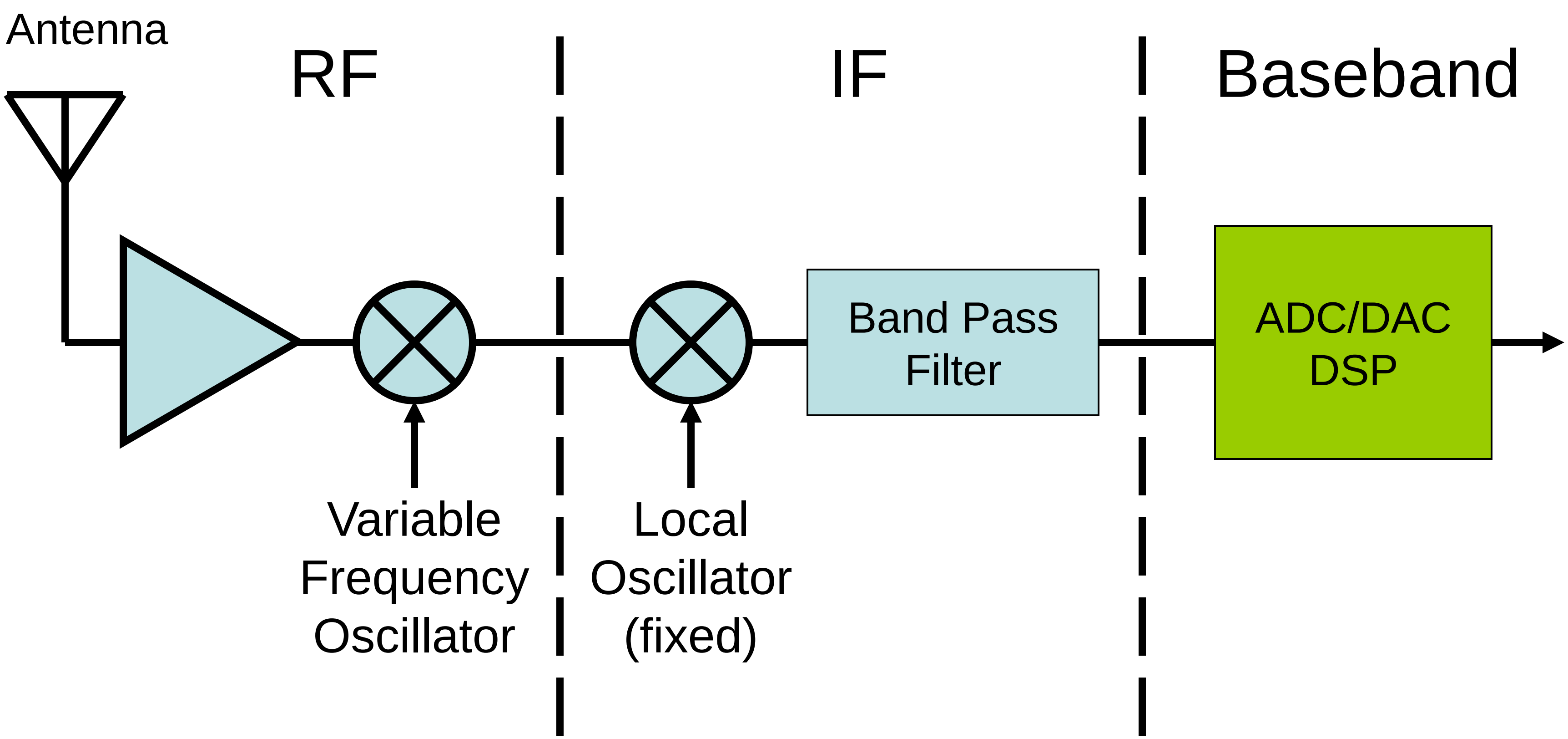
SDR

- Want to make all parameters digitally tunable
  - What Parameters?
    - **RX/TX Frequency**
    - **Bandwidth**
    - **Impedance Match**

- First Reported Publication (February 26-28, 1985):

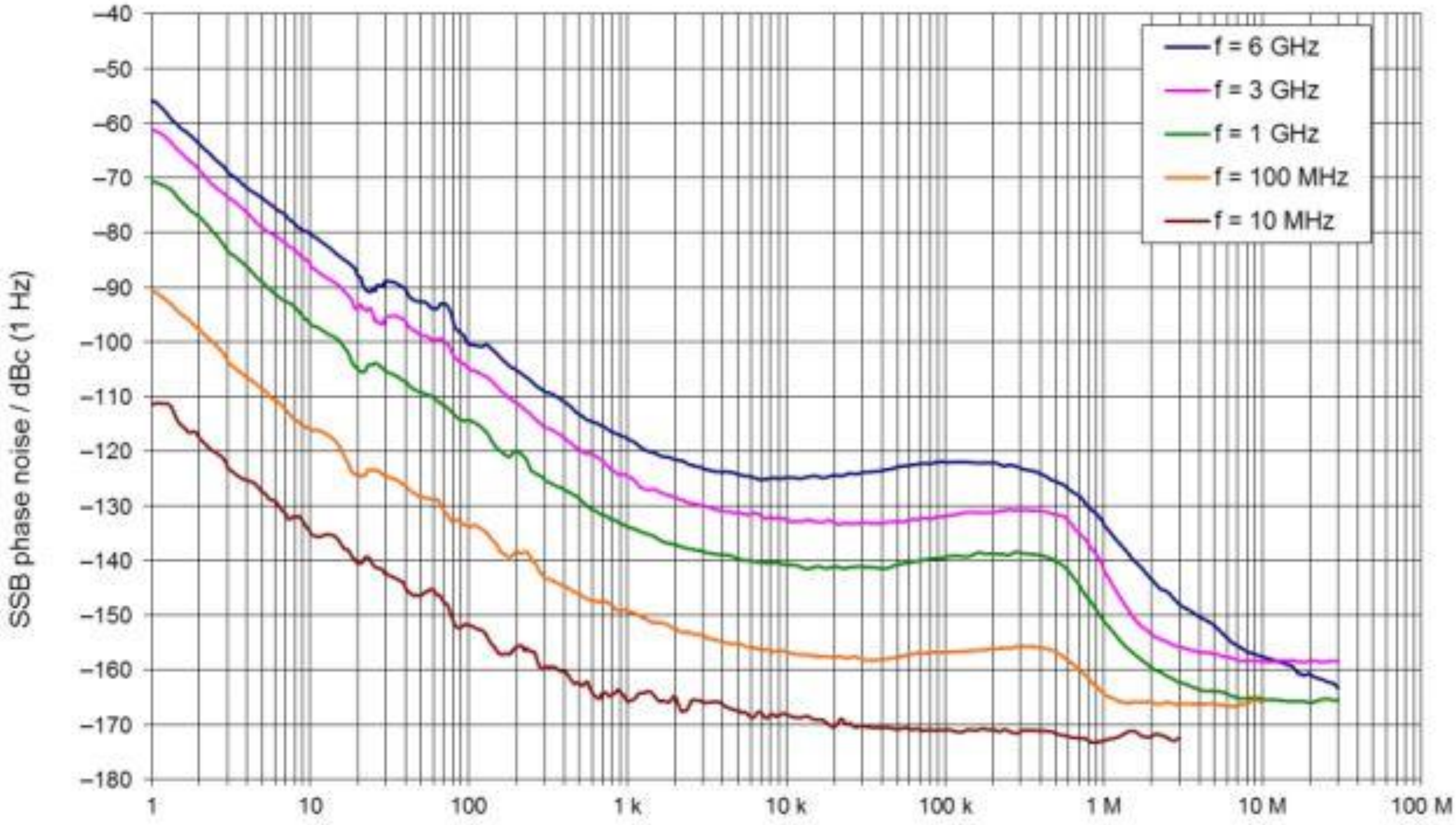
  Ulrich L. Rohde, Digital HF Radio: "A Sampling of Techniques, presented at the Third International Conference on HF Communication Systems and Techniques", London, England, February 26-28, 1985, Classified Session (U.S Secret).
  http://en.wikipedia.org/wiki/Software-defined_radio

Block Diagram: Software Defined Radio



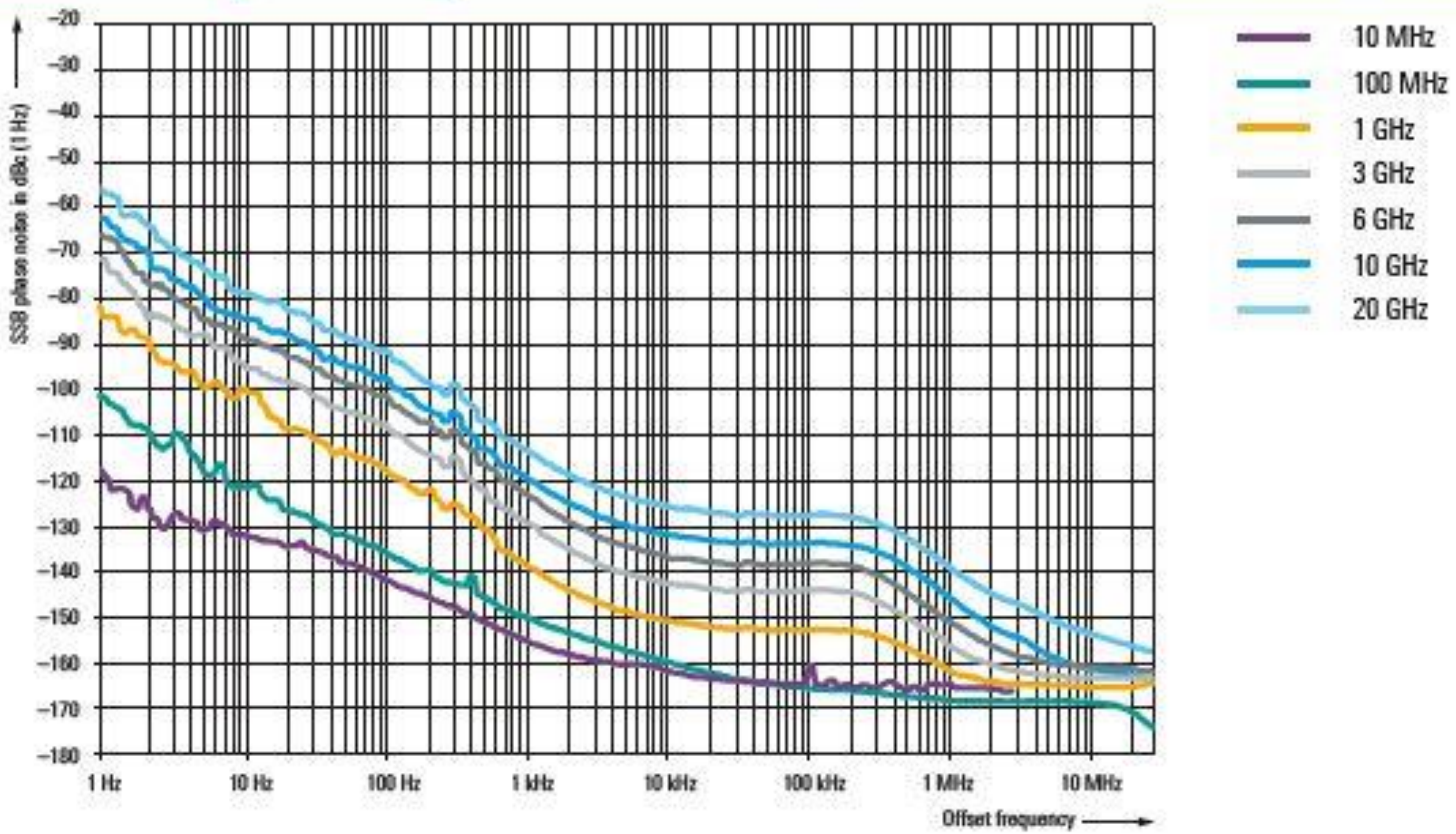
Oscillator Phase Noise - 1

Measured SSB phase noise with internal reference oscillator (standard instrument).



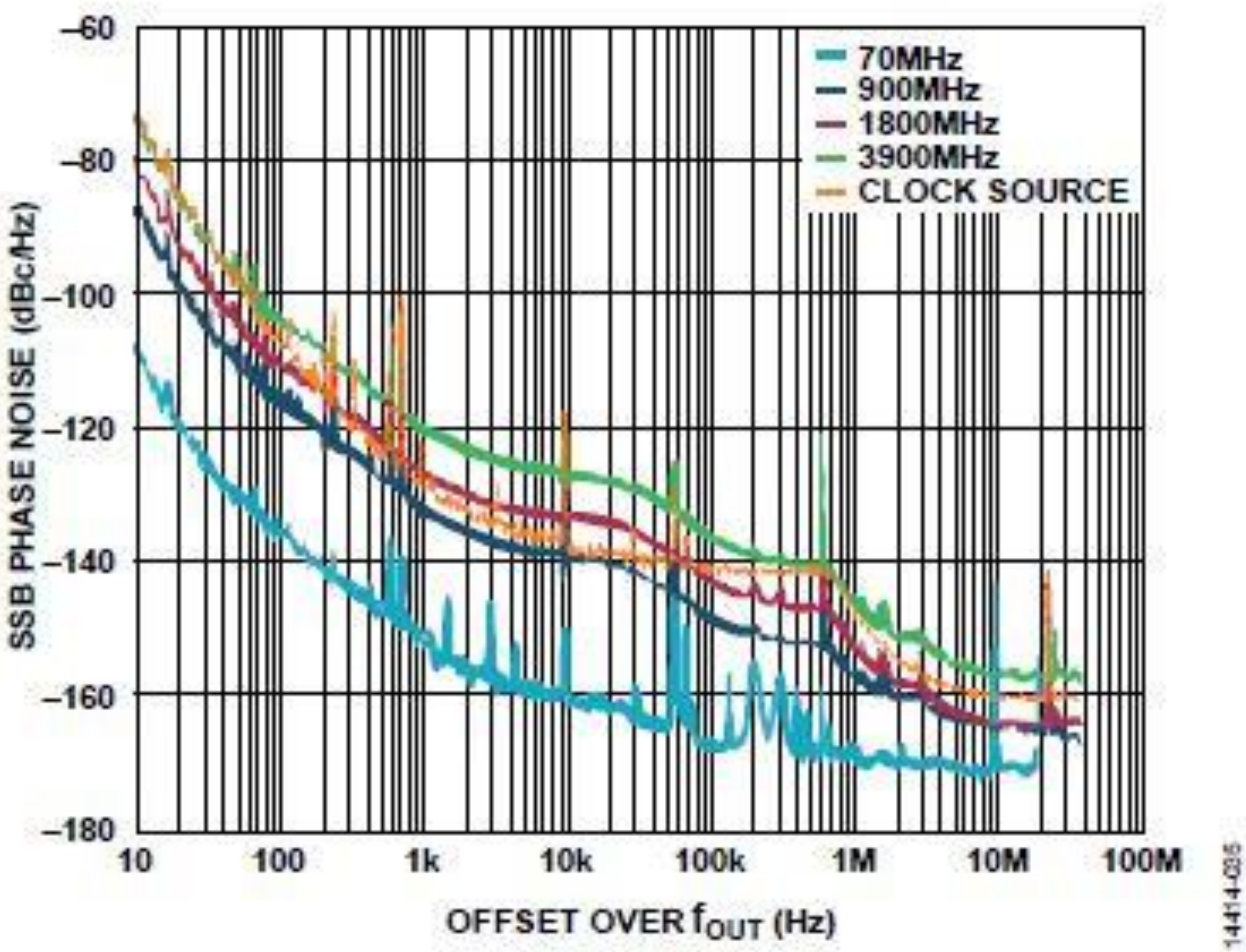
Oscillator Phase Noise - 2

Measured SSB phase noise performance of the R&S®SMA100B with R&S®SMAB-B711 option

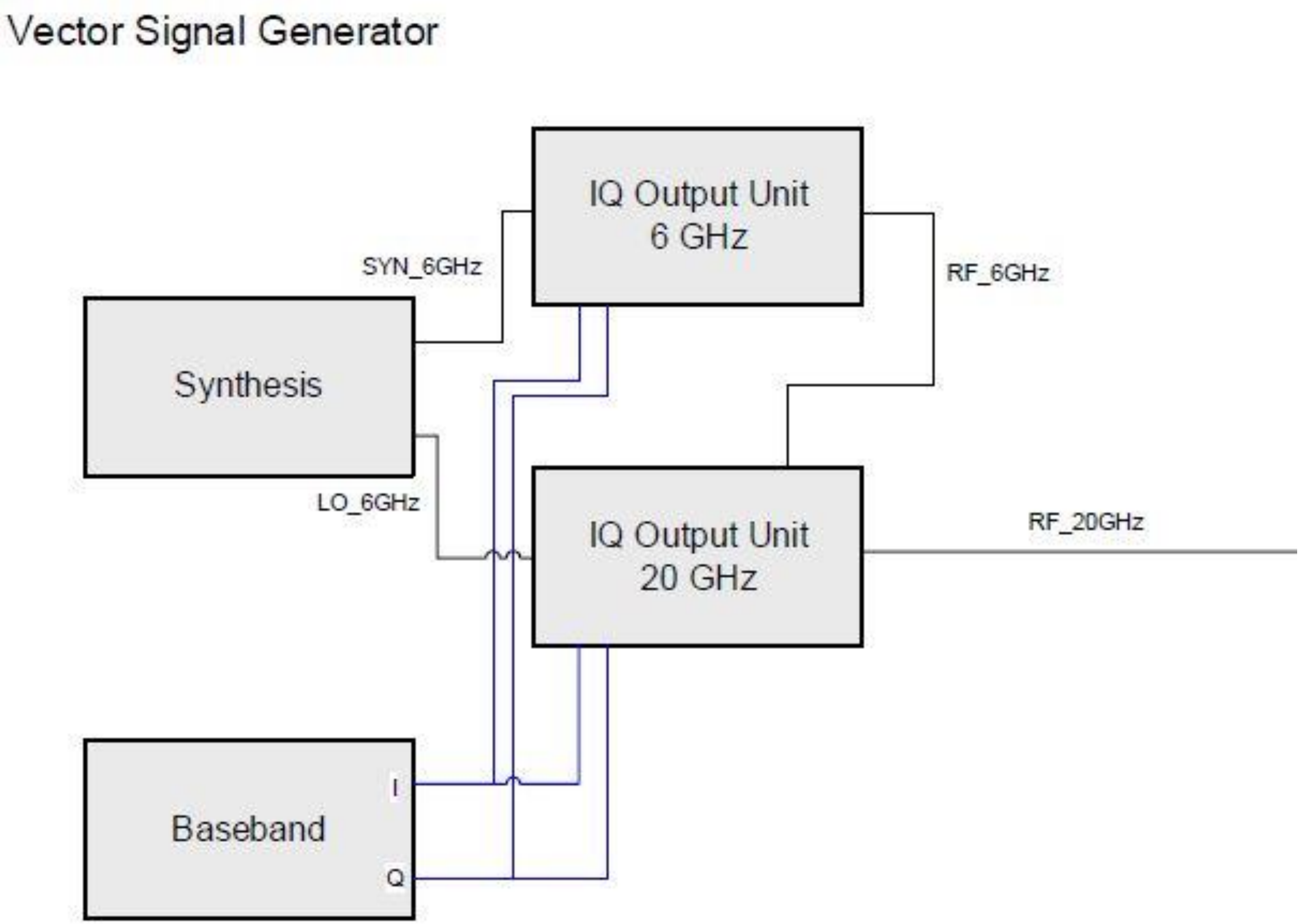


Oscillator Phase Noise – 3

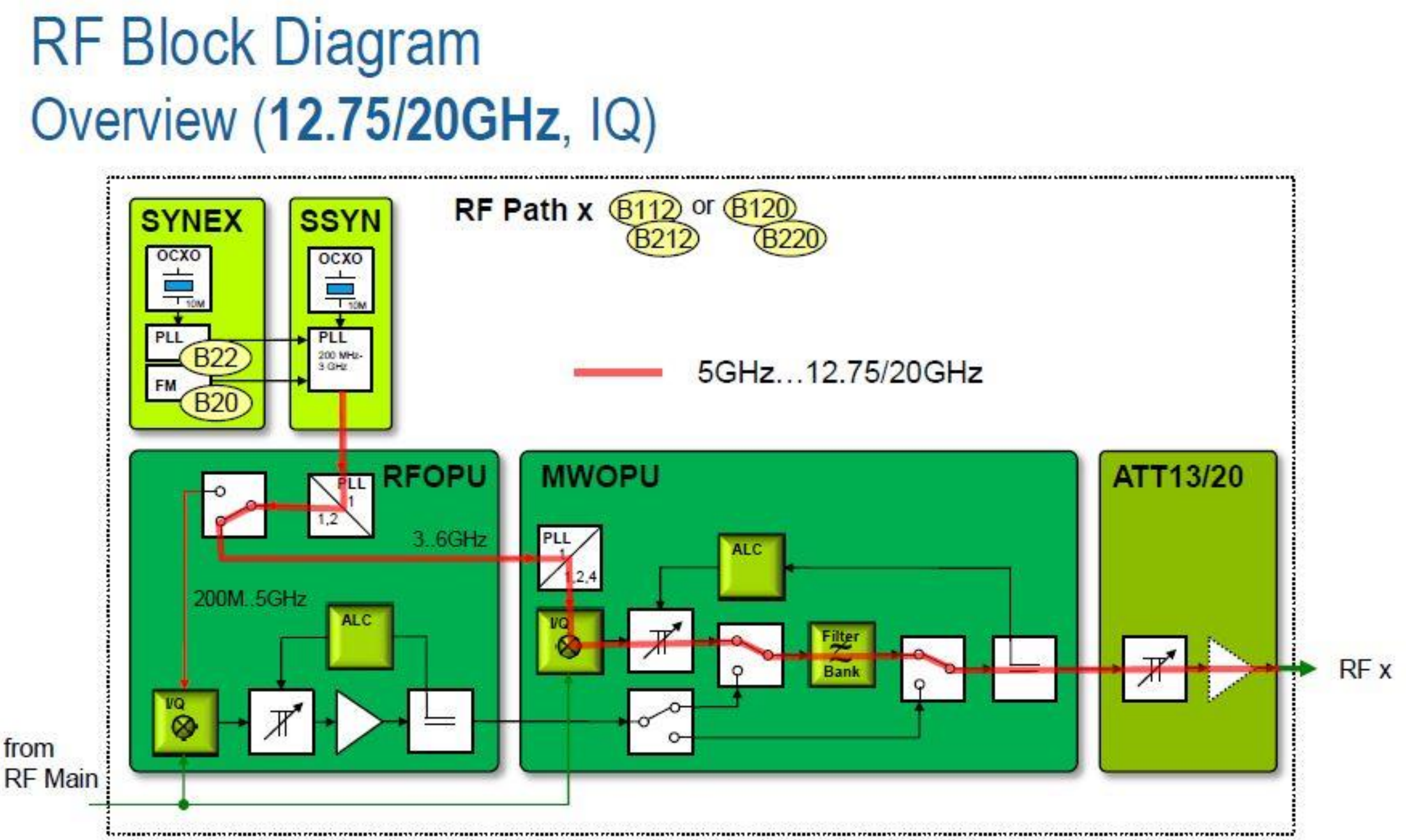
IC -PLL



Frequency Generation

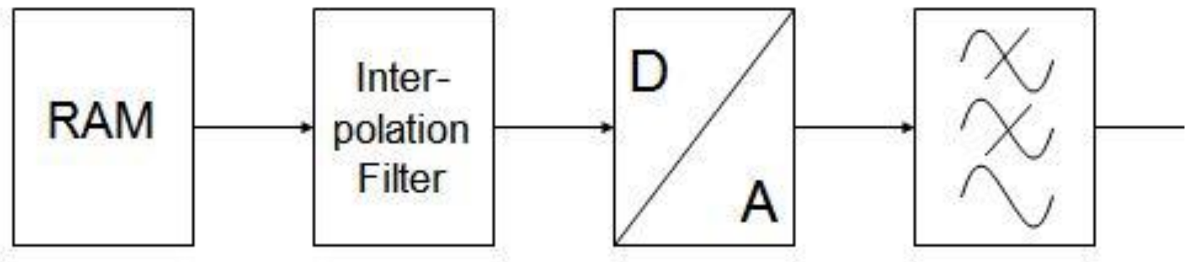


Frequency Generation



Numerically Controlled Oscillator NCO

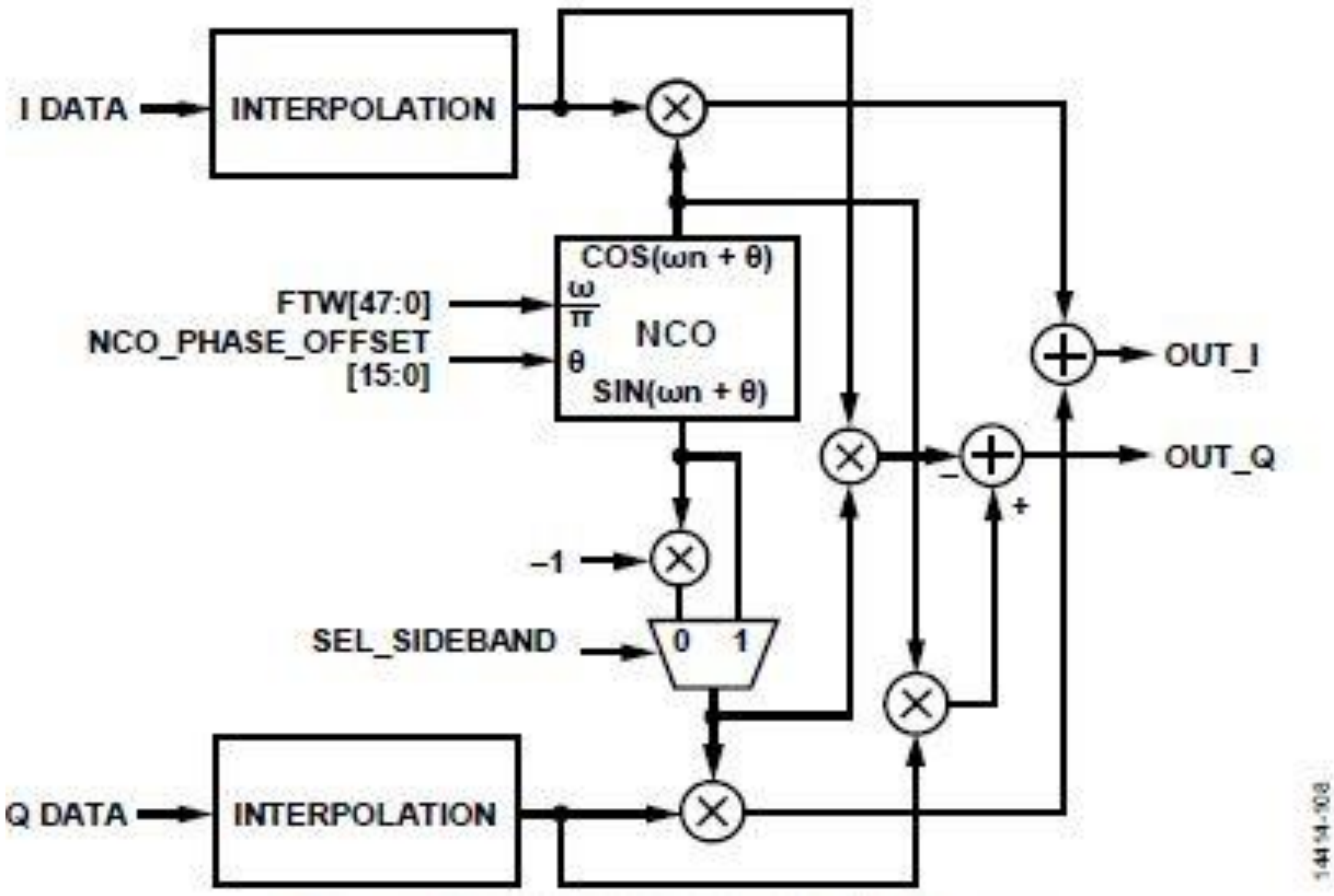
Modern ARB



- A modern ARB substantially consists of
  - Output memory
  - **Interpolation filter**
  - D/A-converter
  - Analog low pass filter

NCO Block Diagram

48 Bits Resolution



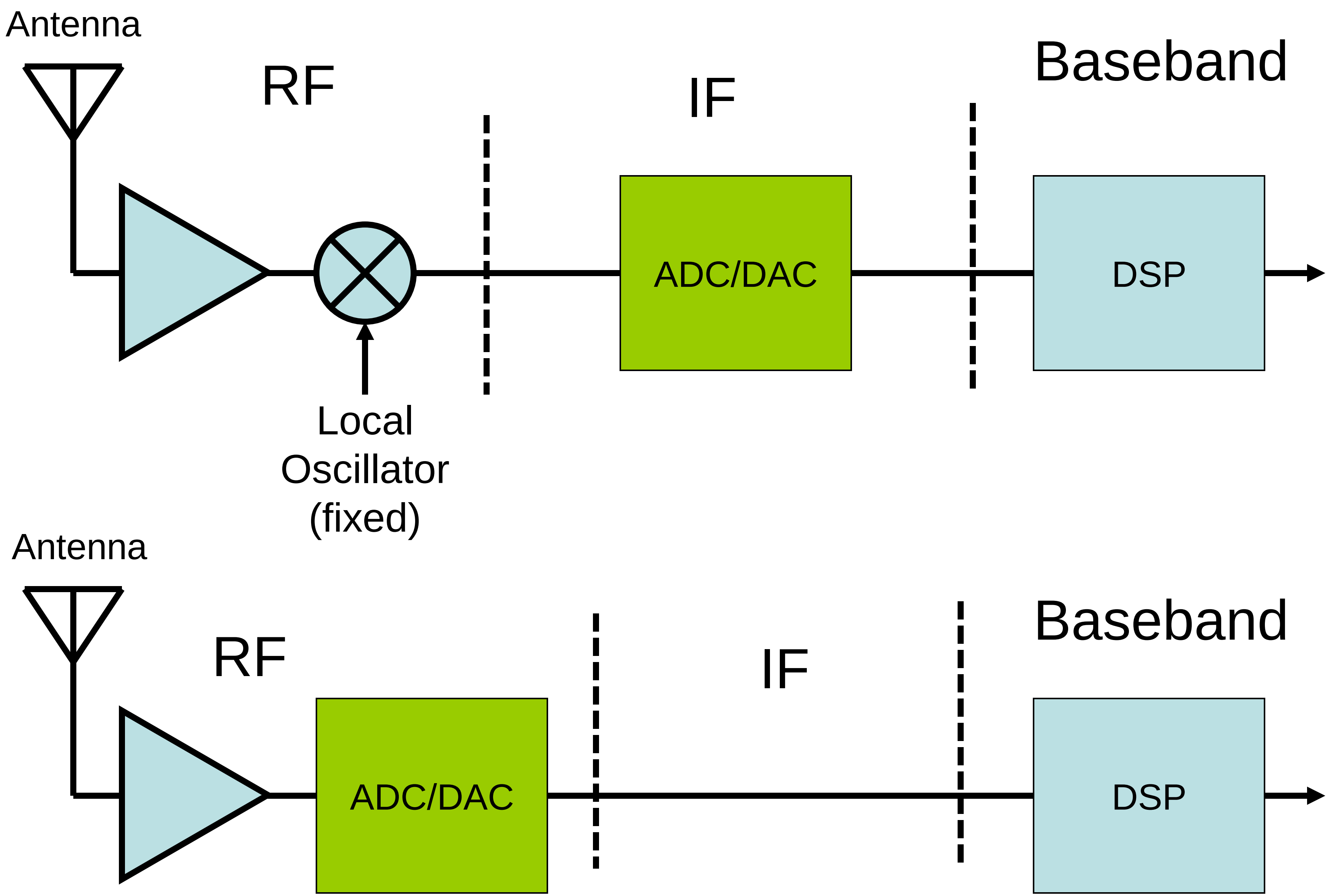
Main NCO Frequency Hopping

- In the main 48-bit NCO, the mode of updating the frequency tuning word can be changed from requiring a write to the FTW _LOAD_REQ bit (Register Ox113, Bit 0) to an automatic update mode.
- In the automatic update mode, the FTW is updated as soon as the chosen FTW word is written.
- To set the automatic FTW update mode, write the appropriate word to the FTW REQ_MODE bits (Register Ox113, Bits[6:4]}, choosing the particular FTW word that causes the automatic update.
  - For example, if relatively coarse frequency steps are needed, it may be sufficient to write a single word to the MSB byte of the FTW, and therefore the FTW _REQ_MODE bits can be programmed to 110 (Register Ox113, Bits[6:4] = Ob 110).
- Then, each time the most significant byte, FTW5, is written, the NCO FTW is automatically updated.
- The FTW _REQ_MODE bits can be configured to use any of the FTW words as the automatic update trigger word.
- This configuration provides convenience when choosing the order in which to program the FTW registers.

48-Bit Dual Modulus NCO

- This modulation mode uses an NCO, a phase shifter, and a complex modulator to modulate the signal by a programmable carrier signal as shown in the Figure. This configuration allows output signals to be placed anywhere in the output spectrum with very fine frequency resolution.
- The NCO produces a quadrature carrier to translate the input signal to a new center frequency.
- A quadrature carrier is a pair of sinusoidal waveforms of the same frequency, offset 90° from each other.
- The frequency of the quadrature carrier is set via a FTW: The quadrature carrier is mixed with the I and Q data and then summed into the I and Q datapaths, as shown in Figure.
- **Integer NCO Mode** The main 48-bit NCO can be used as an integer NCO by using the following formula to create the frequency tuning word (FTW):
  $f_{DAC}/2 \leq f_{CARRIER} < +f_{DAC}/2$
  FTW =$(f_{CARRIER}/f_{DAC}) \times 2^{48}$ where *FTW* is a 48-bit, twos complement number.
- When in 2xNRZ mode (FIR85 enabled with Register Ox111, Bit 0 = 1), the frequency tuning word is calculated as 0 $\leq f_{CARRIER} < f_{DAC}$ and FTW =$(f_{CARRIER}/f_{DAC}) \times 2^{48}$ where *FTW* is a 48-bit binary number.

Block Diagram: Software Defined Radio



Advantages of Software Defined Radio

- Ease of design
  - Reduces design-cycle time, quicker iterations
- Ease of manufacture
  - Digital hardware reduces costs associated with manufacturing and testing radios
- Multimode operation
  - SR can change modes by loading appropriate software into memory
- Use of advanced signal processing techniques
  - Allows implementation of new receiver structures and signal processing techniques
- Fewer discrete components
  - Digital processors can implement functions such as synchronization, demodulation, error correction, decryption, etc.
- Flexibility to incorporate additional functionality
  - Can be modified in the field to correct problems and to upgrade

Benefits of Software Defined Radio

- Flexible/reconfigurable
  - Reprogrammable units and infrastructure
- Reduced obsolescence
  - Multiband/multimode
- Ubiquitous connectivity
  - Different standards can co-exist
- Enhances/facilitates experimentation
- Brings analog and digital worlds together
  - Full convergence of digital networks and radio science
  - Networkable
  - Simultaneous voice, data, and video

Technologies that facilitate SDR systems

- Antennas
- Waveforms
- Analog-to-Digital Converters (ADCs, DACs)
- Digital Signal Processing
- Amplifiers
- Batteries
- Cognition, behaviors
- Design tools

Technologies that enable SDR

- **Antennas**
  - Receive antennas are easier to achieve wide-band performance than transmit ones
  - New fractal & plasma antennas expected in smaller size and wideband capability
- **Waveforms**
  - Management and selection of multiple waveforms
  - Cancellation carriers and pulse shaping techniques
- **Analog-to-digital converters**
  - High ADC sampling speed
  - ADC bandwidth could be digitized instantaneously
- **Digital signal processing/FPGAs**
  - Number of transistors doubles every 18 months
  - More specific purpose DSPs and FPGAs
- **Batteries**
  - More and more power needed (need to focus on more efficient use of power)
  - Fuel cell development for handhelds
- **Terrain databases**
  - Interference prediction, environment awareness
- **Cognitive science**
  - A key aspect will be to understand how multiple CRs work with each other

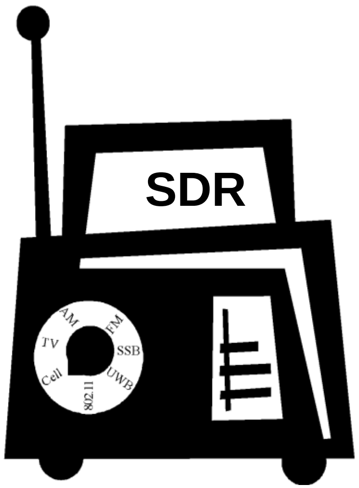
Radio Communication Standard

Problem !

- Myriad of standards exist for terrestrial communications
- Cell phone communication standards change every few years
- Satellite ground station would like to listen to multiple spacecrafts, some launched in the 1970s
- Spectrum space is a precious resource
  - Each frequency is "owned"
  - How do we deal with new technologies like ultra wide band (UWB)?

Solution: SDR (Software Defined Radio)

- Flexible radio systems that allow communication standards to migrate
- Flexible methods for reconfiguring a radio in software
- Flexible, intelligent systems that communicate via different protocols at different times

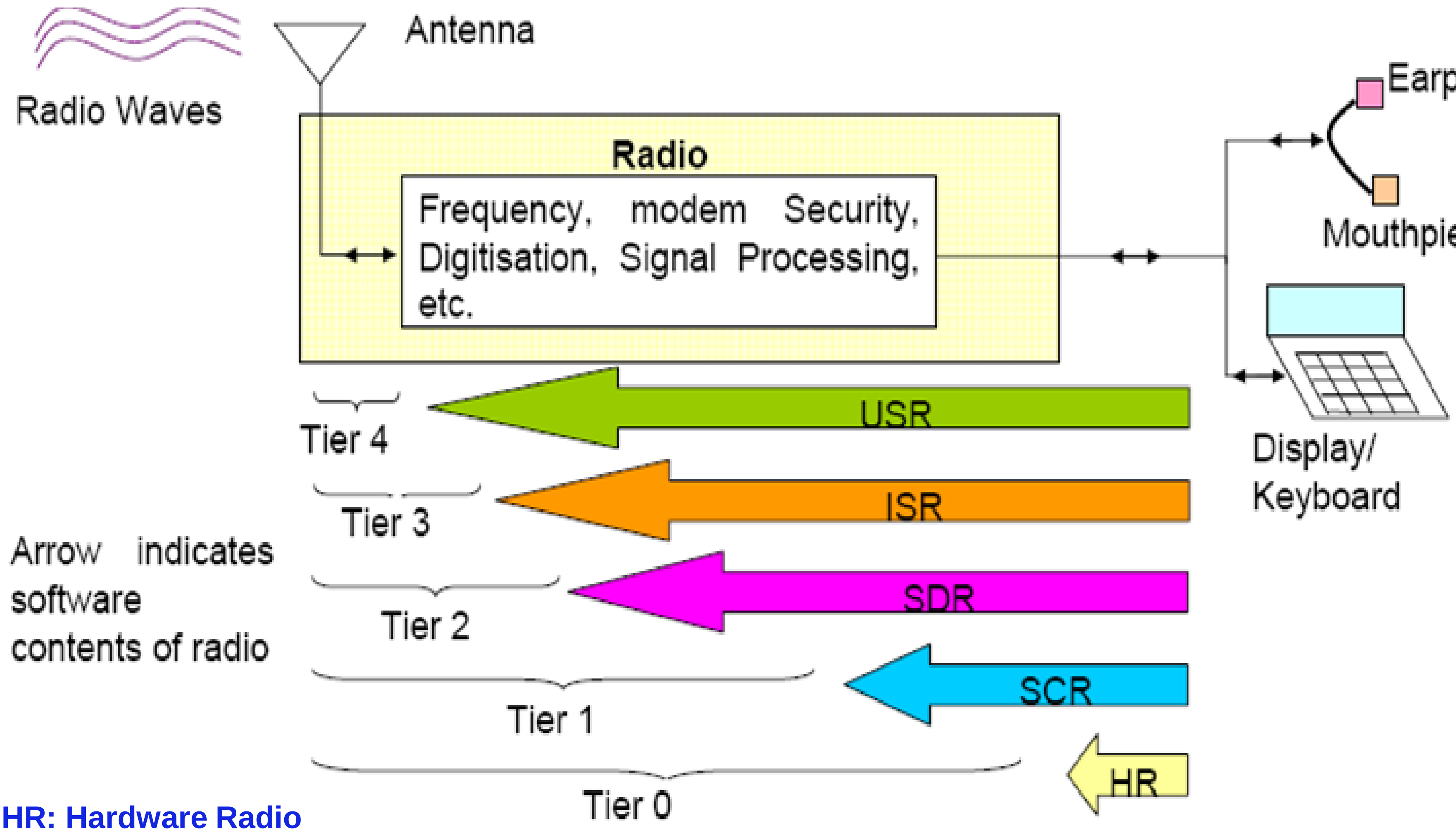


Emerging Trend: Cognitive Radio Solution

Software Radio Classification

- **Tier 0: Hardware Radio (HR)**
  - No changes to system can by done by software
- **Tier 1: Software-Controlled Radio (SCR)**
  - Control functionality implemented in software, but change of attributes such as modulation and frequency band cannot be done without changing hardware
- **Tier 2: Software-Defined Radio (SDR)**
  - Capable of covering substantial frequency range and of executing software to provide variety of modulation techniques, wide-band or narrow-band operation, communication security functions & meet waveform performance requirements of relevant legacy systems
  - Capable of storing large number of waveforms or air interfaces, and of adding new ones by software download
  - System software should be capable of applying new or replacement modules for added functionality or bug fixes without reloading entire set of software
  - Separate antenna system followed by some wideband filtering, amplification, and down conversion prior to receive A/D-conversion
  - The transmission chain provides reverse function of D/A-conversion, analog up-conversion, filtering and amplification
- **Tier 3: Ideal Software Radio (ISR)**
  - All capabilities of software defined radio, but eliminates analog amplification and heterodyne mixing prior to A/D-conversion and after D/A conversion
- **Tier 4: Ultimate Software Radio (USR)**
  - Ideal software radio in a chip, requires no external antenna and has no restrictions on operating frequency
  - Can perform a wide range of adaptive services for user
  - Intended for comparison purposes rather than implementation

Future: Shift from Tier 0 to 4

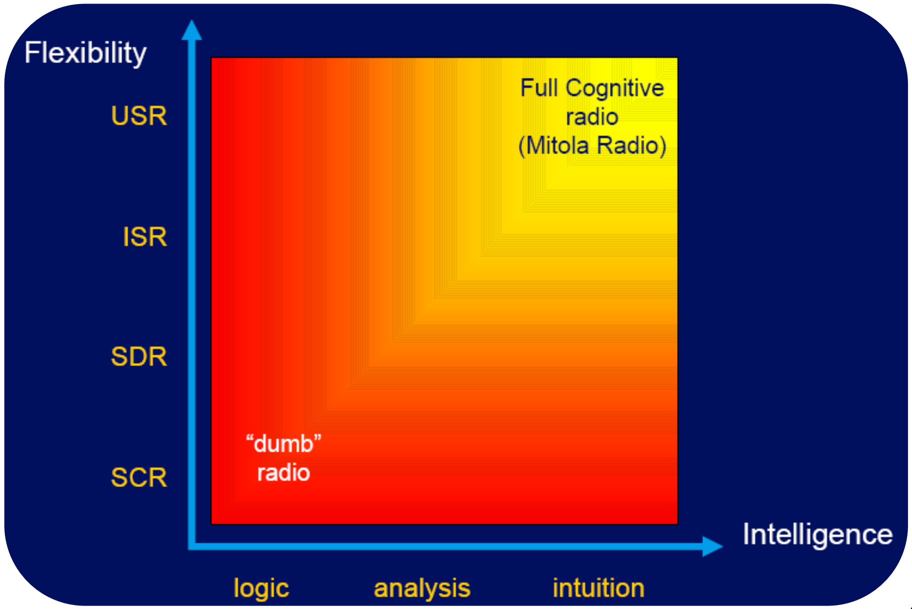


HR: Hardware Radio
CR: Software-Controlled Radio
SDR: Software-Defined Radio
ISR: Ideal Software Radio
USR: Ultimate Software Radio

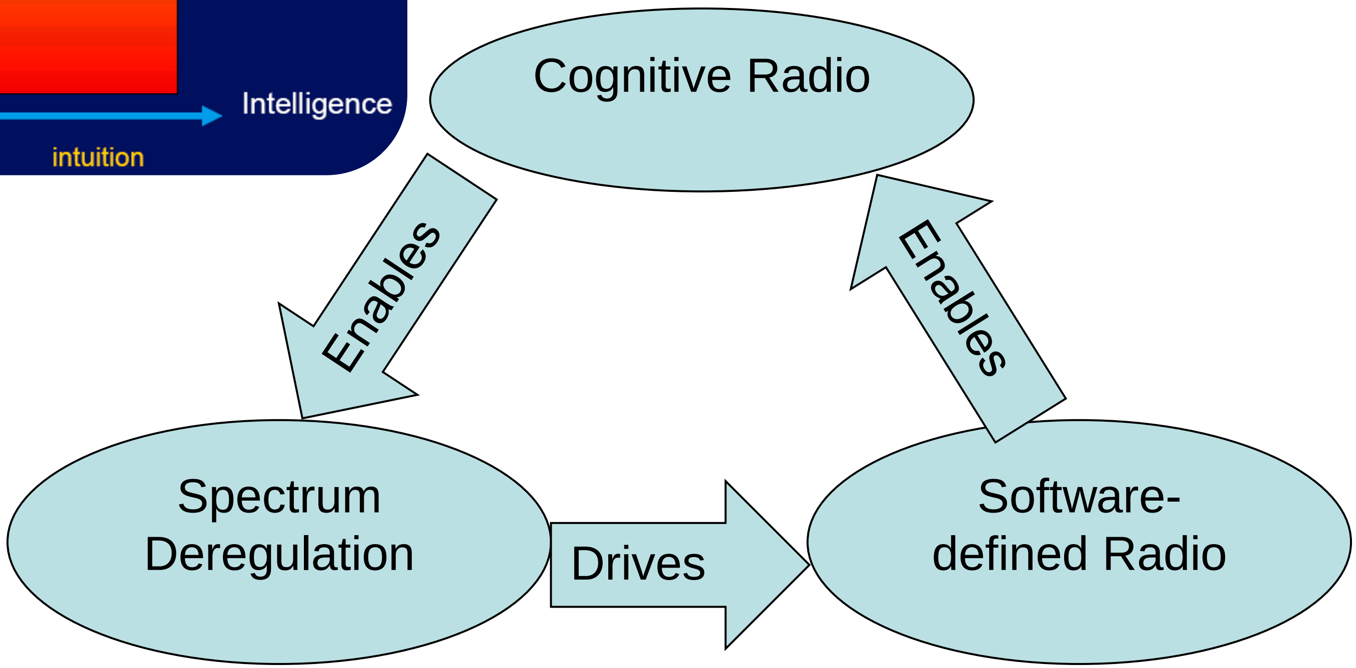
Future: Shift from Tier 0 to 4

Evolution of Cognitive Radio

Cognitive radio: flexibility and intelligence

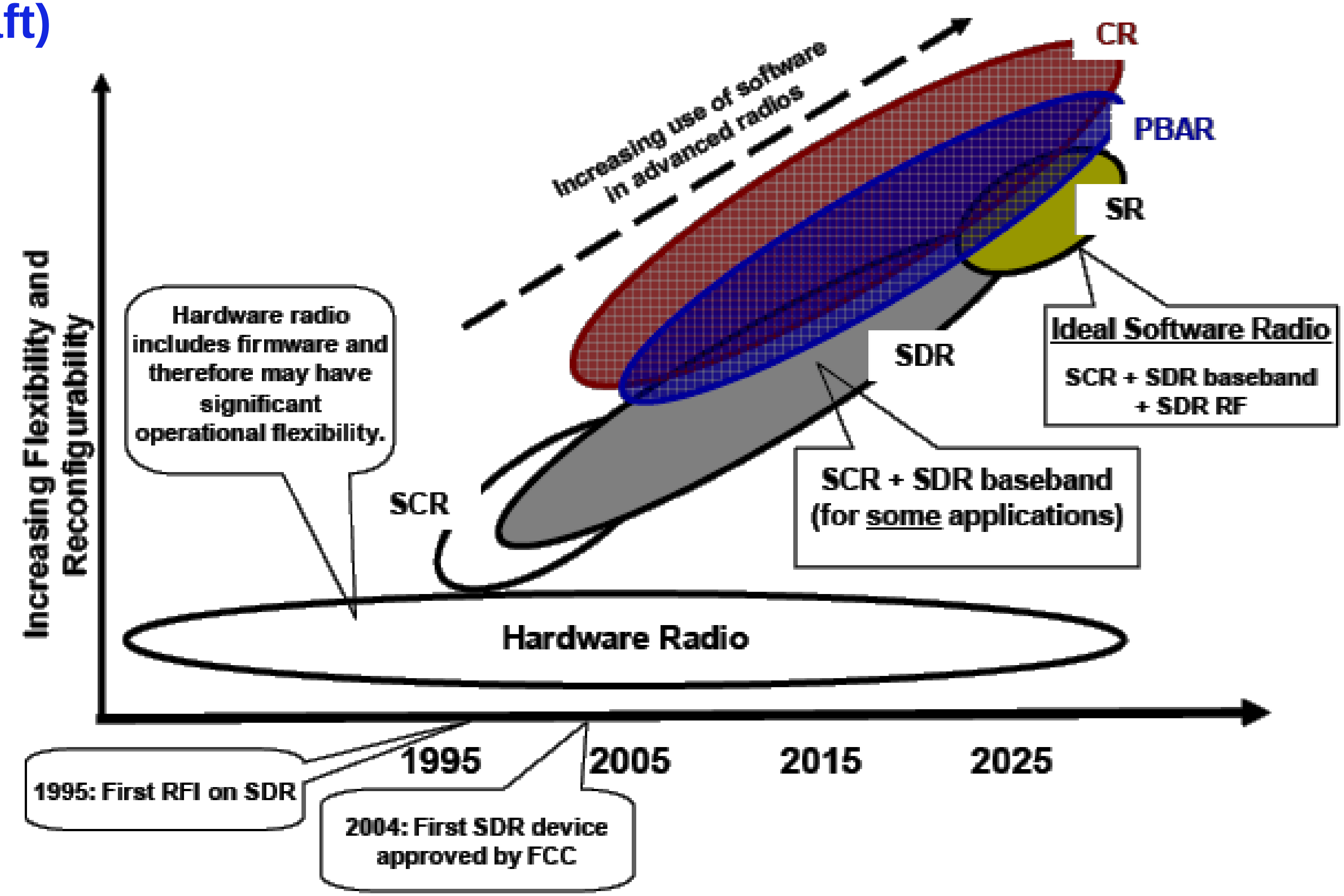


- **Full Cognitive Radio**: every possible radio parameter is taken into account to make spectrum decision
- **Spectrum Sensing Cognitive Radio**: only radio frequency (RF) spectrum is observed and used in decision making
- **Licensed Band Cognitive Radio**: device is capable of using licensed spectrum in addition to unassigned spectrum
- **Unassigned Band Cognitive Radio**: device is only allowed to use unassigned and/or license exempt spectrum



Standards Drive Development

(IEEE - Draft)



Note: SDR currently is practical for some applications such as commercial wireless basestations, but not for some wireless handsets. *Cost, power, size and weight* are critical design requirements that must be considered when considering the use of advanced radio technologies.

CR – Cognitive Radio
RFI – Request for Information
SDR – Software Defined Radio
PBAR – Policy-Based Adaptive Radio
SCR – Software Controlled Radio
SR – Software Radio

Radio Monitoring Receivers

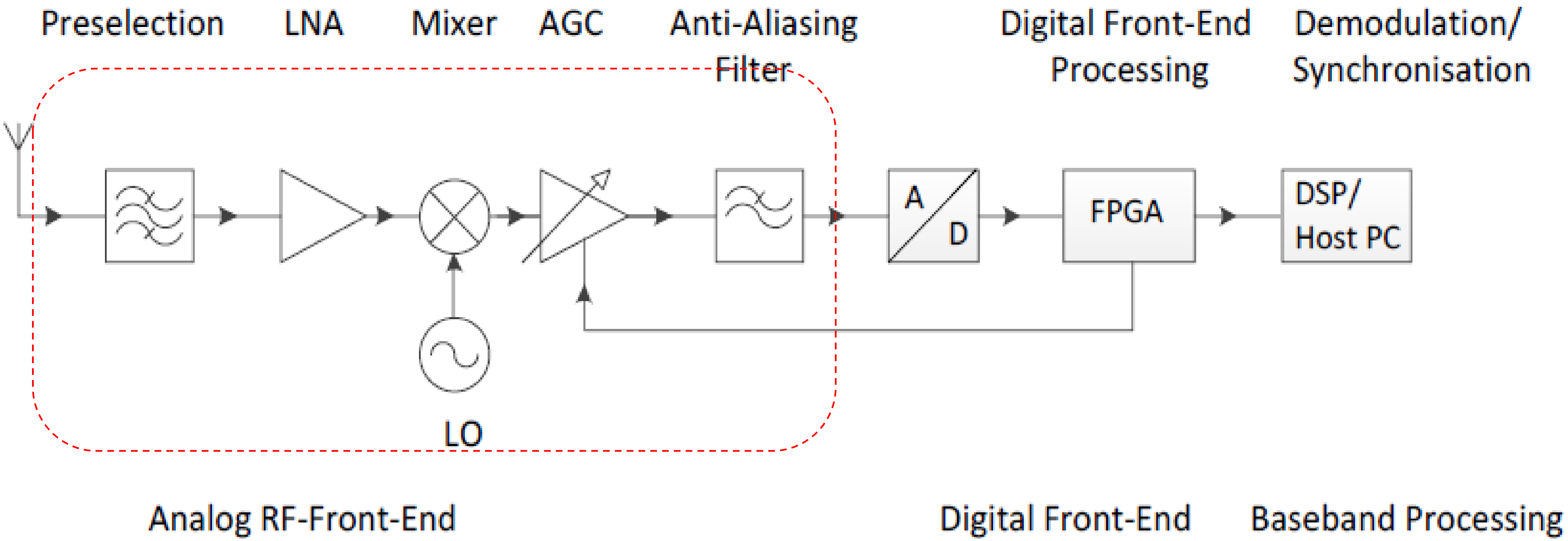
High Dynmaic Range Microwave Monitoring Receivers

- Searching for faults in professional radio networks
- Comprehensive spectrum analysis
- Monitoring of user-specific radio services
- Monitoring on behalf of regulating authorities
- Handoff receivers, i.e. **parallel demodulation** of narrowband signals and simultaneous broadband spectrum scanning=High Dynamic Range
- Critical Parameters: Noise Figure, IP2, IP3, and instantaneous dynamic range

Best solution: → Software Defined Radio

Typical Microwave Receiver

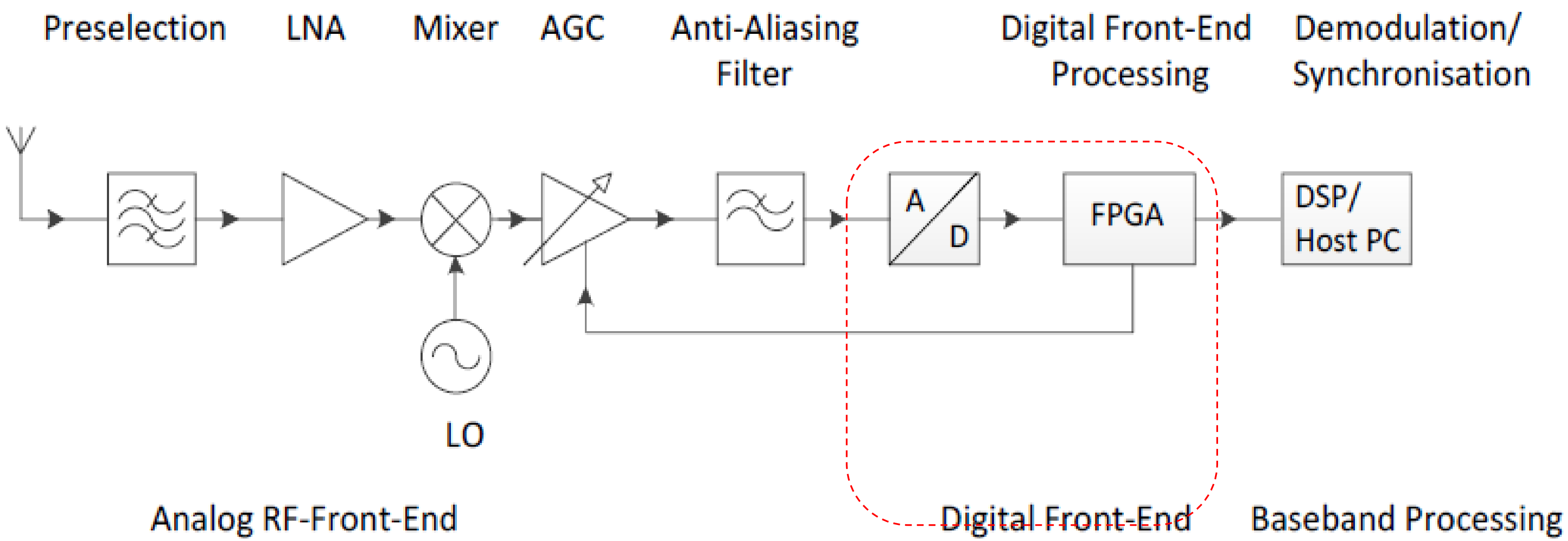
Principal Arrangment for Typical Microwave Receivers



The analog front end is downconverting the RF signals into an IF range <200MHz

Microwave Receiver, Cont‘d.

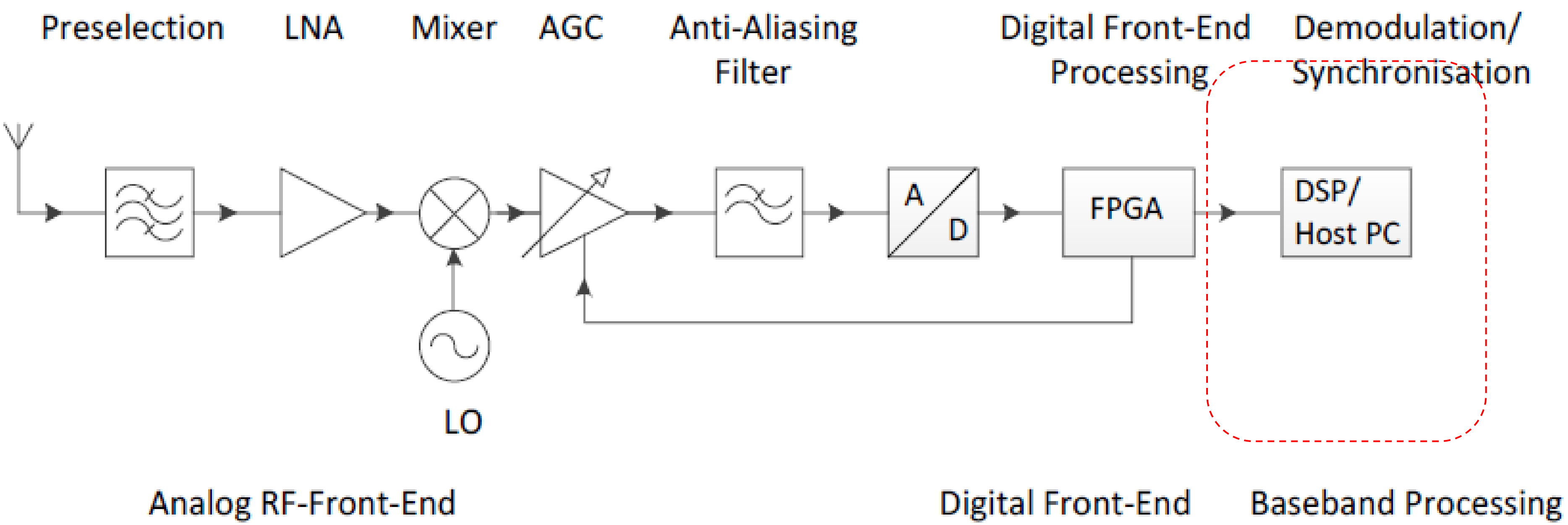
Principal Arrangment for Typical Microwave Receivers



The digital front end consists of an Analog to Digital converter and a digital down-converter to reduce the sample rate down to the bandwidth needed by the application. Sampling rate of AD converters are rising up to 250Msps with resolutions of 14 or 16 bits.

Microwave Receiver, Cont‘d.

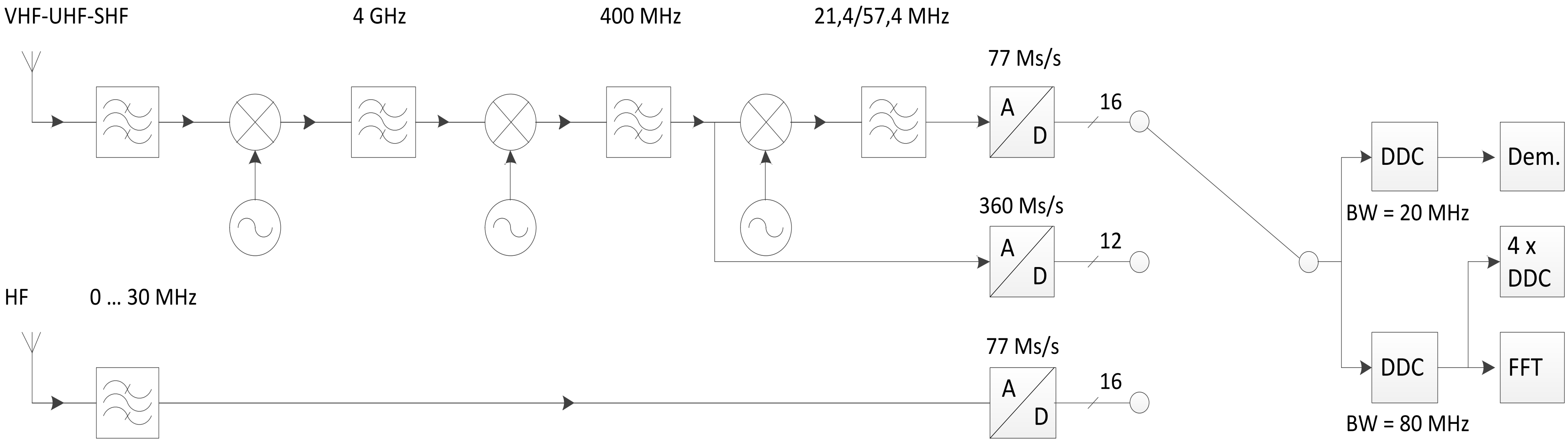
Principal Arrangment for Typical Microwave Receivers



The baseband processing takes over the base band filtering, AGC, demodulation, and the signal regeneration...

Typical Analog Front End

Possible Drawbacks on the Analog Front End



- **Wide band microwave receivers need tripple conversion to prevent image reception**
- **Several expensive and switchable filters are required for pre- and IF-selection**
- **Intermodulation and Oscillator Phase Noise are the main issues**
- **Low noise and high dynamic range are contradictionary**

Image Rejection Mixer

Solution to eliminate tripple Conversion

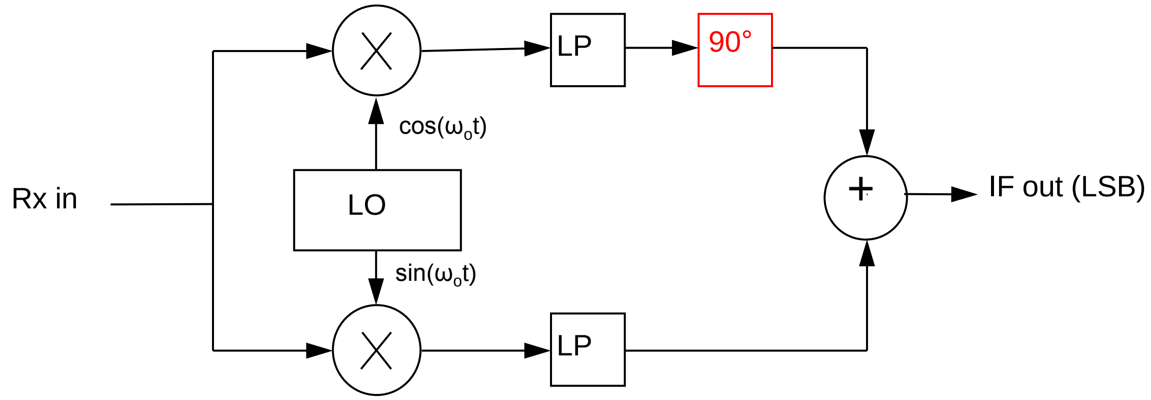
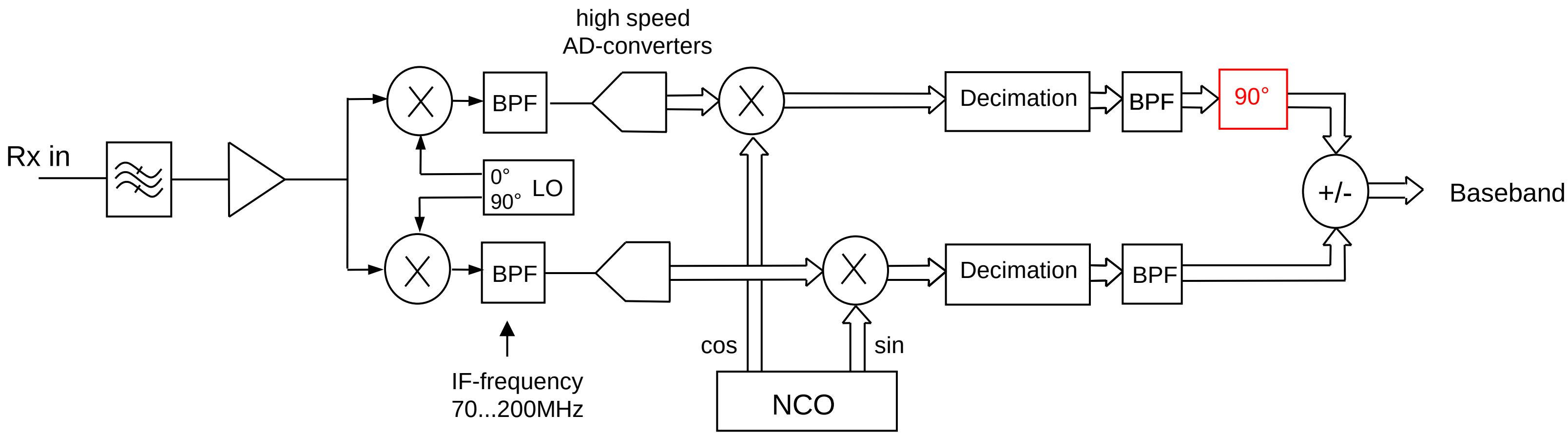


Image Rejection Mixer

- **An analog Image Rejection Mixer is capable to attenuate the Image by 30 to 40dB**
- **Criterions for the image attenuation are amplitude and phase errors in both branches**
- **The most critical element is the 90° phase shifter, mainly for wide band IF**
- **The SDR technology allows to move the phase shifter from analog into the digital part, where it can be realized near to ideal by means of a Hilbert Transformer**

Image Rejection Mixer

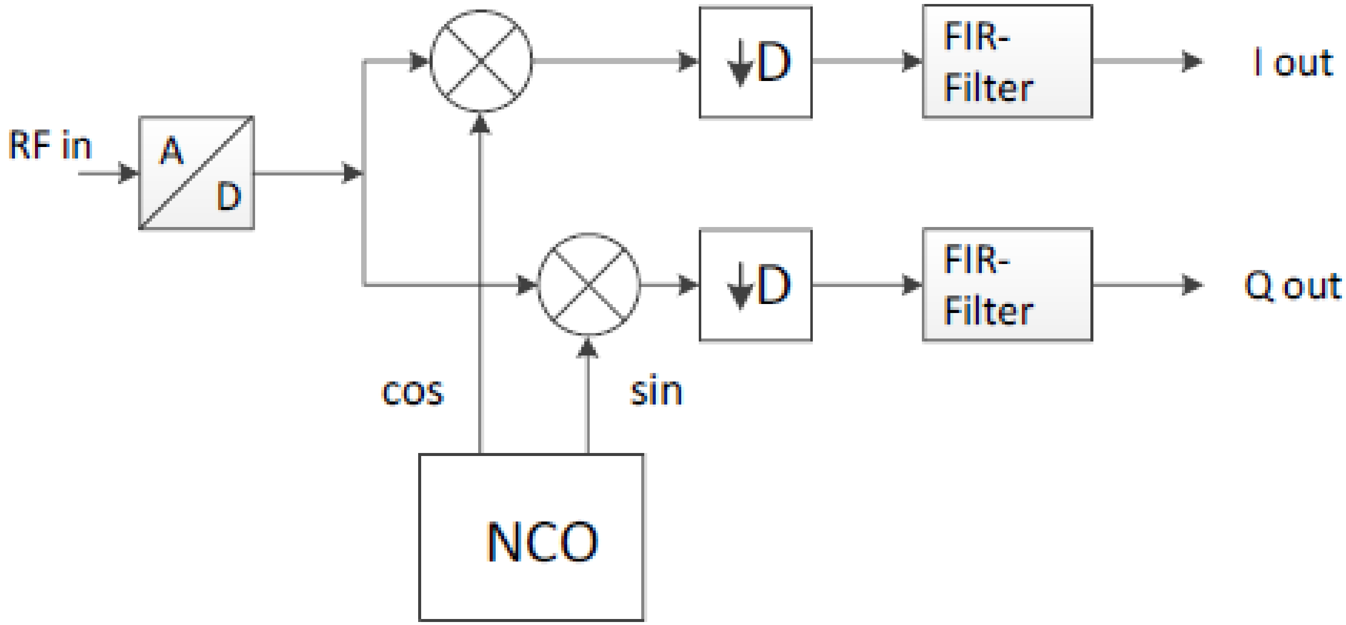
Solution with a distributed Image Rejection Mixer



- The preselector filters may be wider, as they are no longer used for image rejection
- The digital parts, following the AD converter, can be realized in a FPGA
- In a wide band receiver, the LO can be tuned in steps from up to 10MHz which is simplifying the PLL loop filter design. The fine tuning will be done by the NCO
- The image rejection can be further improved by calibration algorithms in the digital part to values up to 80dB

Down Converters

Digital Down Converter

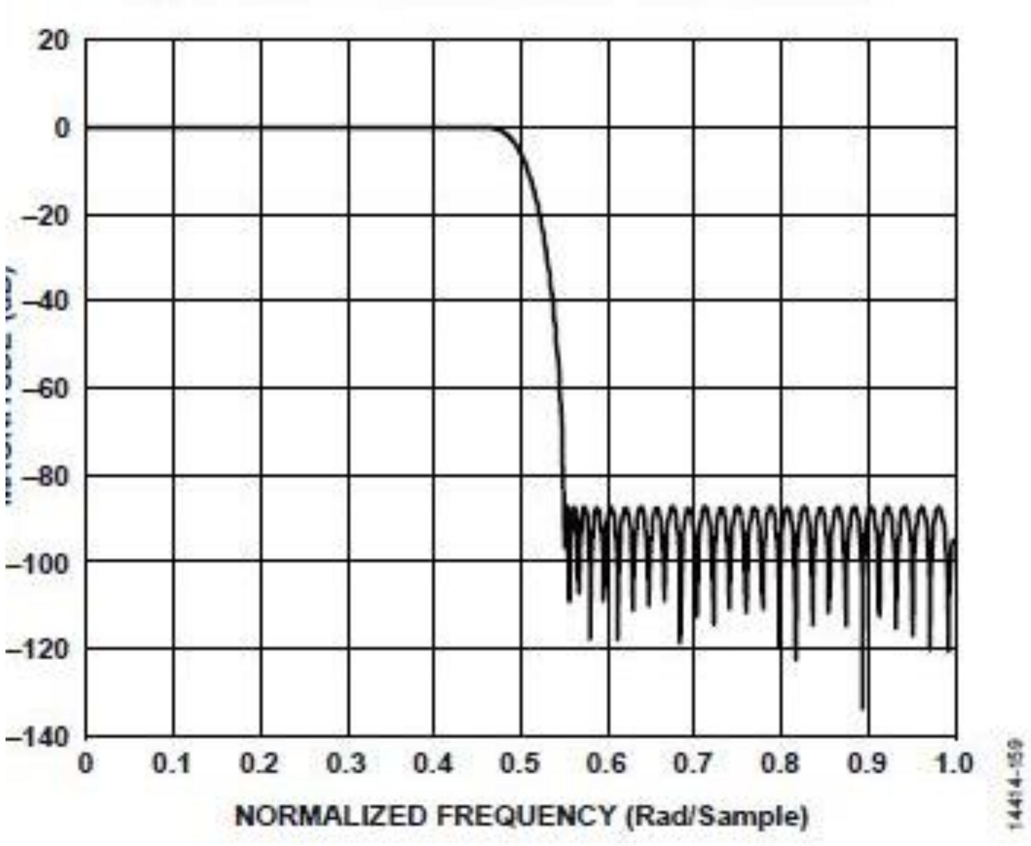


The digital down converter includes:

- a numerically oscillator (NCO)
- a complex IQ-mixer to convert the IF down to approx. 0Hz (zero-IF)
- several decimation filter stages for reducing the sampling rate
- final lowpass FIR-filters (Finite Impulse Response)

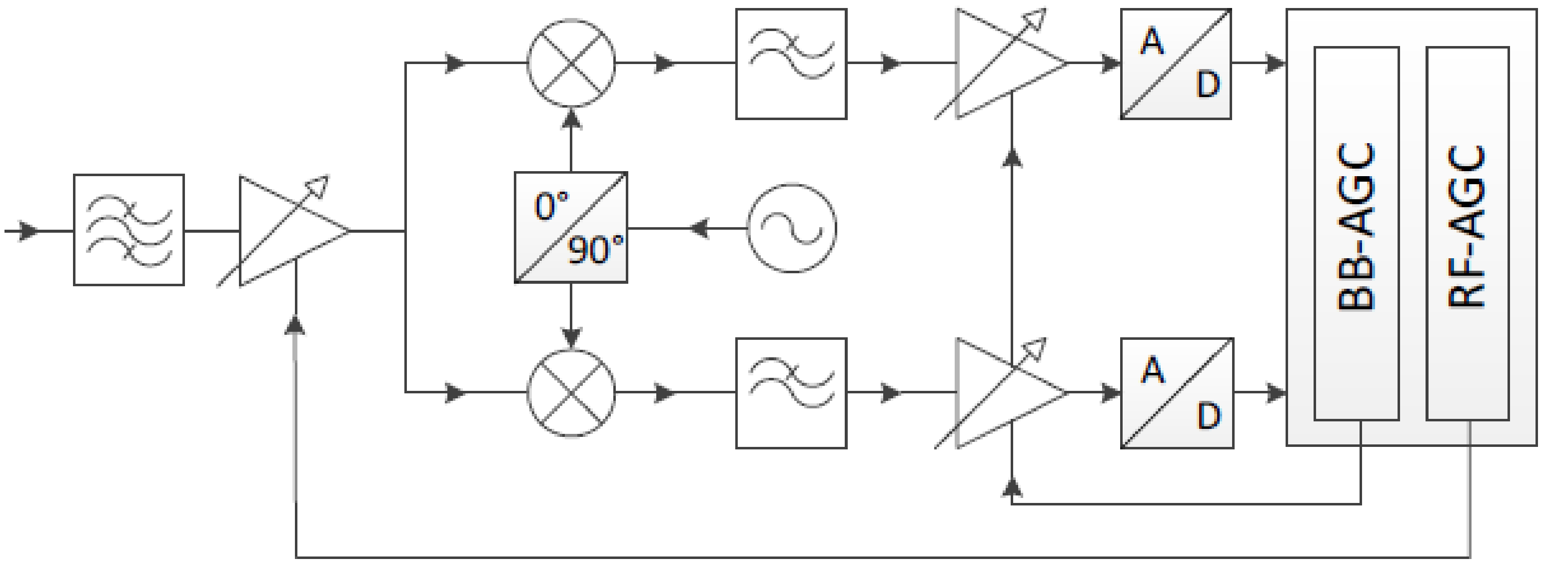
Composite Filter

Avoiding Gibbs Phenomenon (Ringing)



Can only be done in DSP, look up table avoids group delay ears at the corner

Automatic Gain Control



The broadband AGC serves to protect the AD converter from overvoltages. The RF-AGC can be used to set the receiver sensitivity just below the external noise.

The digital processing part is free from distortions, therefore the final AGC can be placed near the analog output.

Evolution Characteristics

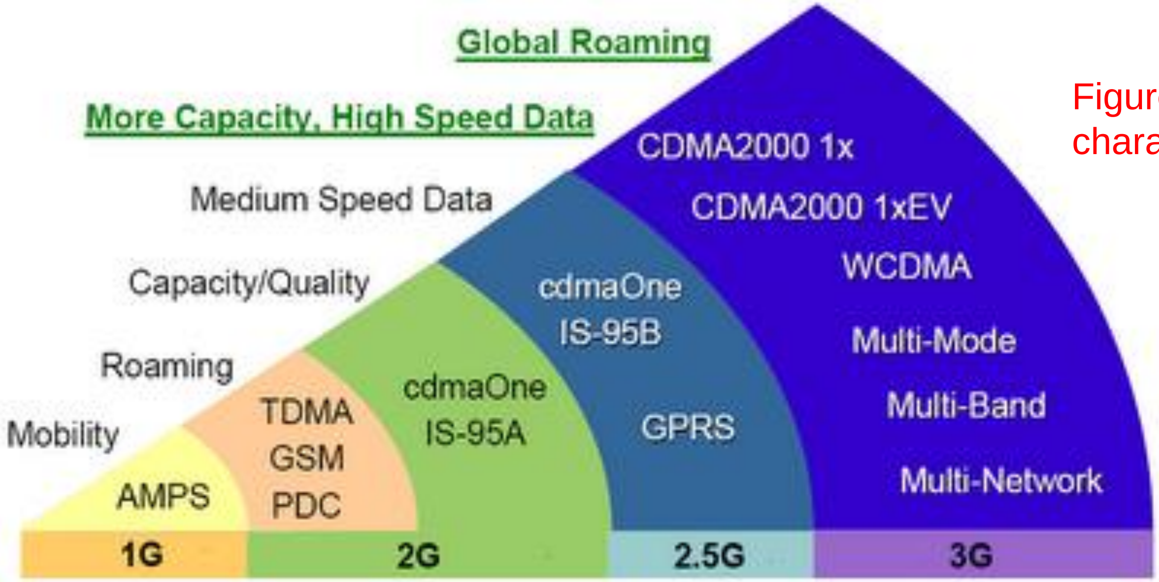


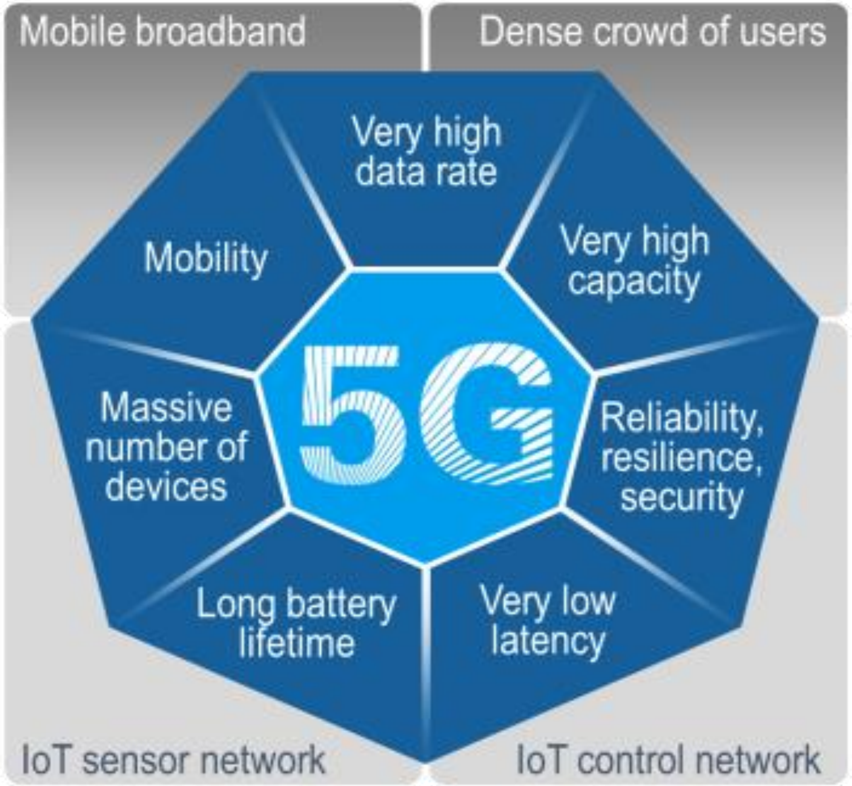
Figure 1 shows the evolution characteristics of 1G to 3G

Table 1: shows the critical deviation between 4G and 5G

Specifications	4G	5G
Full Form	Fourth Generation	Fifth Generation
Data Bandwidth	2Mbps to 1Gbps	1Gbps and higher
Frequency Band	2 to 8 GHz	3 to 300 GHz
Standards	AI access convergence including OFDMA, MC-CDMA, Network-LMPS	CDMA and BDMA
Technologies	Unified IP, seamless integration of broadband LAN/WAN/PAN & WLAN	Unified IP, seamless integration of broadband LAN/WAN/PAN/WLAN and advanced technologies based on OFDM modulation used in 5G
Service	Dynamic information access, wearable devices, HD streaming, global roaming	Dynamic information access, wearable devices, HD streaming, any demand of users
Multiple Access	CDMA	CDMA, BDMA
Core Network	All IP Network	Flatter IP Network, 5G network interfacing (5G-NI)
Handoff	Horizontal and vertical	Horizontal and vertical
Initiation from	Year 2010	Year 2015

5G: Emerging Cellular Networks

5G drivers

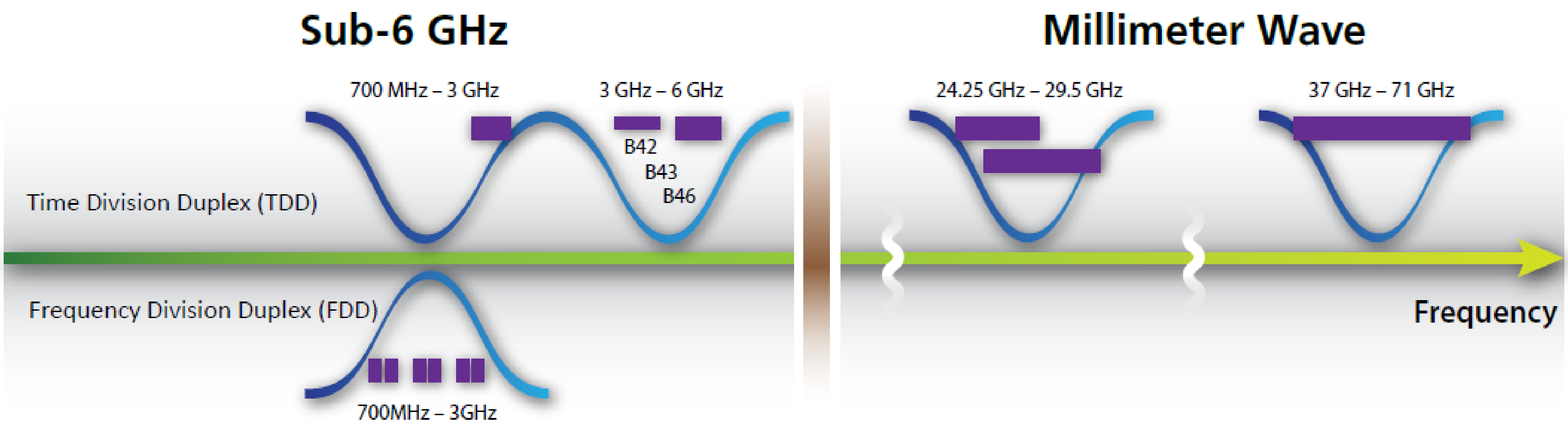


Mobile operators have just commercialized LTE and few of the features that make LTE a true 4G technology have made it into live networks. **So why is industry already discussing 5G?**

- Constant user demands for higher data rates and faster connections require a lot more wireless network capacity, especially in dense areas.
- The industry is expecting demand for 100x higher peak data rate per user and 1000x more capacity, and better cost efficiency defined these as targets for the 5th generation of mobile networks (5G).
- Internet of Things (IoT) provides new challenges to be addressed. It is anticipated that millions of devices will "talk" to each other, including machine to machine (M2M), vehicle-to-vehicle (V2V) or more general x-2-y use cases.

Beyond doubt there is a need to improve the understanding of potential new air interfaces at frequencies above current cellular network technologies, from 6 GHz right up to 100 GHz, as well as advanced antenna technologies such as massive MIMO and beam forming, very long battery lifetimes (years instead of days) and very low response times (latency) call for another "G" in the future !!!

Present Technology and Planned 5G Spectrum



Product Format Example	FEMiD / PAMiD / DRx	FEMiD / PAMiD / DRx	8T / 8R Antenna Complete Front-end	8T / 8R Antenna Complete Front-end
		Technology		
Power Amp	III-V / SiGe / Bulk CMOS	III-V / SiGe / Bulk CMOS	InP / SiGe BiCMOS / Advanced SOI	InP / GaN / SiGe BiCMOS / Advanced SOI
Low Noise Amp	III-V / SiGe / SOI CMOS	III-V / SiGe / SOI CMOS	Advanced SOI / GaN	SiGe BiCMOS / Advanced SOI
RF Switching	SOI CMOS	SOI CMOS	Advanced SOI	Advanced SOI
Filtering	Acoustic / IPD / Ceramic	Acoustic / IPD / Ceramic	IPD / Ceramic	IPD
Antenna Integration	N/A	N/A	Yes	Yes
Signal Generation	N/A	N/A	Advanced SOI / SiGe BiCMOS	Advanced SOI / SiGe BiCMOS

Table represents existing technology and spectrum for SDR frequency spectrum in terms of waveforms

Typical Representation of 5G Environment

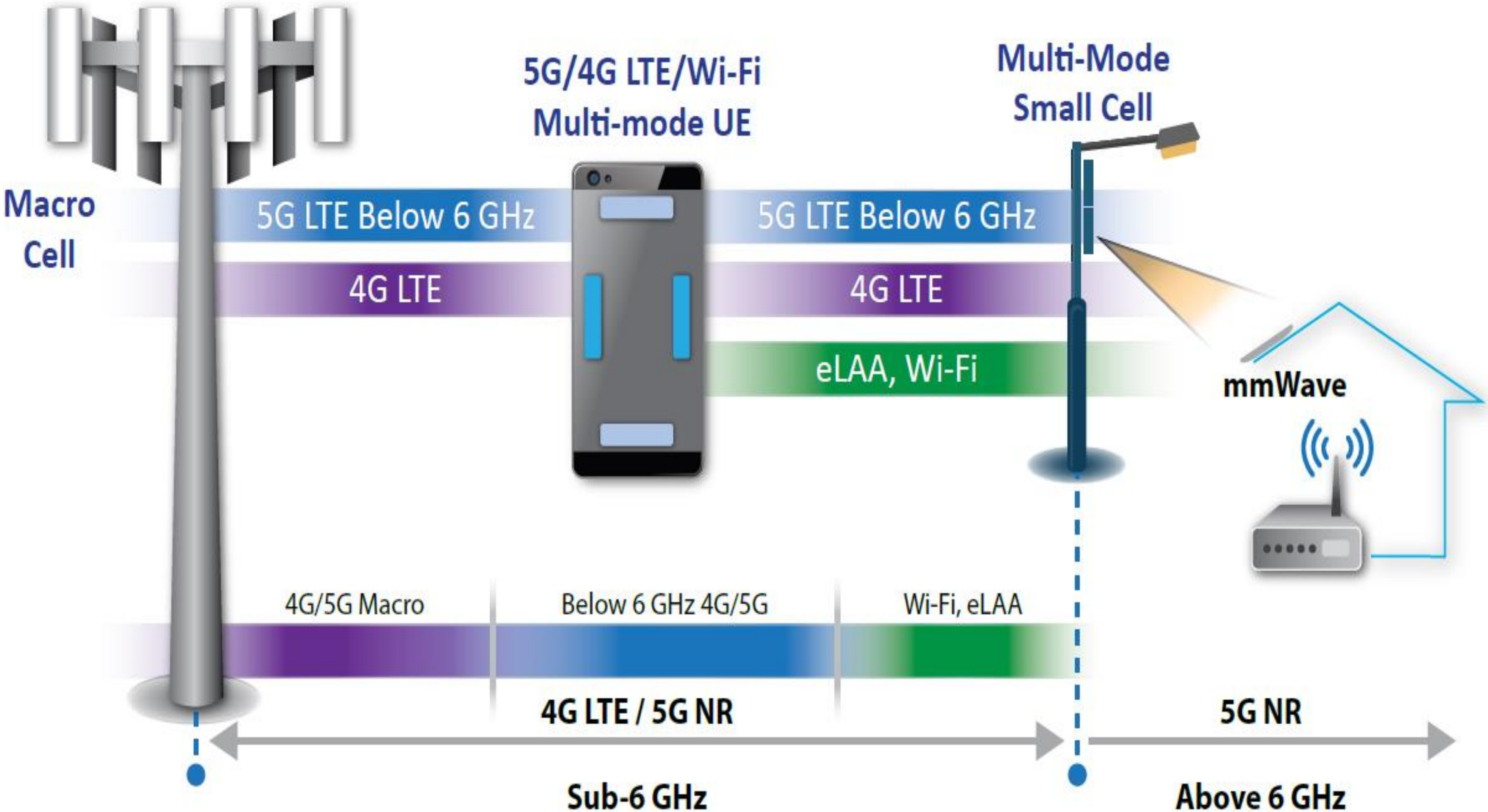


Figure shows the typical representation of a 5G environment

Typical 4G to 5G MIMO System

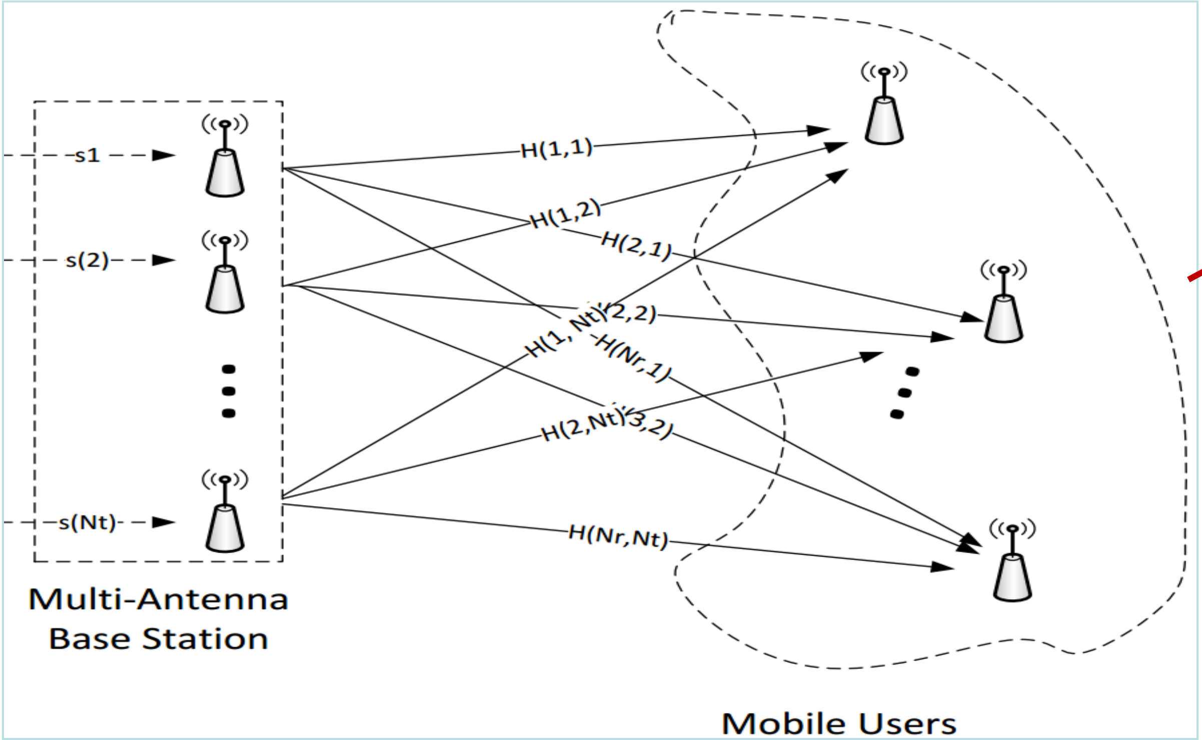
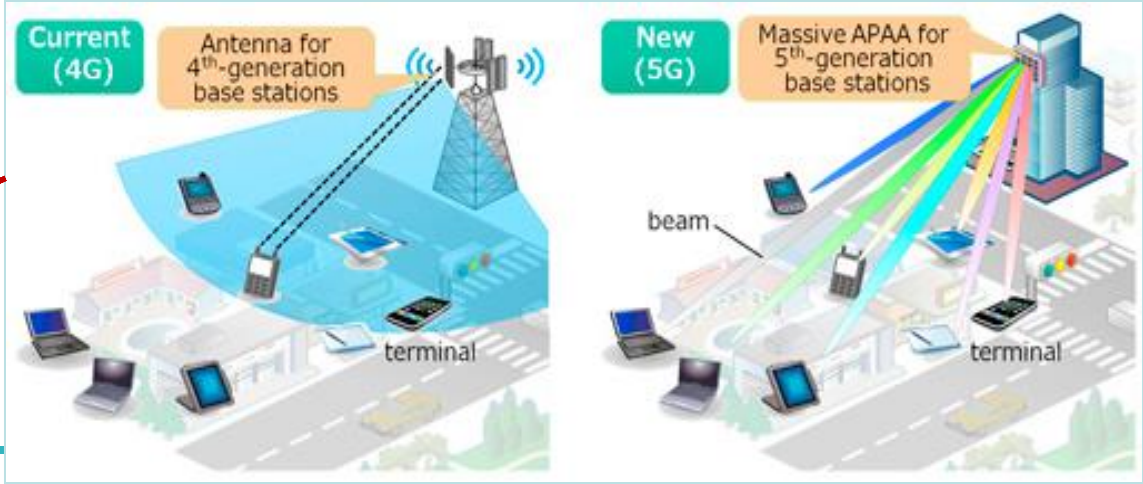
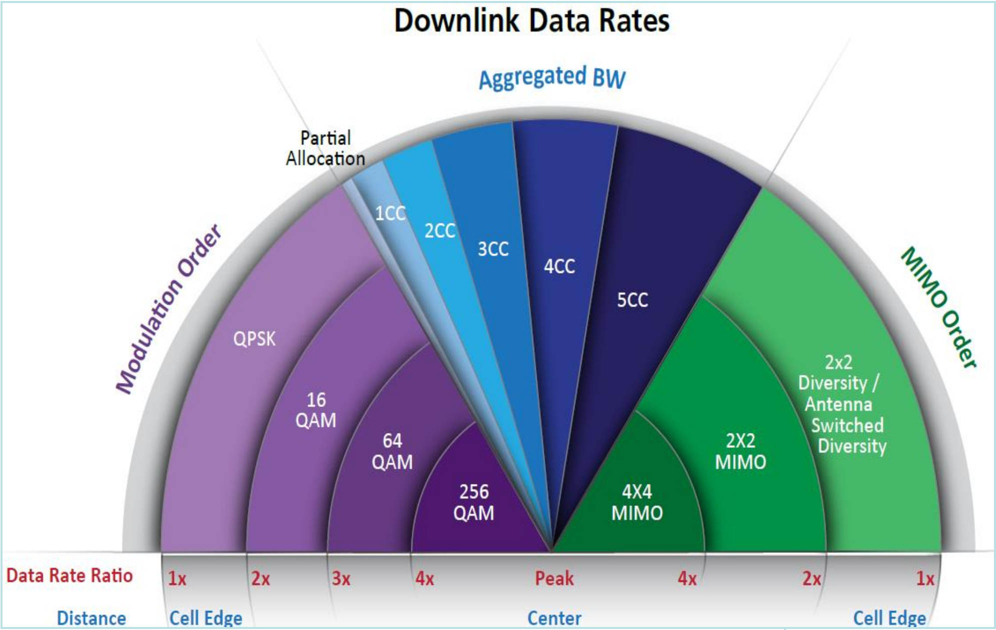


Figure 1 shows the system model of typical MIMO system

Figure 2 shows the antenna technology from 4G to 5G MIMO

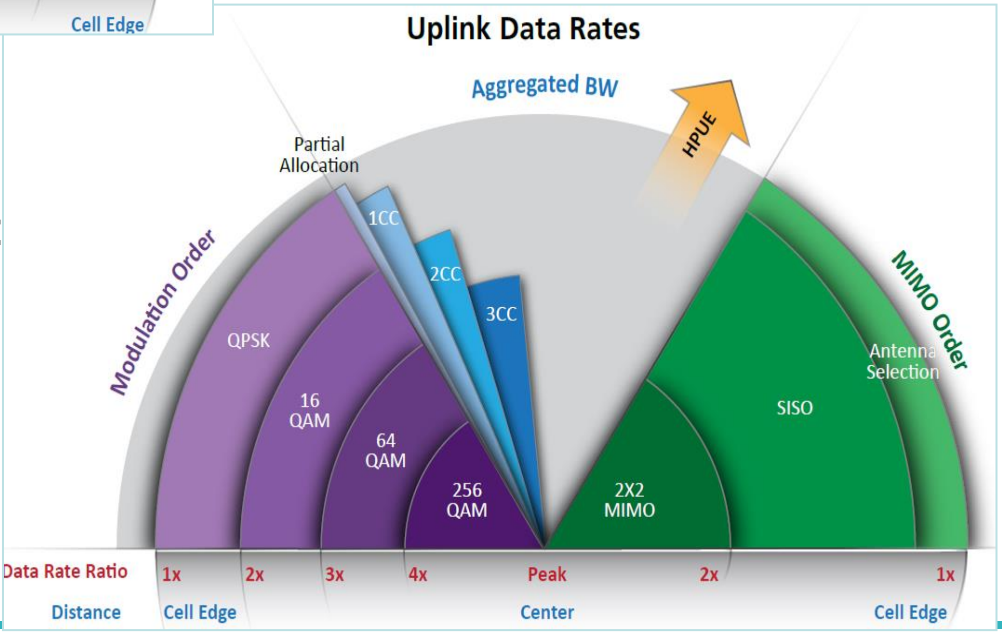


Typical Representation of 5G Environment



(a) Downlink

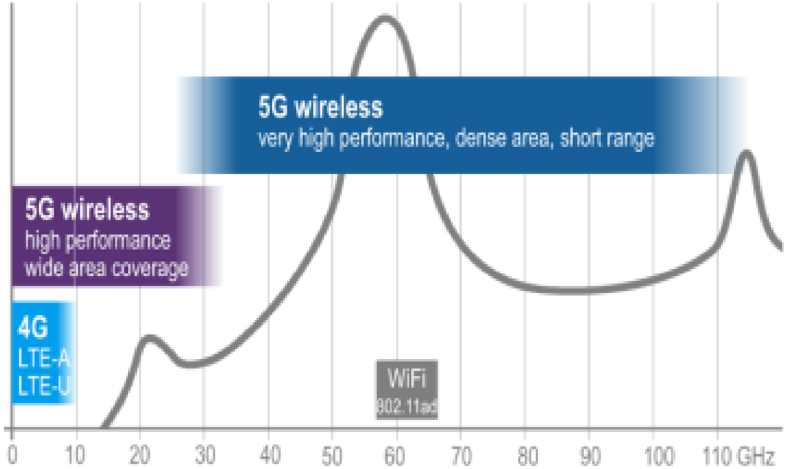
(b) Uplink



Figures Show the impact of Modulation, Bandwidth and MIMO to: (a) Downlink and (b) Uplink Data Rate as a Function of Distance to Cell Center

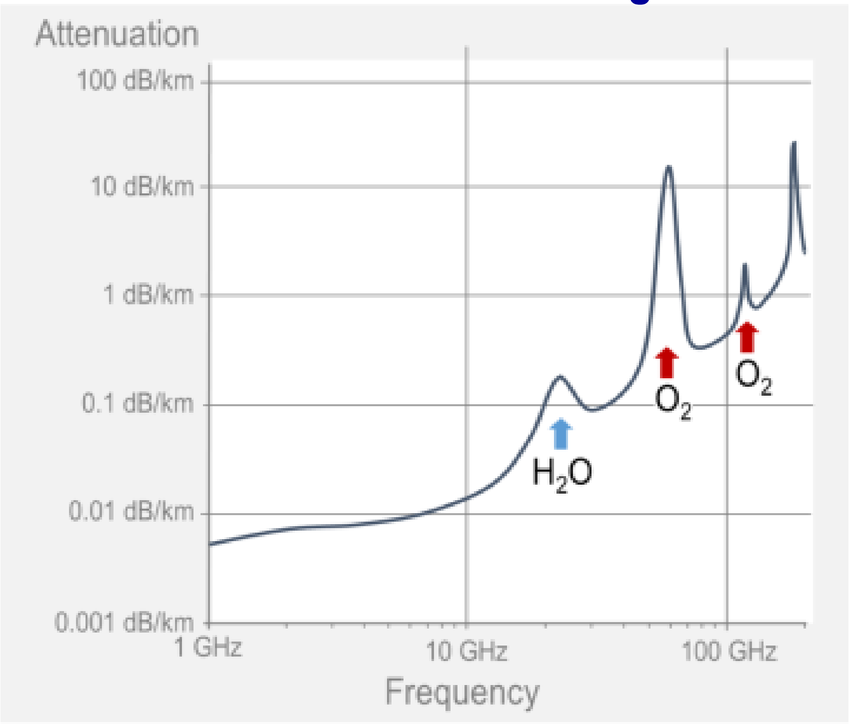
5G: Emerging Cellular Networks

The need for higher bandwidth and thus higher data rates for 5G makes it necessary to adopt significantly higher carrier frequencies compared with today's cellular network implementations below 6 GHz.



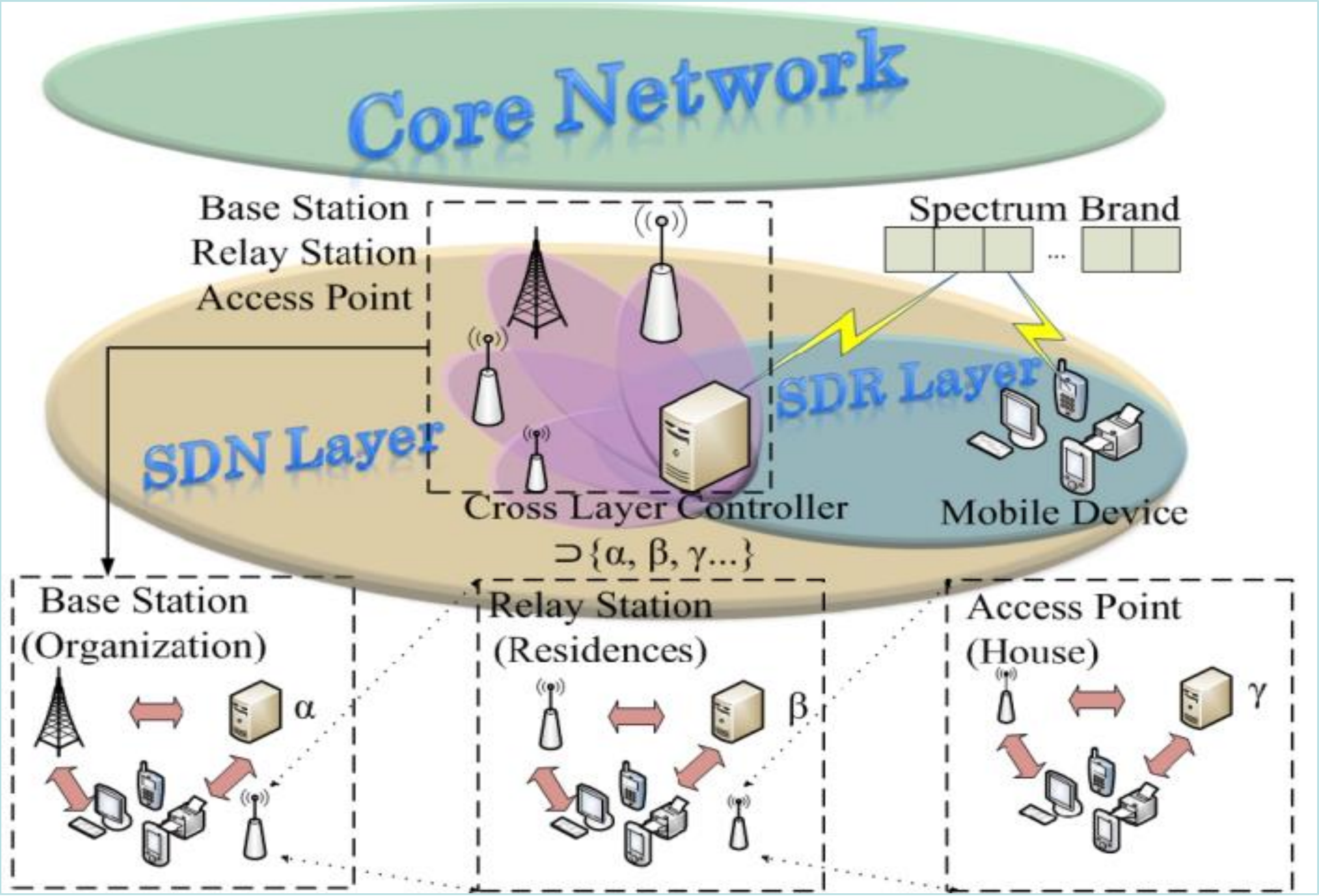
- The path loss is significantly higher so that highly directional beam forming will be required in the mm-wave domain.
- Oxygen and water absorption (e.g. rain or humidity loss) needs to be taken into account for specific bands below 70 GHz and above 100 GHz and above a range of 200 m.
- The attenuation of most obstacles is stronger, e.g. even foliage loss, but reflections too.
- Line-of-sight (LOS) conditions cannot always be ensured therefore non-line-of-sight (NLOS) communications is essential (and possible).

5G Channel Sounding



Channel sounding is a process that allows a radio channel to be characterized by decomposing the radio propagation path into its individual multipath components. This information is essential for developing robust modulation schemes to transmit data over the channel.

SDR AND SDN Architecture



SDR and SDN are two different technologies, but both have a ”software-defined" feature.

Figure shows the typical architecture of SDR and SDN

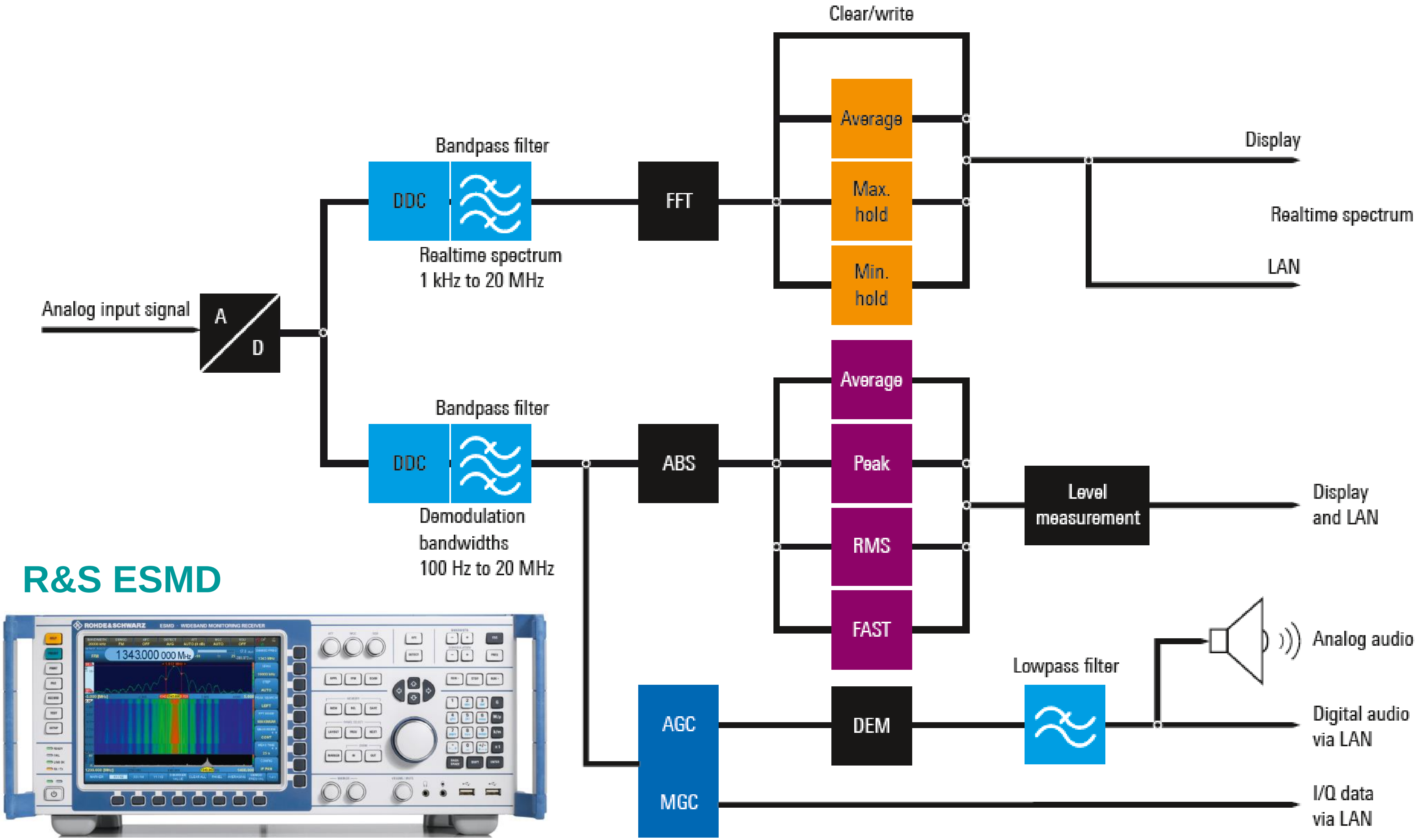
SDR-SDN Inspired Radio Receiver

Requirements on a SDR-SDN Inspired Receiver

- **Fast detection of unknown signals**
- **Search for activities over wide frequency ranges**
- **Monitoring of individual frequencies, lists frequency ranges**
- **Measurement of spectral characteristics of very short or rarely occurring signals**
- **Storage of activities**
- **Triggering of further activities after a signal is detected**
- **Demodulation of communications and/or transfer of demodulated signals for processing**
- **Integration into civil and military dedicated systems**
- **Homing, i.e. localization of signal sources and direction finding**
- **Simple coverage measurements**
- **Measurements in line with ITU recommendations**

Widebnad Monitoring Receiver

Figure 1: R&S ESMD Wide Band Monitoring Receiver



R&S ESMD

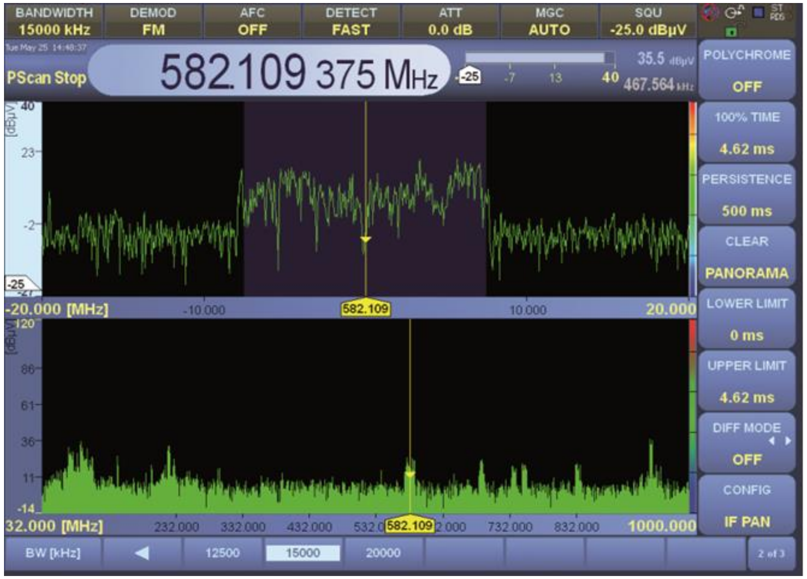
High Dynamic Range

Spectrum Analysis in Receiver

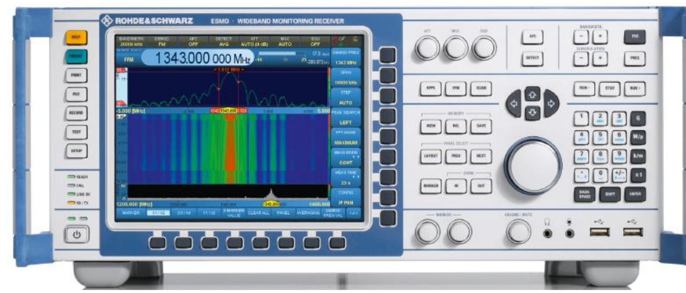
Spectrum Analysis in Communication Receivers

Narrowband Analysis

Wideband Analysis

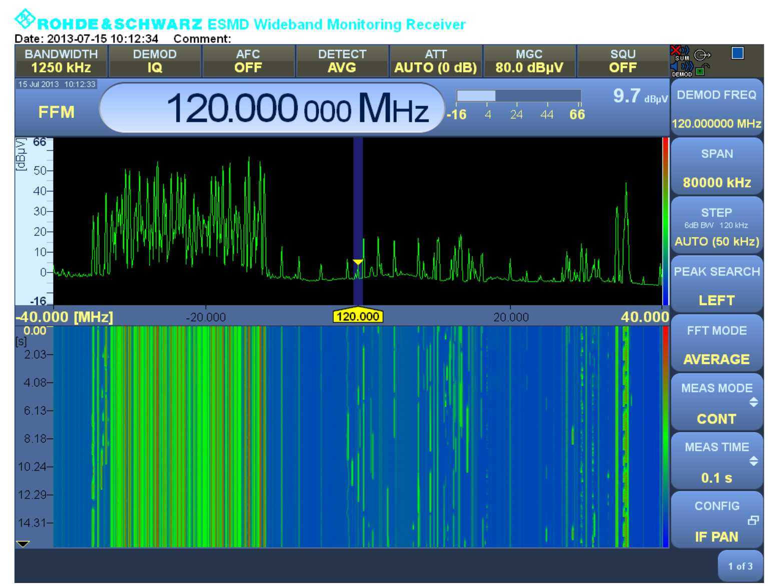


R&S ESMD



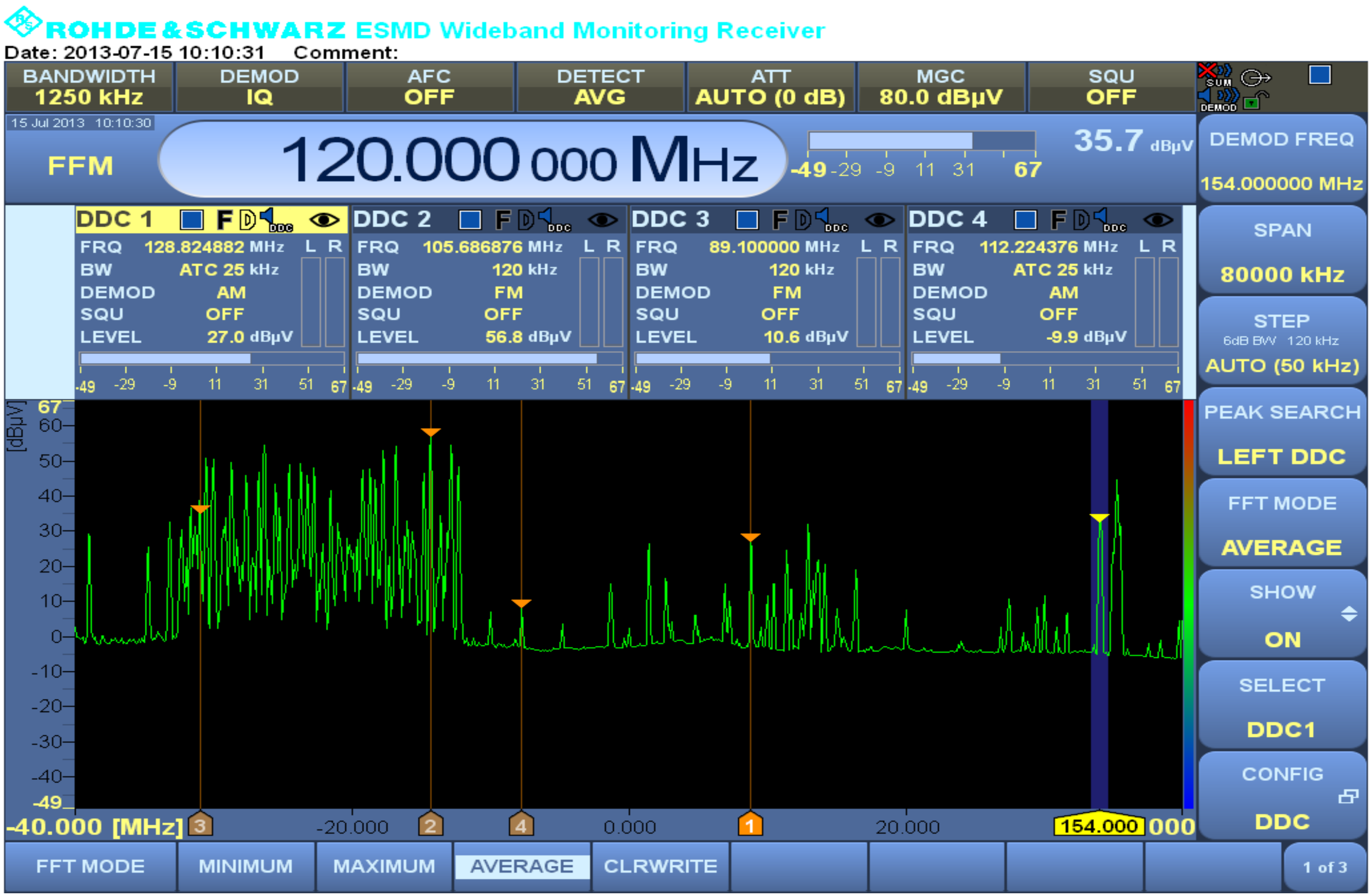
High Dynamic Range

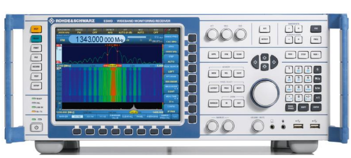
Aircraft Radio Communication Receiver can be monitored and demodulated in the presence of strong FM Radio signal



Spectrum Analysis in Communication Receiver

Figure 1 shows the R&S ESMD multi channel operation capability





All 5-Channels can be anlayzed

Conclusion

- **This presentation shown the trends of next generation radios for the application in radio monitoring receiver applications.**
- **In a rich scattering environment, massive MIMO technique can enable significant performance gains with simple beam forming strategies such as maximum ratio transmission or zero forcing. Furthermore, millimeter wave frequencies can be used for outdoor point-to-point backhaul links or for supporting indoor high-speed wireless applications (e.g., high-resolution multimedia streaming).**
- **Tthere are several challenges to be solved in 5G, including propagation issues, mobility aspects, hardware imperfections such as power amplifier non-linearity and low efficiency of radio frequency components at these frequencies. In addition to the existing multiple access schemes such as TDMA, FDMA, CDMA, OFDMA and Space Division Multiple Access (SDMA), several multiple access schemes such as Polarization Division Multiple Access (PDMA), Interweave Division Multiple Access (IDMA), Universal Filtered Multi-Carrier (UFMC), Sparse Code Multiple Access (SCMA), Generalized Frequency Division Multiple Access (GFDMA) and Non-Orthogonal Multiple Access (NOMA)**
- **There are blocks of spectrum, which makes massive processing quite easy, including neighboring channels (whether in freq, code, or time) are under control. Nevertheless, it is a far cry from randomly spaced channels, as in paging systems (except in the 900 MHz range where some coordination exists).**
- **Paging system may not benefit from SDR, except marginally, channel by channel. For example, in the same way that an old (but frequency stable) SSB ham radio has SDR capability by the addition of a sound card, a PC, and software like WSJT-X or FLDIGI - and operate on a multiple signals in a whole SSB channel - multiple sub channels at a time. A true, but limited SDR! The later G's can do this in multiple MHz BW, almost GHz BW at a slice, and in multiple waveforms.**
- **Now in 4G and 5G there is a need to bridge multiple spread out gardens of friendly spectrum, supposedly the 700 MHz band of random channels will lead the way in that technology. Authors' opinion that the "SDR" has many definitions. It is multiple waveforms perhaps in the realm of a near-zero IF on one end, and a creep of digitization closer and closer to the antenna.**
- **HAM Radio folks have shown parallel approaches for the physical hardware, and they will be "ham strung" (pun intended) by long-obsolete FCC over-regulation. For example, HAM radio group have the technology of simultaneously accessing any of all of the HF channels to take advantage of massive frequency diversity, except rules prohibit such multiband operation.**
- **Future is SDR-SDN inspired Cognitive Radio Receivers**

Thank You