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How to Implement Digital IF

2002. 11. 6

School of Electronic Engineering

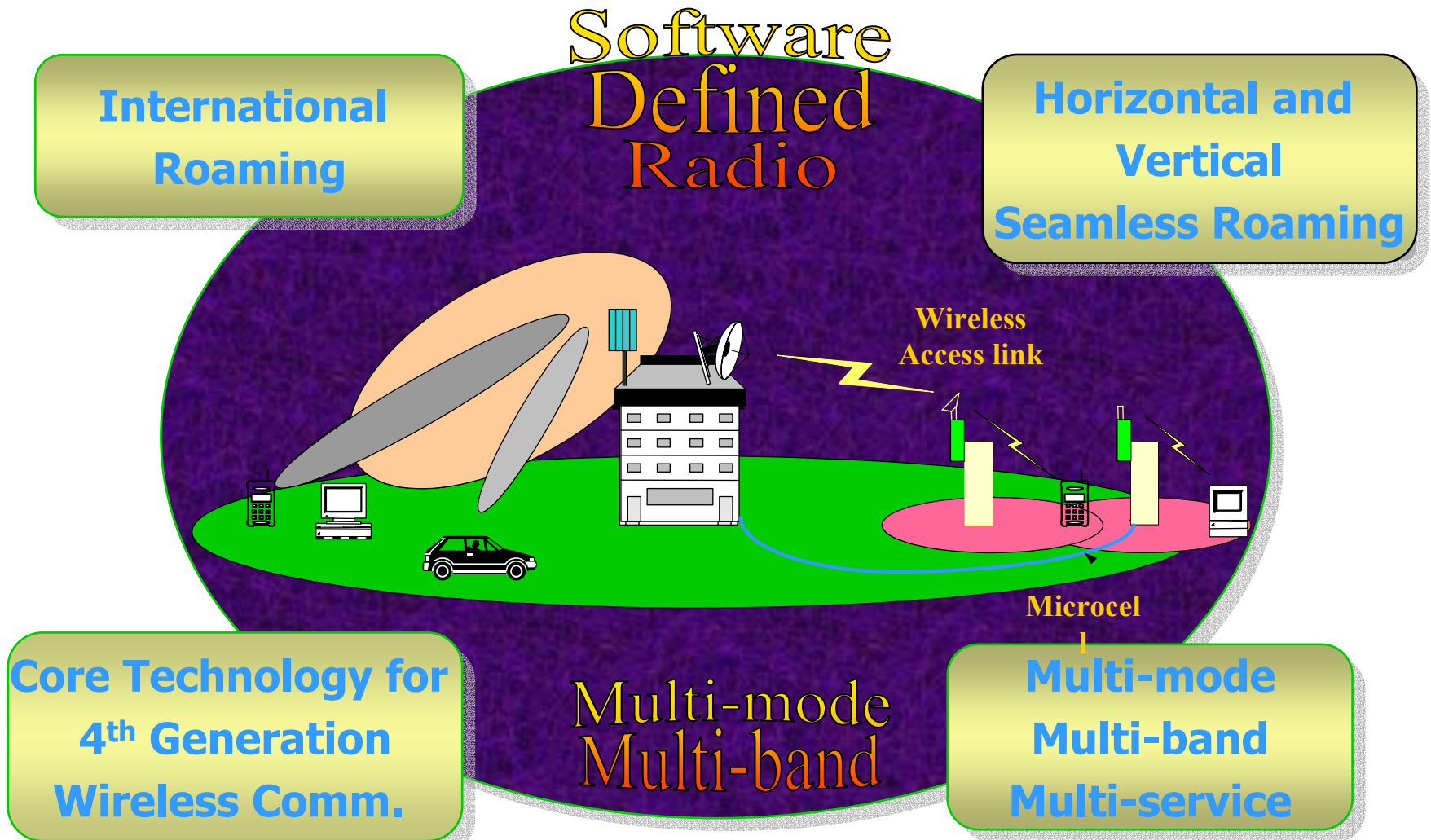
Advanced Wireless Communication Systems Lab.

Won Cheol Lee

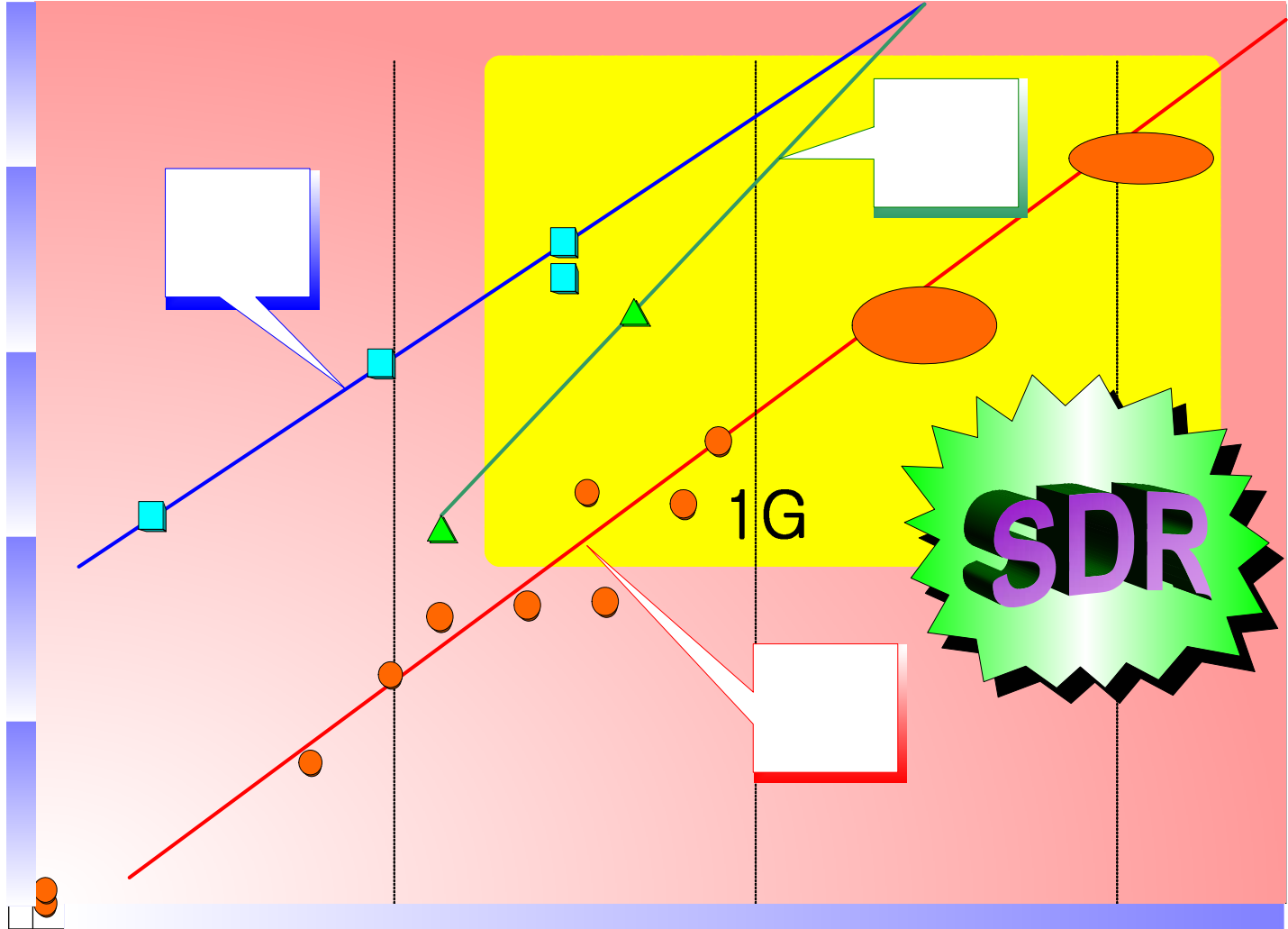
Contents

- Background
- SDR for beyond 3G
- What is Digital IF?
- ADC & DAC Technology for Digital IF
- Filtering Technology for Digital IF
- Digital IF based Channelization
- Conclusion

SDR for Beyond 3G

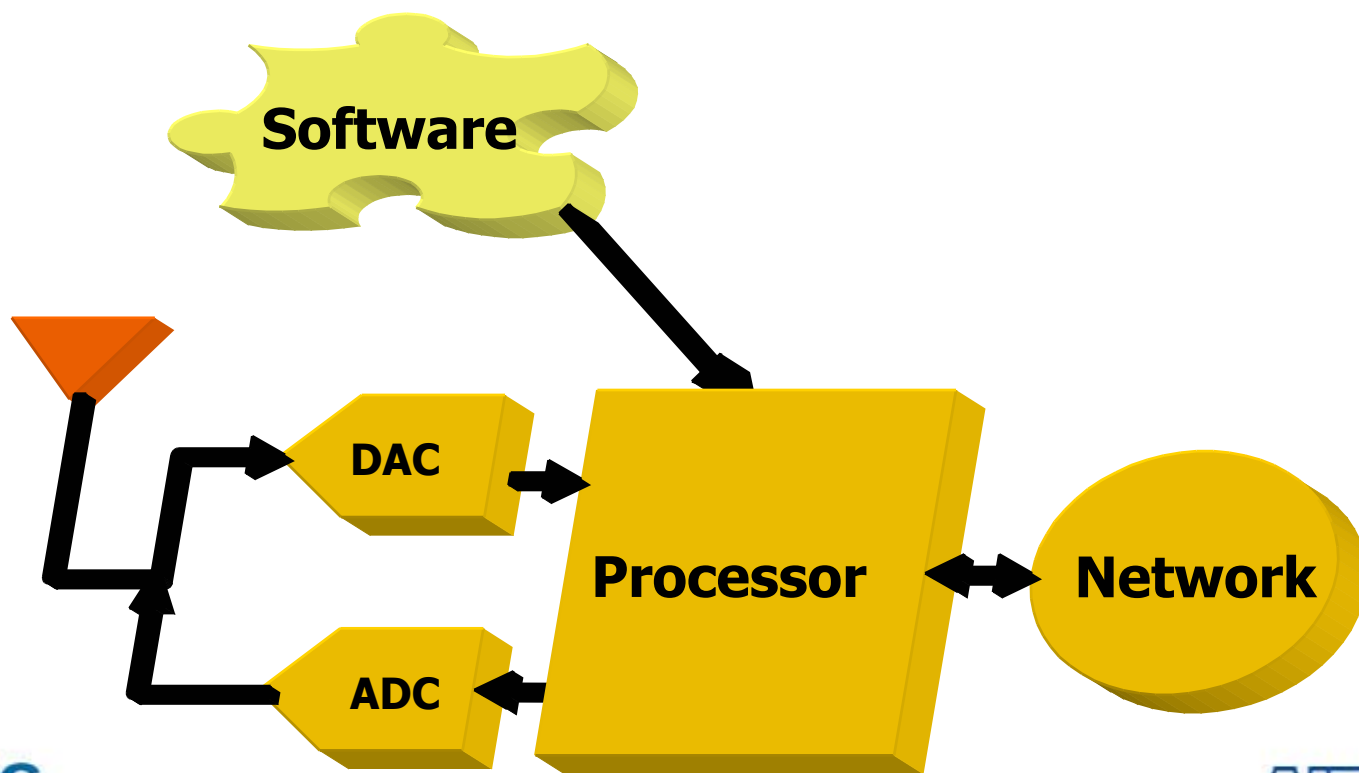


Evolution of Wireless Comm. Systems



Definition of SDR Technology

“The process of managing complexity whilst maximizing flexibility by using the techniques of non real time software engineering in hard real time domain.”



Core Technologies for SDR (cont.)

Features of Software Radio

Flexibility

**Multi-mode
/Multi-band**

Adaptability

**Adaptive
Signal
Processing**

Technical Issues

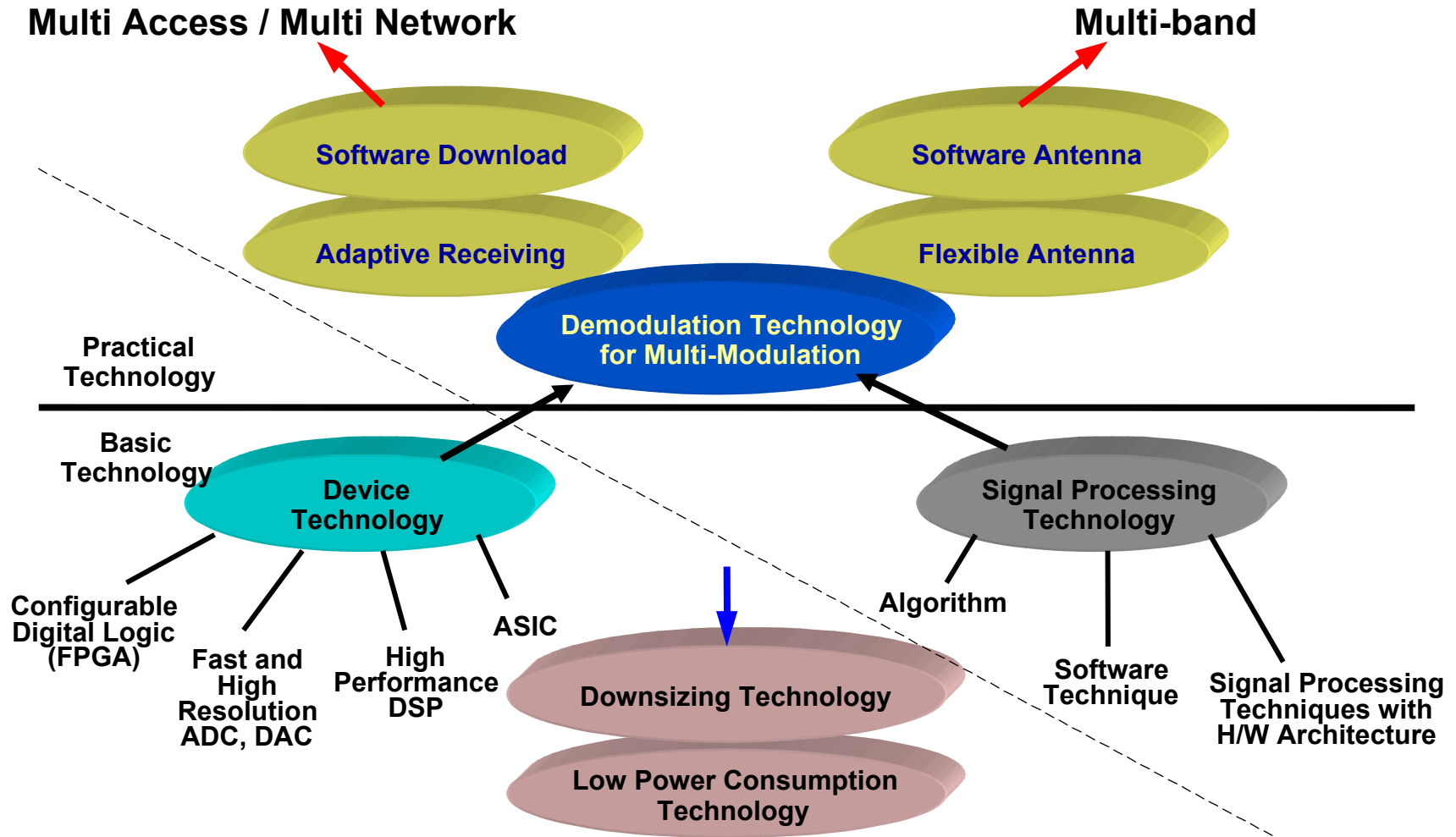
Wideband RF

**Wideband/High speed
/High Resolution ADC, DAC**

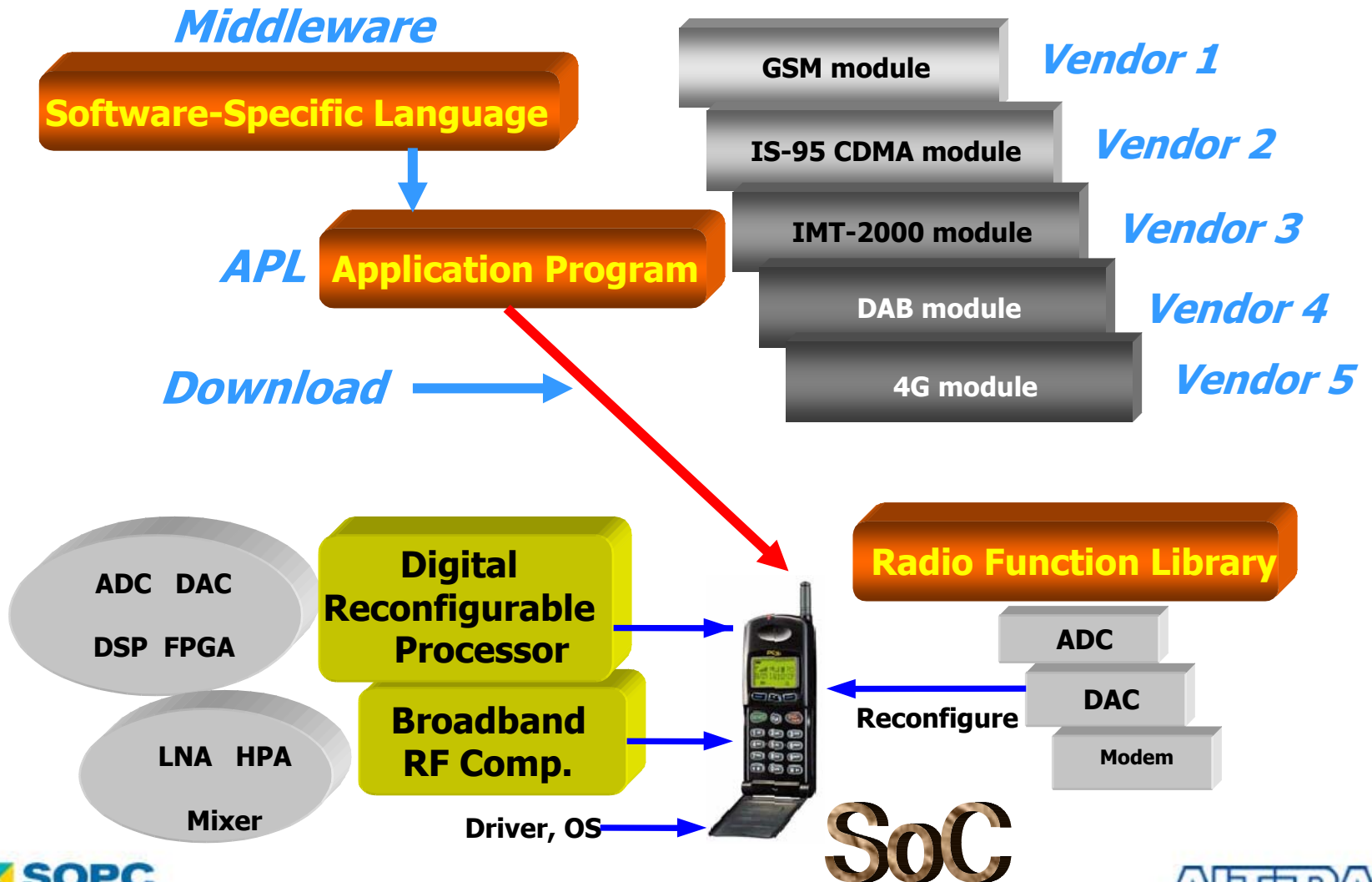
**High Performance
Digital Signal Processing Devices
(DSP, FPGA, etc.)**

Software

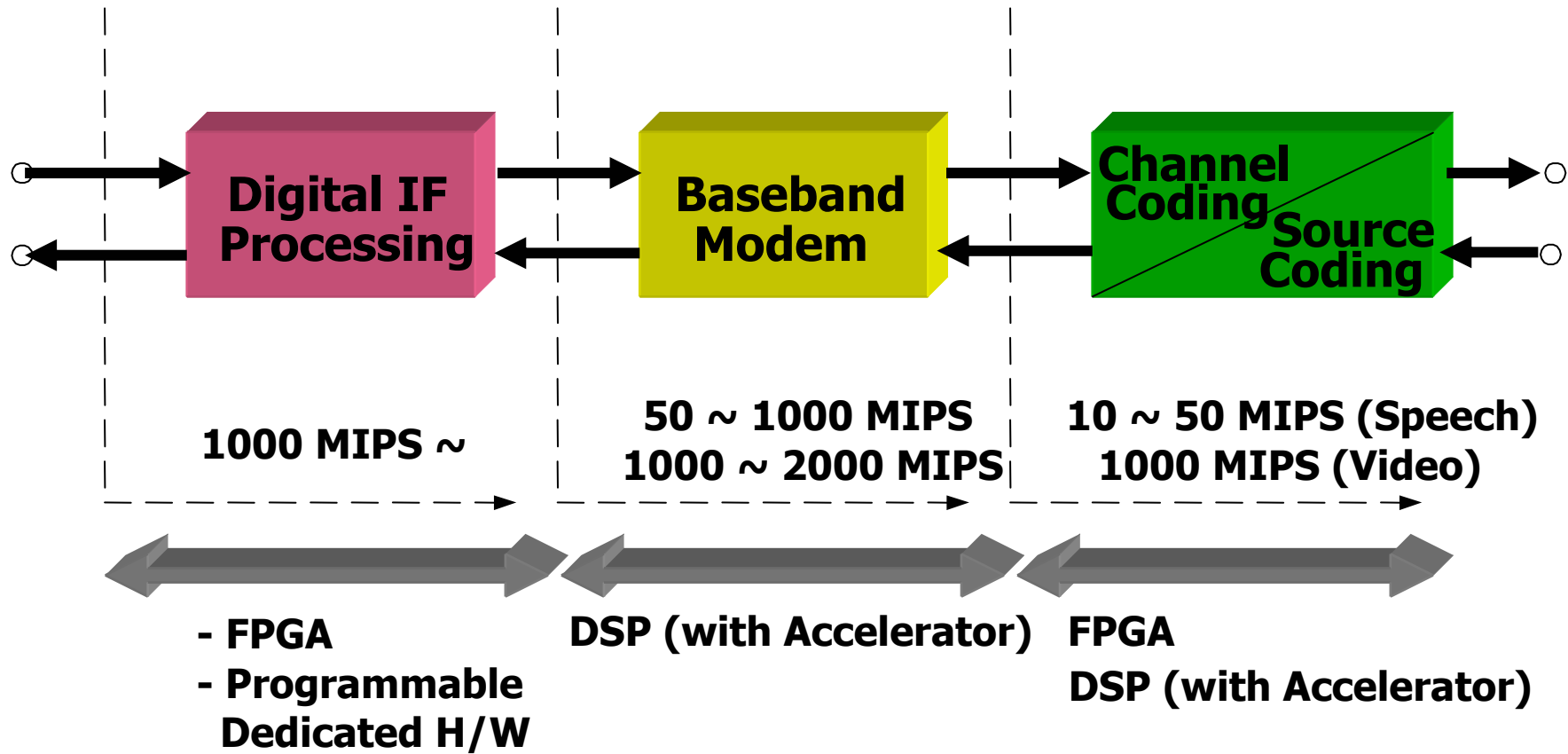
Core Technologies for SDR



Functionalities for SDR-based Handset

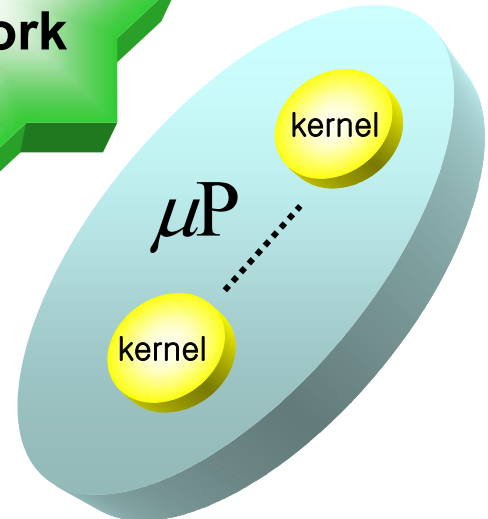
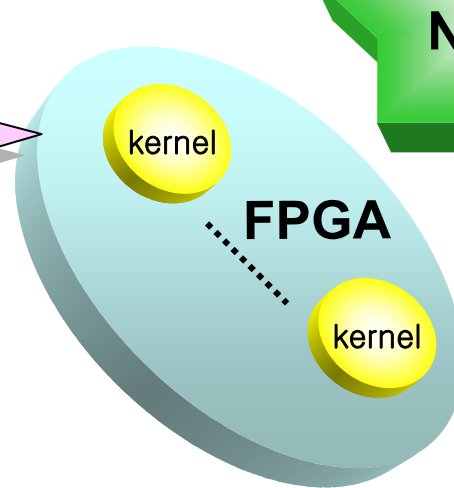
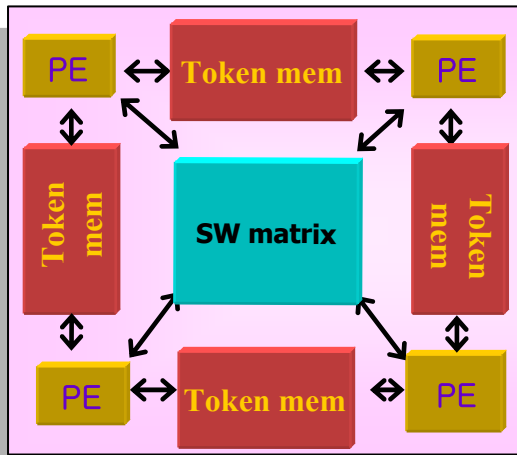
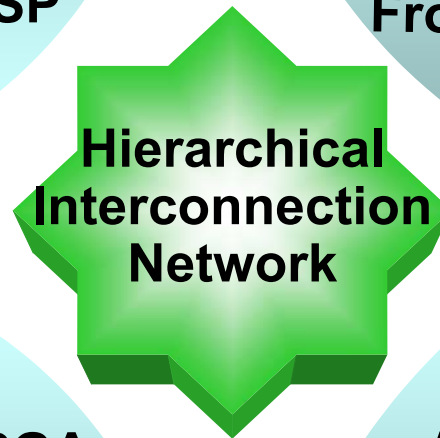
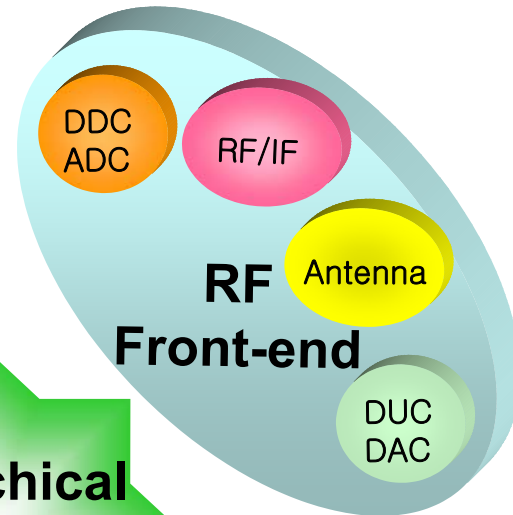
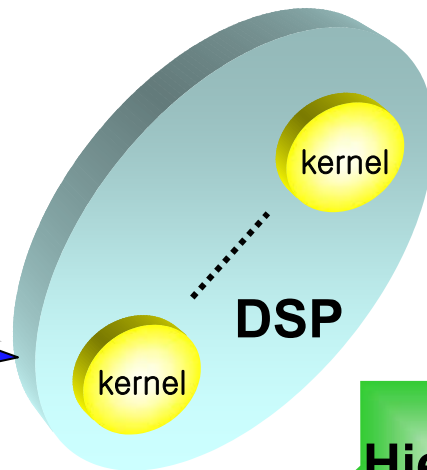
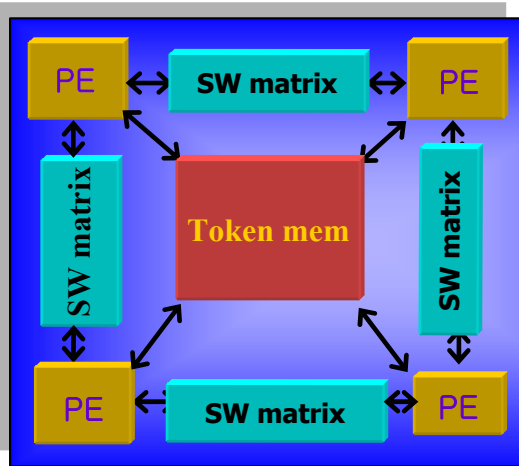


Digital Hardware Resources for SDR

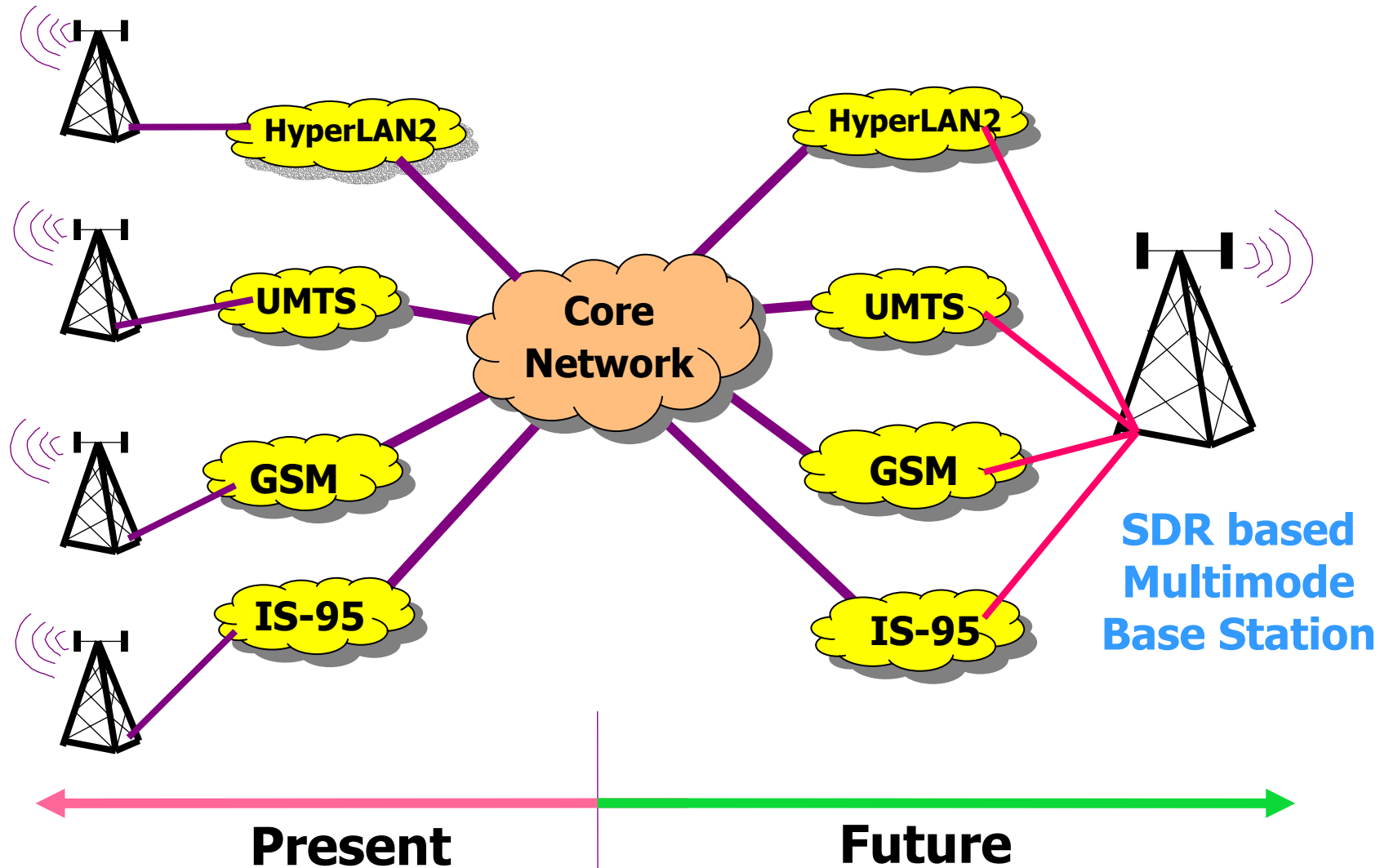


“More sophisticated signal processing algorithms must be employed to increase throughput over limited frequency resource”

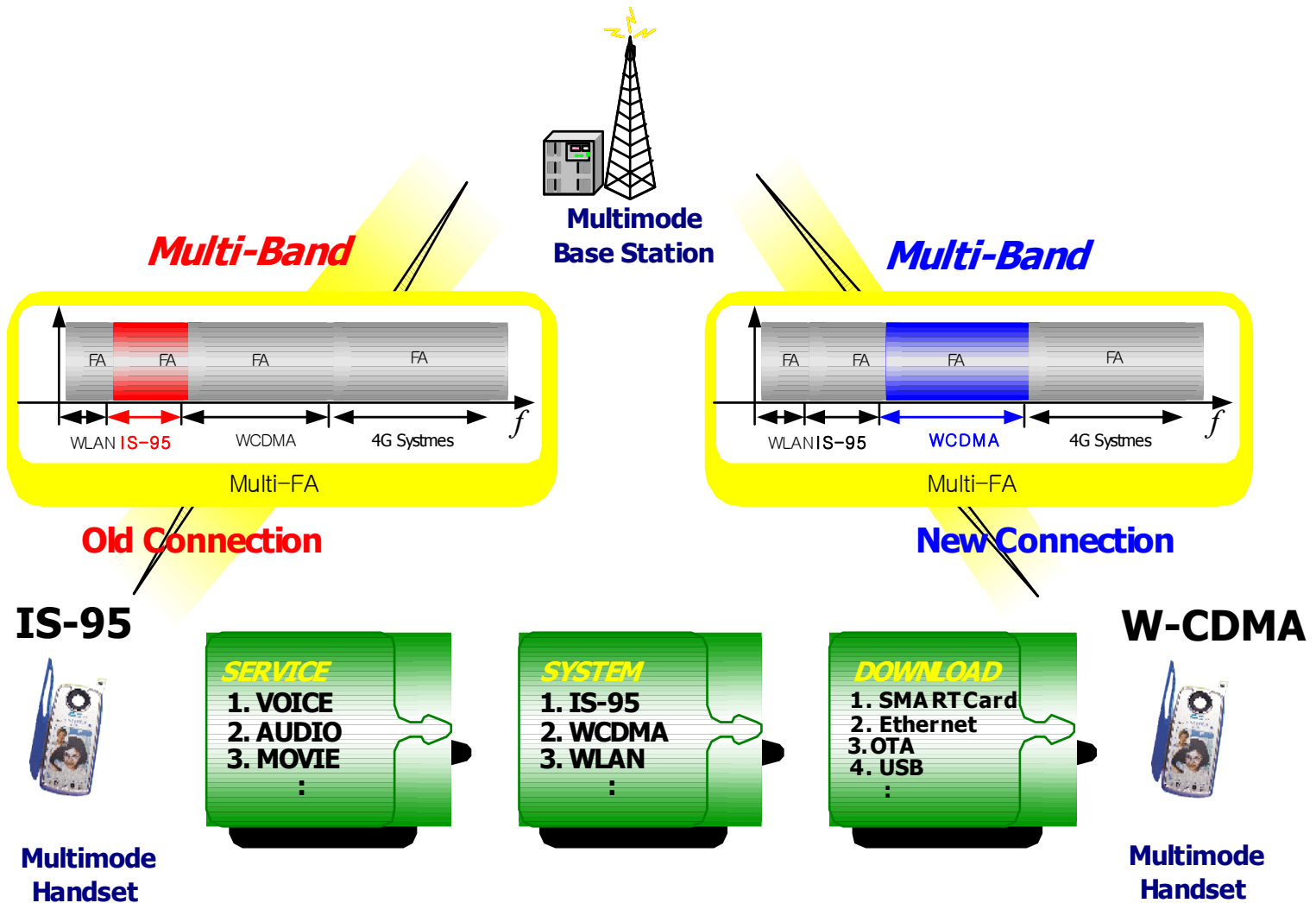
Generic Structure of SDR Platform



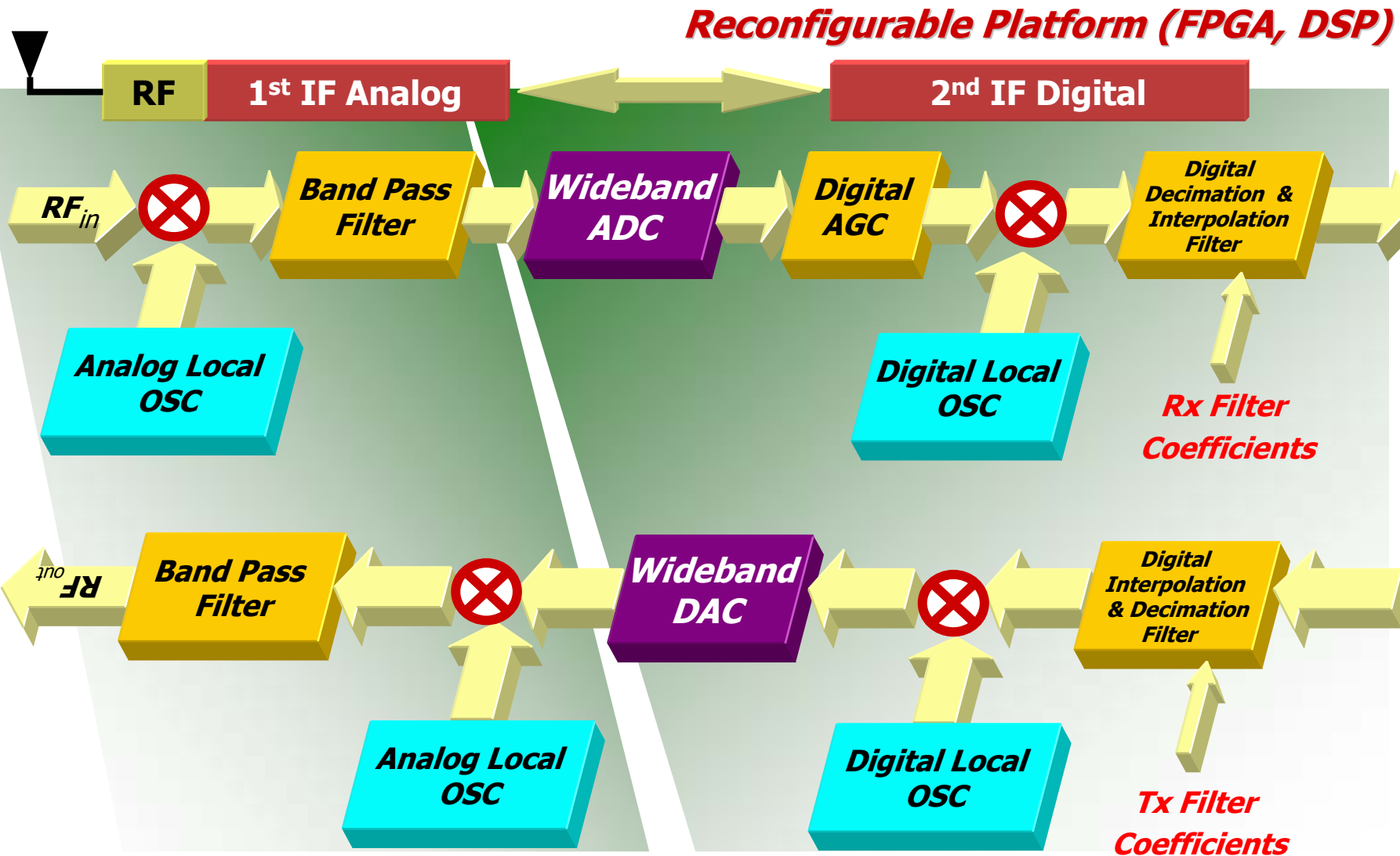
Enhancement of Radio Access by SDR



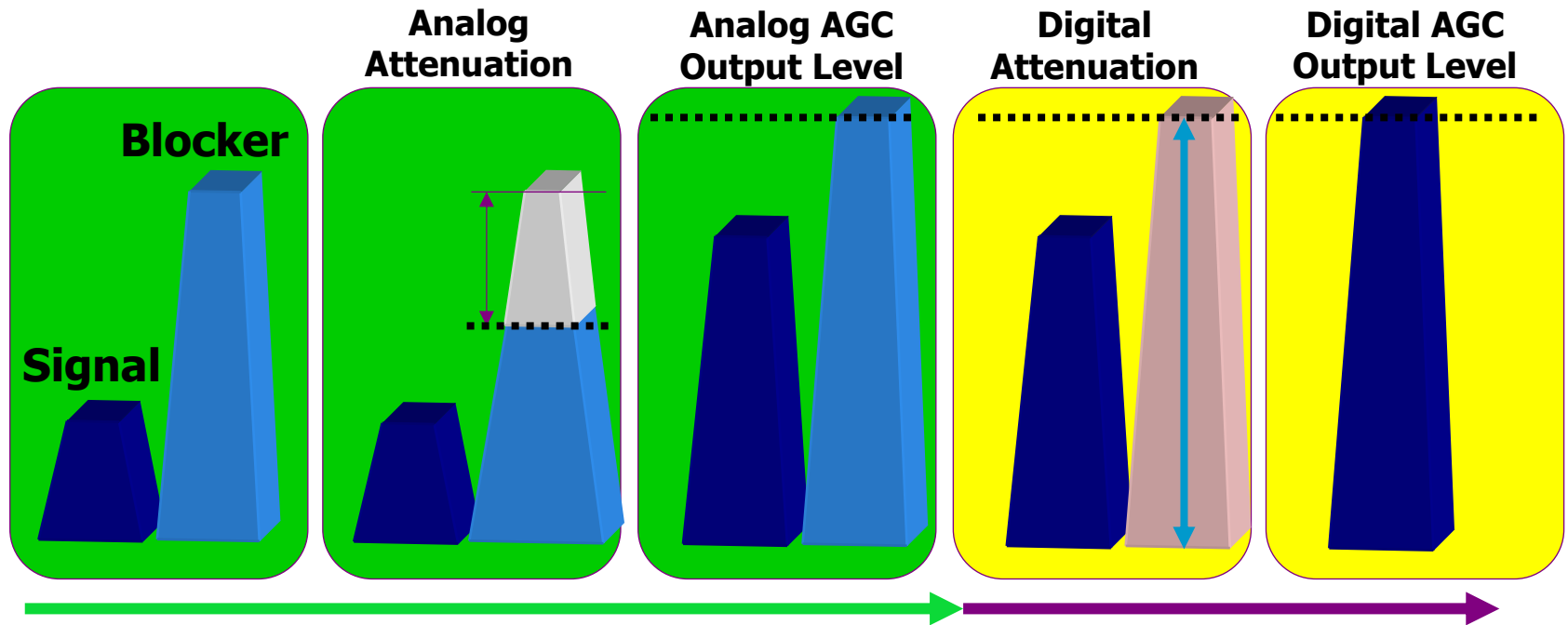
SDR-based Multimode BS and Handset



What is Digital IF?



Blocker Rejection and Digital AGC



Analog Processing

Digital Processing

RF Input

**Analog SAW
filter output**

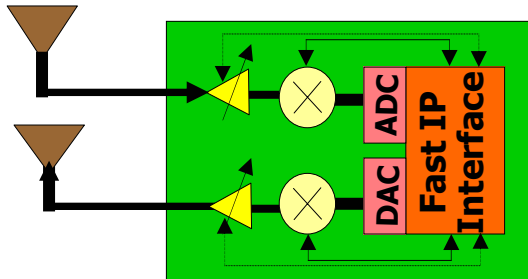
**Analog AGC
output**

**Digital filter
output**

**Digital AGC
output**

Open Digital IF Architecture for BS

Antenna



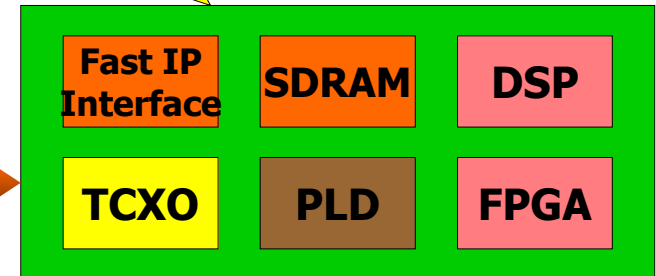
RF
Modules

RTP/UDP/IPv6
Digitised IF

Feed up Tower

Open Interface allows third parties to supply just the RF/amp modules

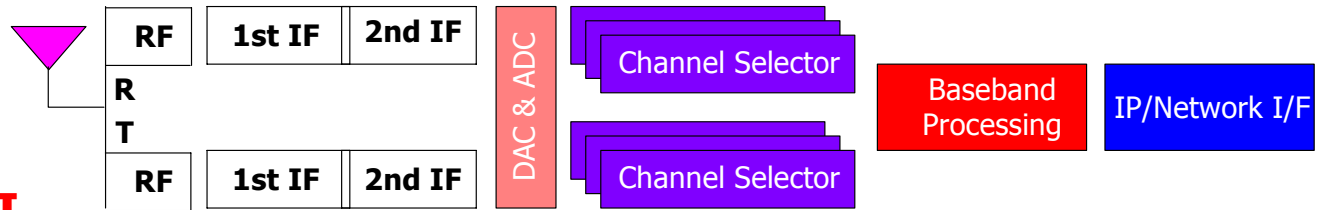
IF card is a modification of the generic processing card design



Iub/IP (Fast Ethernet)

Evolution of Digital RF/IF Technique

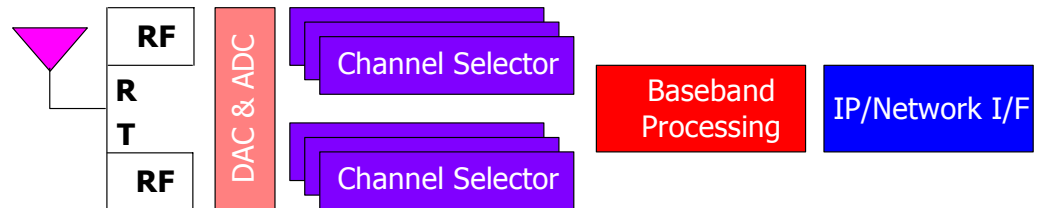
RF/IF Type I



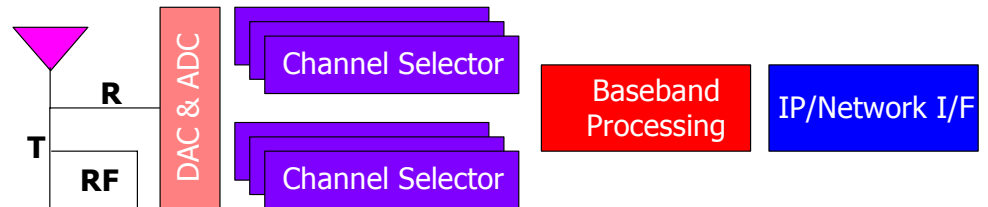
RF/IF Type II



RF/IF Type III



RF/IF Type IV



Advantages of Digital IF

- More digital components in Analog Front End
- More digitally tunable components
- More strong to adjacent co-channel interference
- Easy to adapt sophisticated digital signal processing in IF
(eg., Adaptive pre-distorter, IF bandpass filtering, etc)
- Easy to upgrade by software to fit released spec.
- More robust to aging problem
- Cost effective by reducing analog components

Components for implementing Digital IF

<i>Analog IF</i>	<i>Digital IF</i>
Amplifier	Digital Multiplier
Mixer	Digital Multiplier & LUT
Local Oscillator	Numerical Oscillator
Filter	Digital Filter & RAM
	ADC,DAC

Characterisitics of Analog-to-Digital Converter

■ Sampling Speed

- As increasing
 - Processing bandwidth is widened
 - Processing gain for baseband is increased
 - Power consumption is increased
- As decreasing
 - Power consumption is decreased
 - Suitable for handset with using Zero IF technique

■ Bit Resolution

- It determines dynamic range of ADC (N bit ADC $\sim 6 \cdot N$ [dB])
- ENOB(Effective Number of Bits)
 - It is less than $6 \cdot N$ [dB] Dynamic Range due to harmonic noise

■ Analog Input Bandwidth

- It should be greater than Nyquist Freq. for bandpass sampling

Considerations for ADC Circuit Design

- Input center frequency is set to $f_{\text{Nyquist}}/2$ due to mitigate
 - **1/f Noise around DC**
 - **Image around f_{Nyquist}**
- Isolation between analog input and digital circuit
 - **Isolation between analog components and digital components**
 - **Isolation between analog ground and digital ground**
- Input Clock for ADC should have
 - **Very low noise**
 - **Be isolated with the clock for digital circuit**
 - **Be differential clock to alleviate noise**

Performance of current and future ADCs

Feature	Performance Range	
	Semiconductor-Based	Superconductor-Based
Frequency	Up to 200 MHz	Up to > 2 GHz
Resolution	10 to 14 bits quoted (ENOB typically 2 to 4 less)	14 to 24 bits ENOB
Spur Free Dynamic Range	60 to 90 dB	100 to 150 dB
Sensitivity	N/A (normally post LNA)	-120 to -180 dBm

Characterisitics of Digital-to-Analog Converte

- Sampling Speed
 - **determines available output frequency**
- SFDR(Spur Free Dynamic Range)
 - **determines output dynamic range with considering Harmonic Distortion**
- Inverse Sinc Filter
 - **is required for the flatness of inband frequency characteristic**
- Image Rejection Filter
 - **Is required for unintentional harmonic image**

Bandpass Sampling Technique (cont.)

Bandpass Sampling

The technique of under-sampling a modulated signal to achieve frequency translation via intentional aliasing.

Sampling Conditions

$$0 < F_{IF} - \frac{BW_I}{2}$$

$$F_{IF} + \frac{BW_I}{2} < \frac{F_S}{2}$$

Bandpass Sampling Technique (cont.)

Frequency Selection Rule

IF frequency in information bandwidth which is occurred from folding can be determined from sampling frequency F_s and center frequency F_a .

$$\text{If } \text{fix}\left(\frac{F_a}{F_s/2}\right) \text{ is } \begin{cases} \text{even, } F_{IF} = \text{rem}(F_a, F_s) \\ \text{odd, } F_{IF} = F_s - \text{rem}(F_a, F_s) \end{cases}$$

where F_a = input frequency to ADC

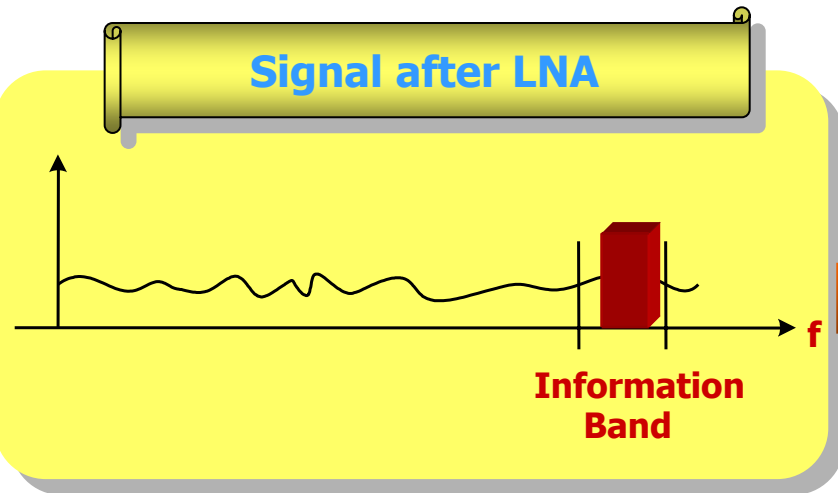
F_{IF} = intermediate frequency

$\text{fix}(a)$: truncated portion of argument a

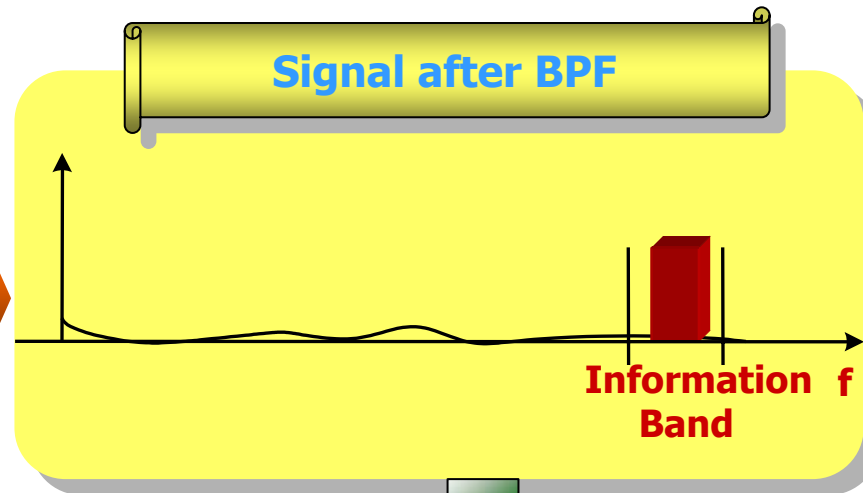
$\text{rem}(a, b)$: remainder after division of a by b

Bandpass Sampling Technique

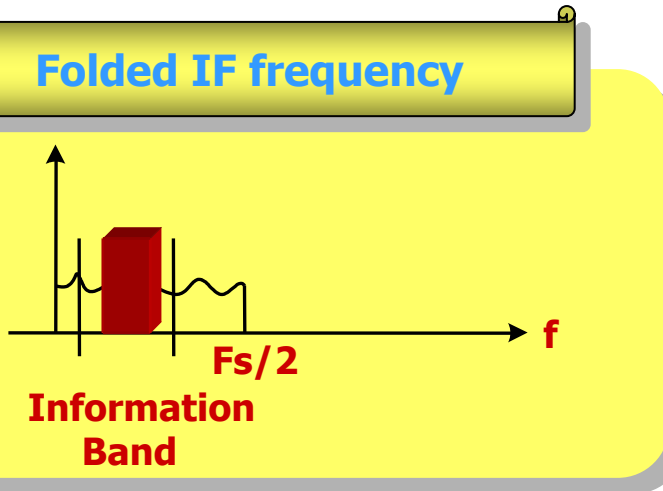
Signal after LNA



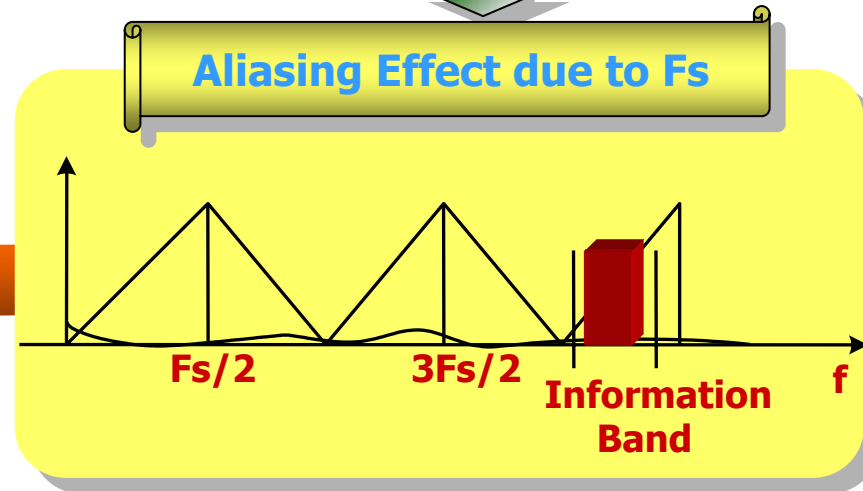
Signal after BPF



Folded IF frequency

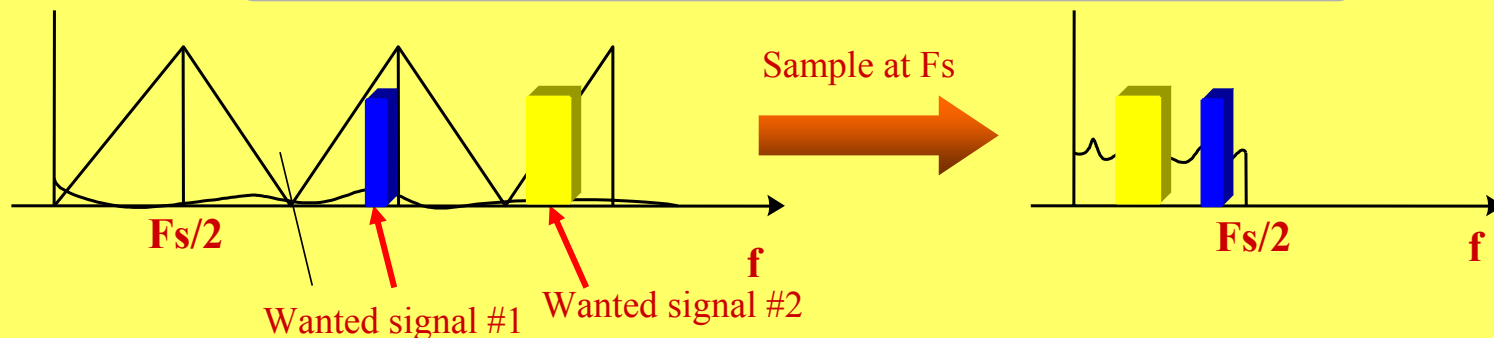


Aliasing Effect due to F_s



Bandpass Sampling for Multiband Signal

Bandpass Sampling for Multiband Signal



Sampling Condition

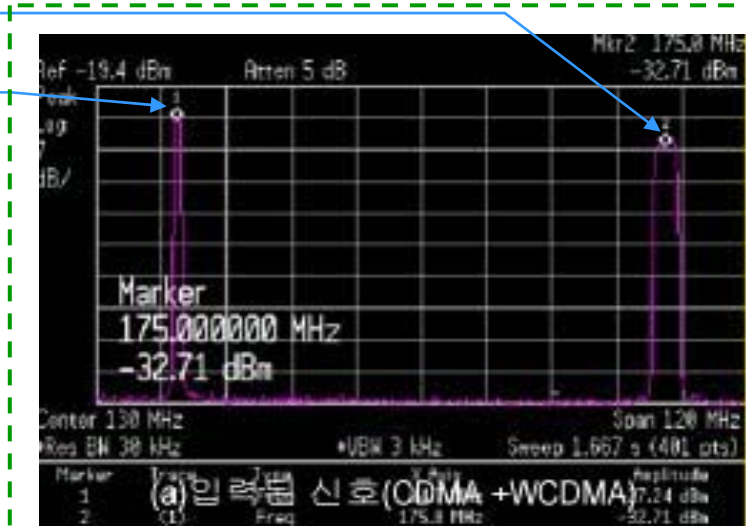
Multiband signals resulted from folding effect should not be overlapped each other in information band.

$$|F_{IF_1} - F_{IF_2}| \geq \frac{BW_{I_1} + BW_{I_2}}{2}$$

An Example : IS-95 and W-CDMA

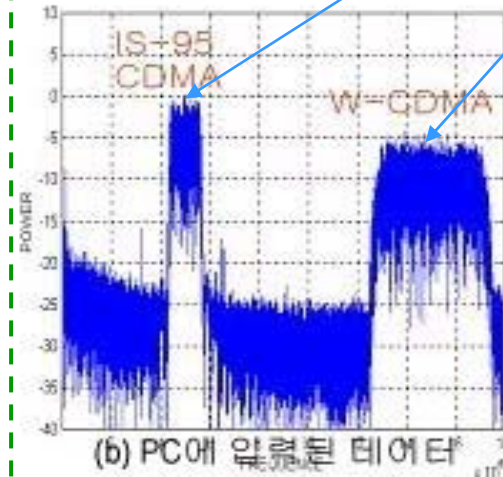
175MHz

85MHz



5MHz

15MHz



SIGNAL GENERATOR (IS-95)
S1

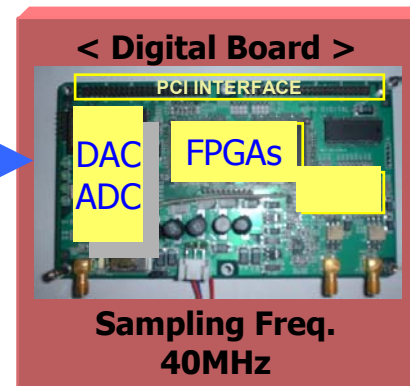
IS-95 Signal
Fc=85MHz
-10dBm

SIGNAL GENERATOR (IMT-2000)
S2

IMT-2000 Signal
Fc=175MHz
-10dBm



S1 + S2



PC

Multimode Input (IS-95, W-CDMA, W-LAN)

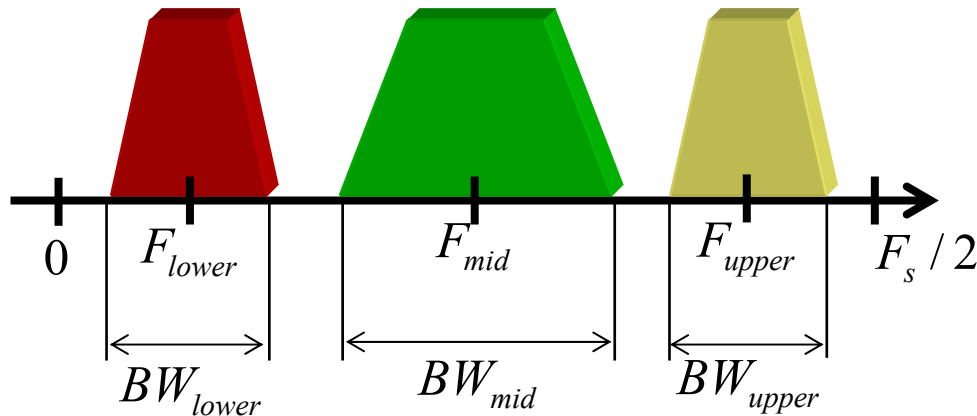
- Signals considered here
 - **IS-95**
 - Bandwidth : 1.25 MHz/1FA
 - Chip rate : 1.2288 Mcps
 - **W-CDMA**
 - Bandwidth : 5 MHz/1FA
 - Chip rate : 3.84 Mcps
 - **IEEE 802.11a W-LAN**
 - Effective Bandwidth : 16.6MHz
 - Transmission Bandwidth : 20 MHz
- Total information bandwidth : 26.25 MHz

IF Freq. Plan for IS-95, W-CDMA, W-LAN

■ Conditions

$$0 < F_{lower} - \frac{BW_{lower}}{2} \quad F_{upper} + \frac{BW_{upper}}{2} < \frac{F_s}{2}$$

$$|F_{mid} - F_{lower}| \geq \frac{BW_{mid} + BW_{lower}}{2} \quad |F_{mid} - F_{upper}| \geq \frac{BW_{mid} + BW_{upper}}{2}$$

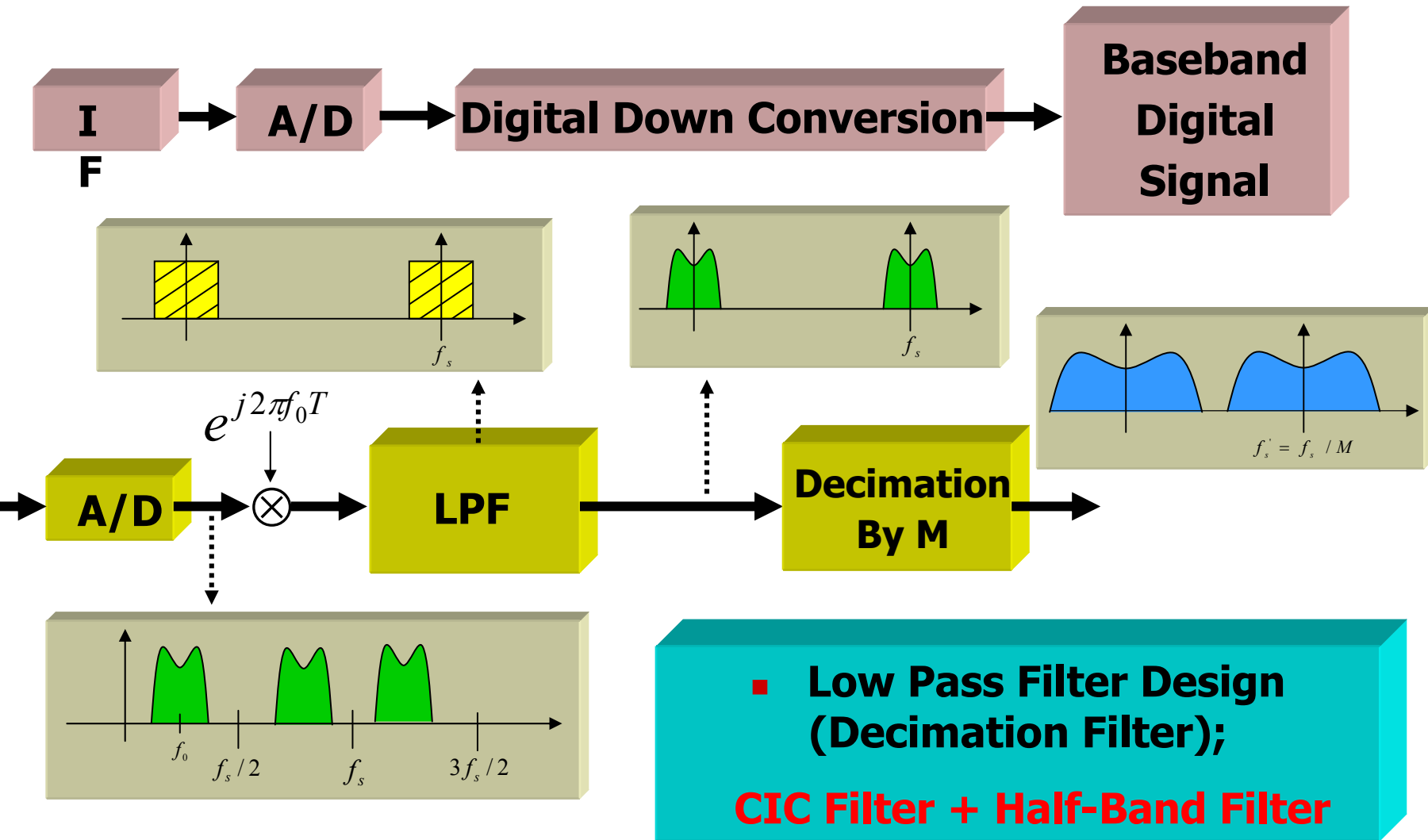


Selected IF Frequency Plans

- IF frequency band : 70~130 MHz
- Sampling Frequency : 65 MHz

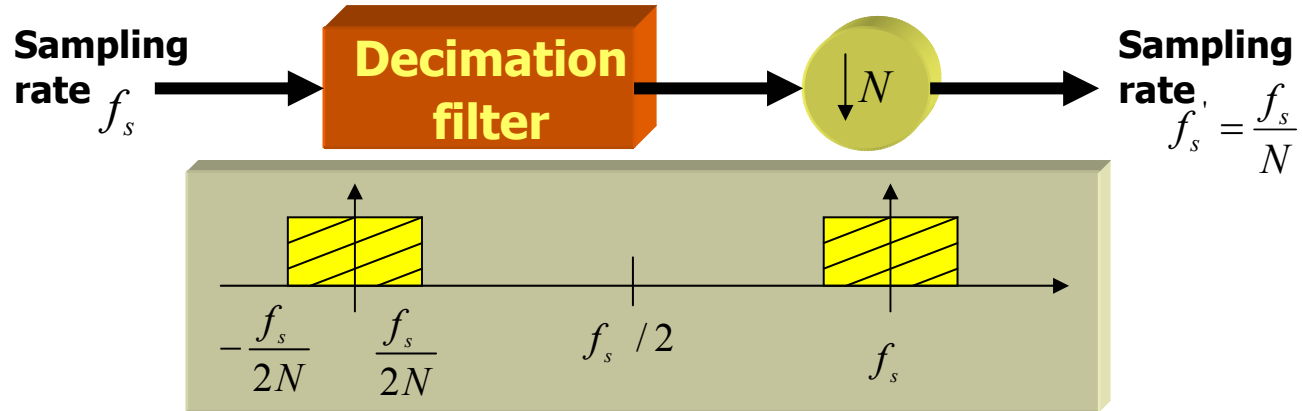
IF Frequency (MHz)			Digital Frequency (MHz)		
IS-95	W-CDMA	W-LAN	IS-95	W-CDMA	W-LAN
128	123	109	2	7	21
127	122	88	3	8	23
119	125	107	11	5	23
98	104	118	32	26	12
96	126	84	31	4	19
74	126	109	9	4	21

Digital IF Down Conversion

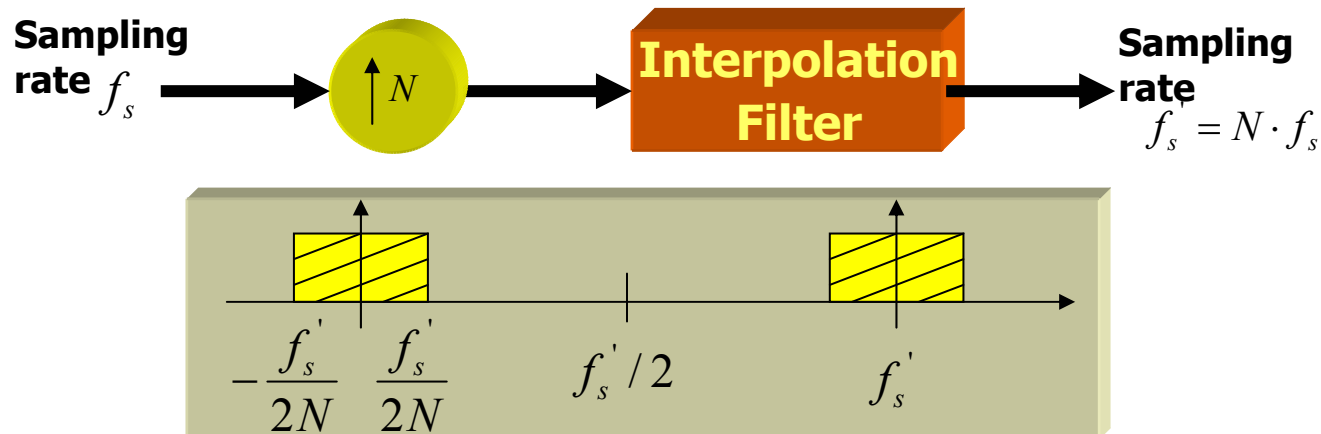


Decimation and Interpolation process

■ Decimation Process N : Decimation ratio

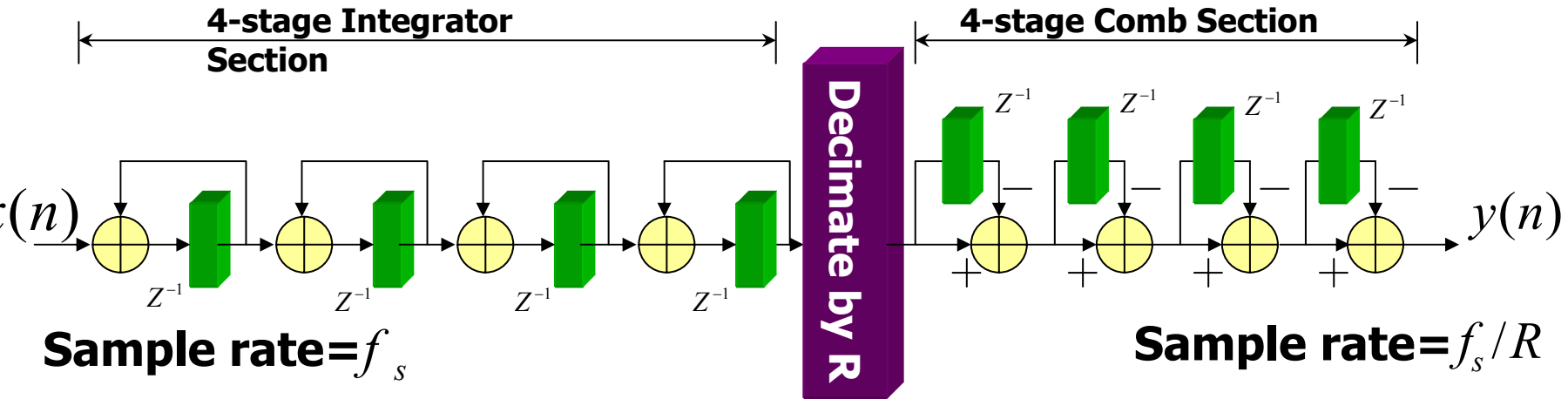


■ Interpolation Process p : Interpolation ratio

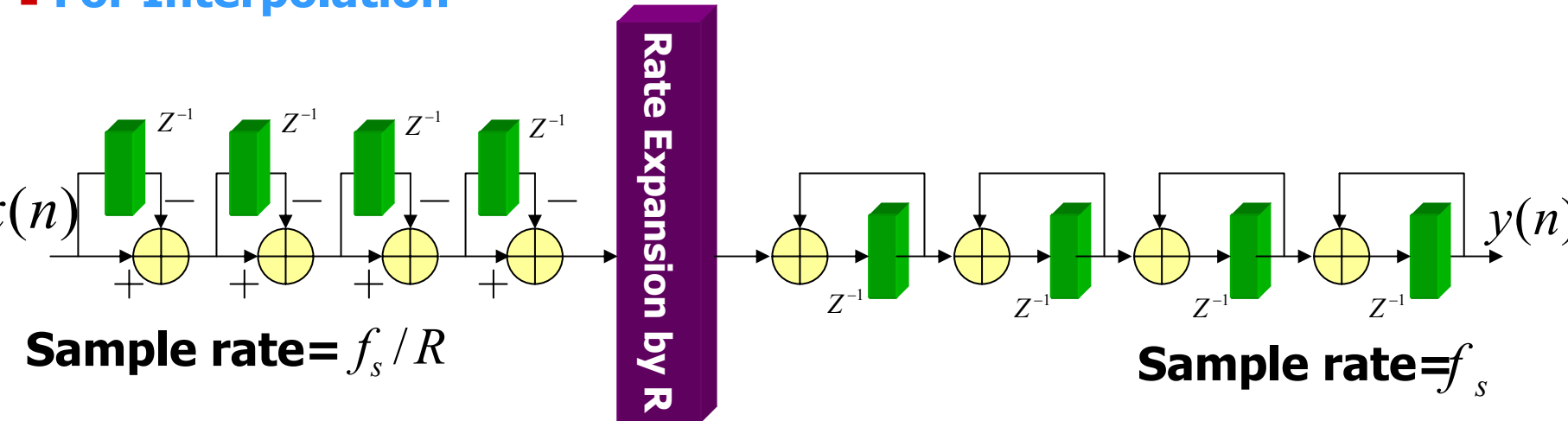


Structure of CIC Filter

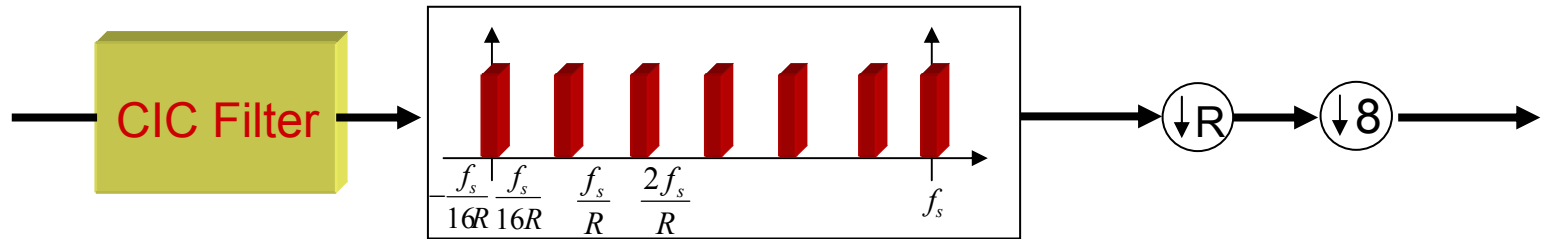
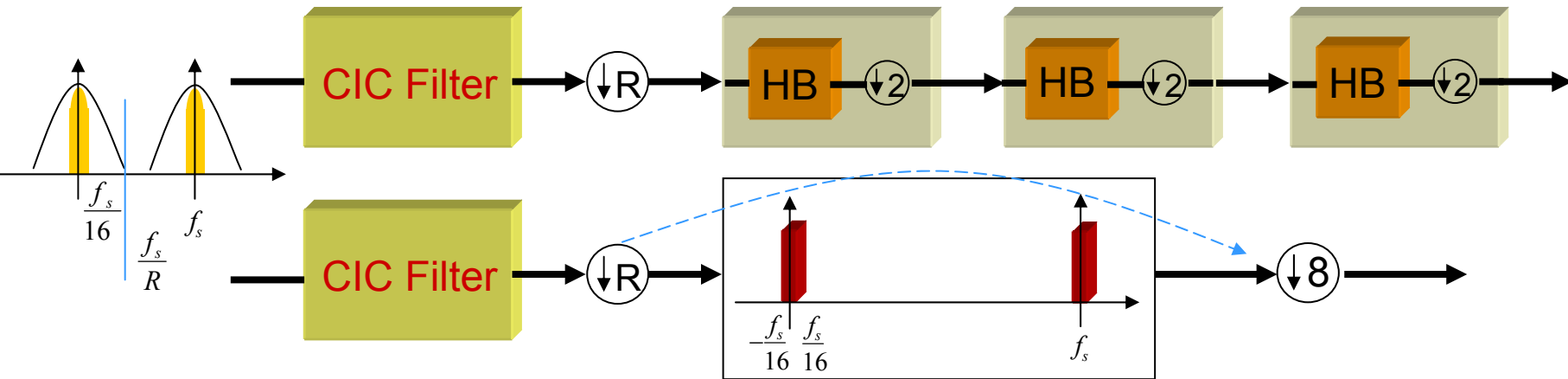
■ For Decimation



■ For Interpolation

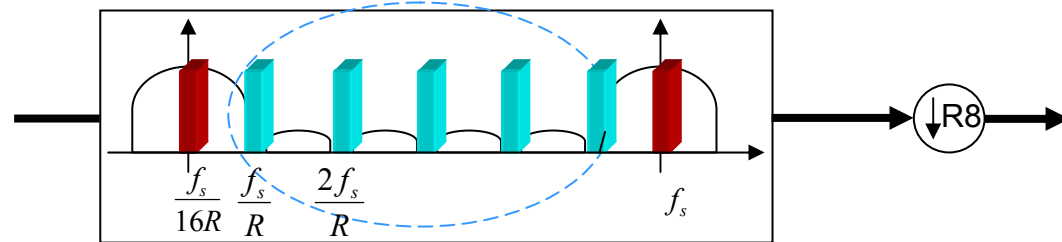


Decimation Filter using CIC & HB Filter

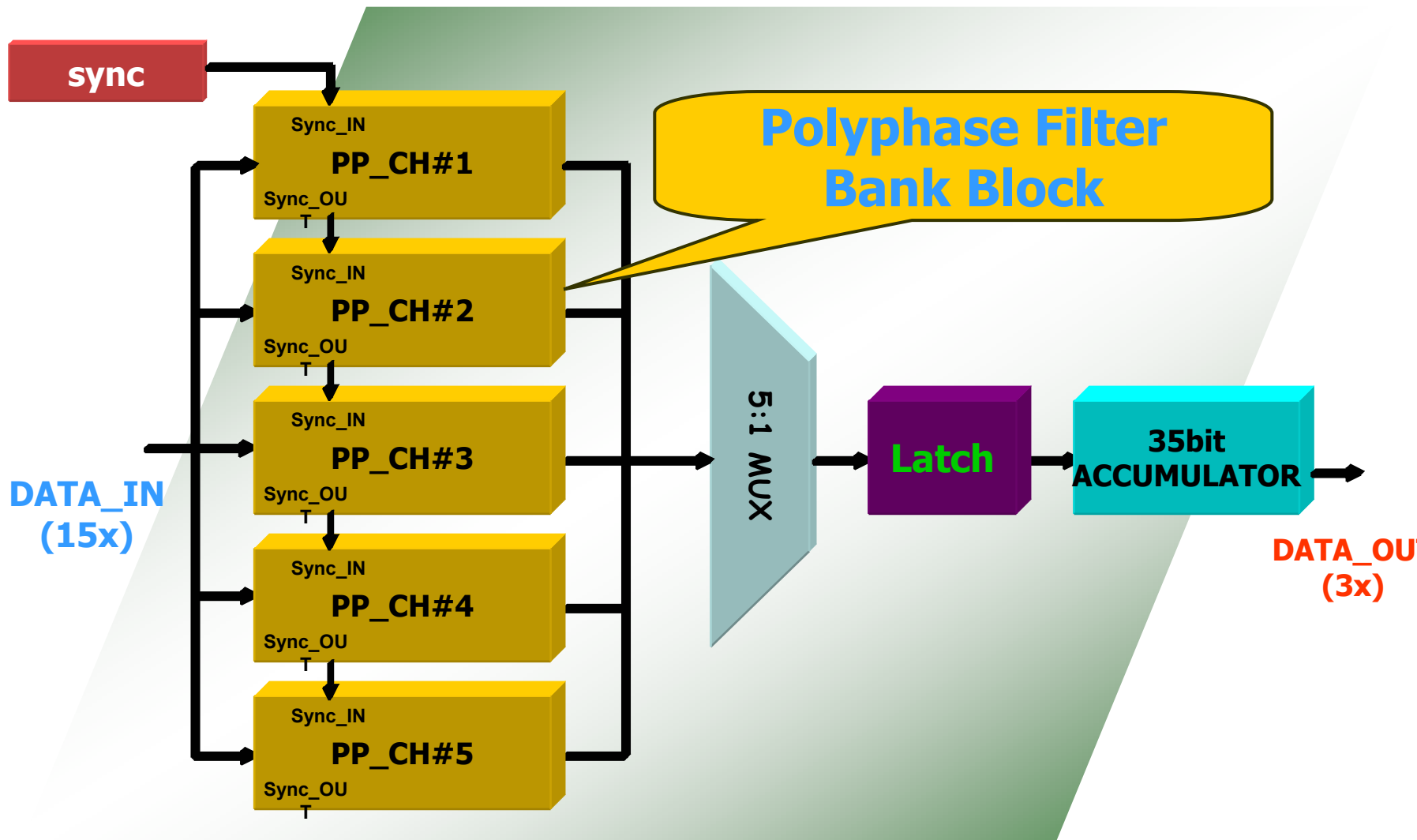


$$H(z) = \left(\frac{1 - z^{-R}}{1 - z^{-1}} \right)^k$$

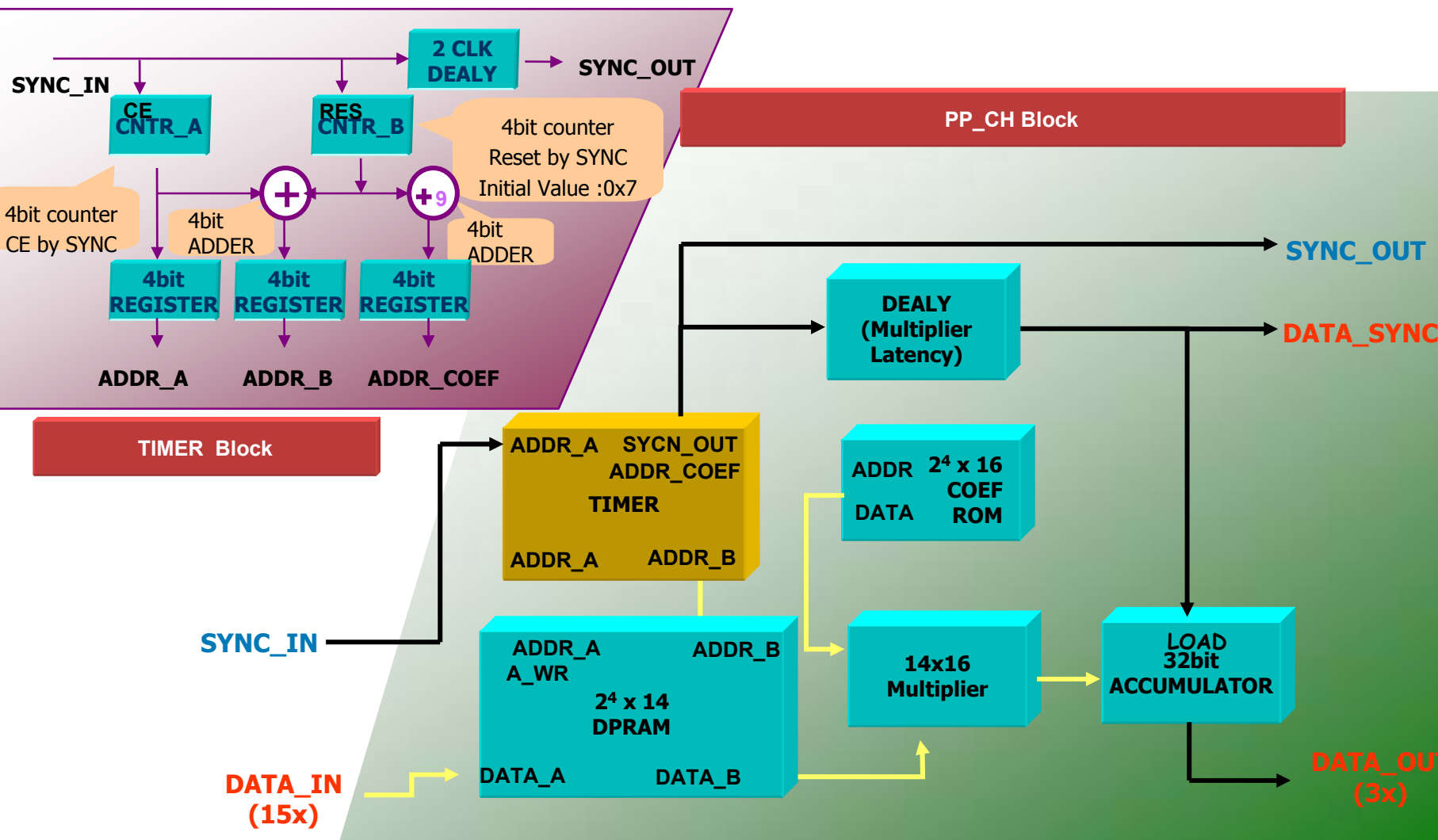
$$= \left\{ \sum_{i=0}^{R-1} z^{-i} \right\}^k$$



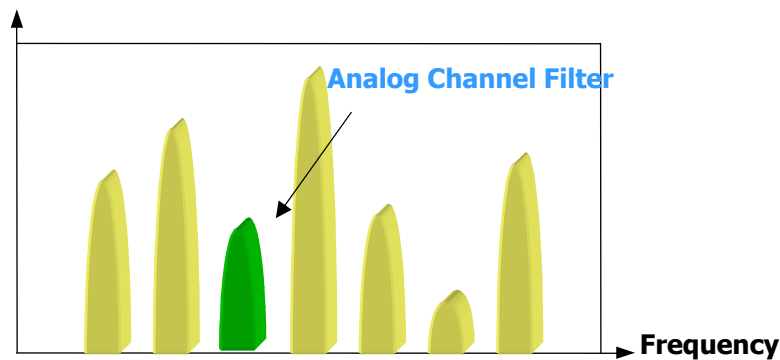
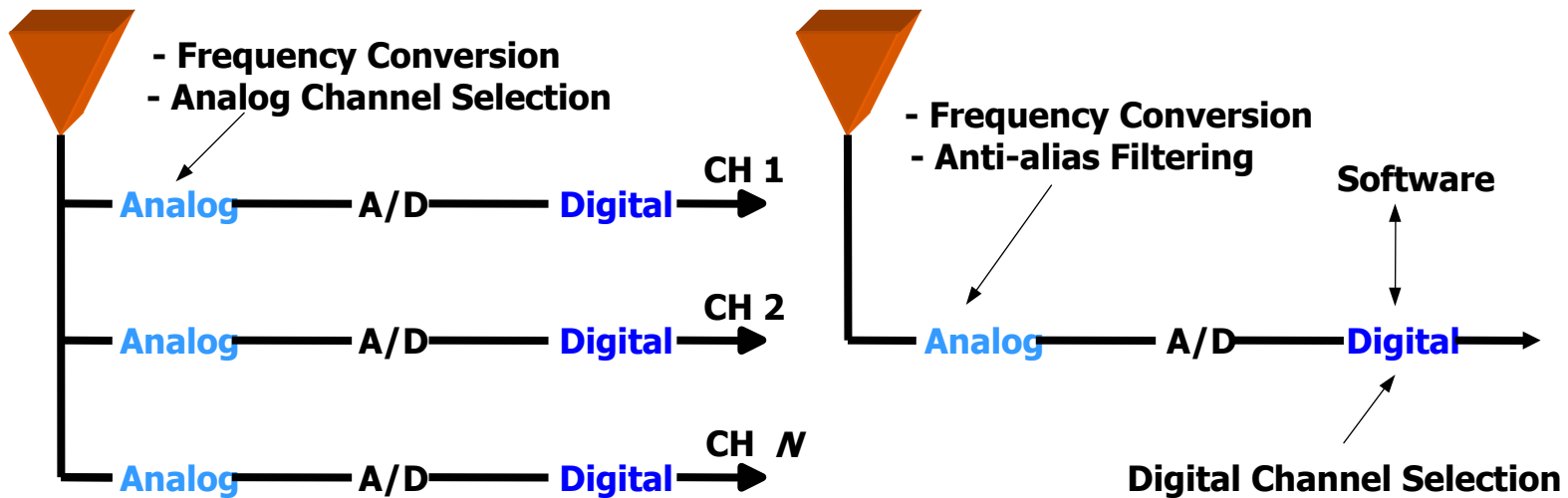
Efficient FIR Filter Processing (cont.)



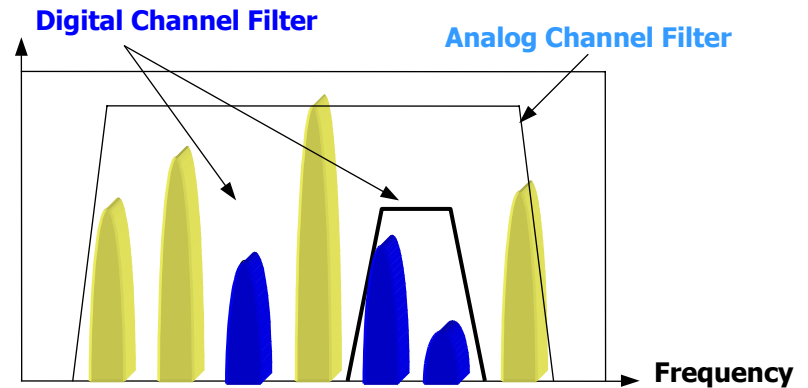
Efficient FIR Filter Processing



Digital IF Channelizer

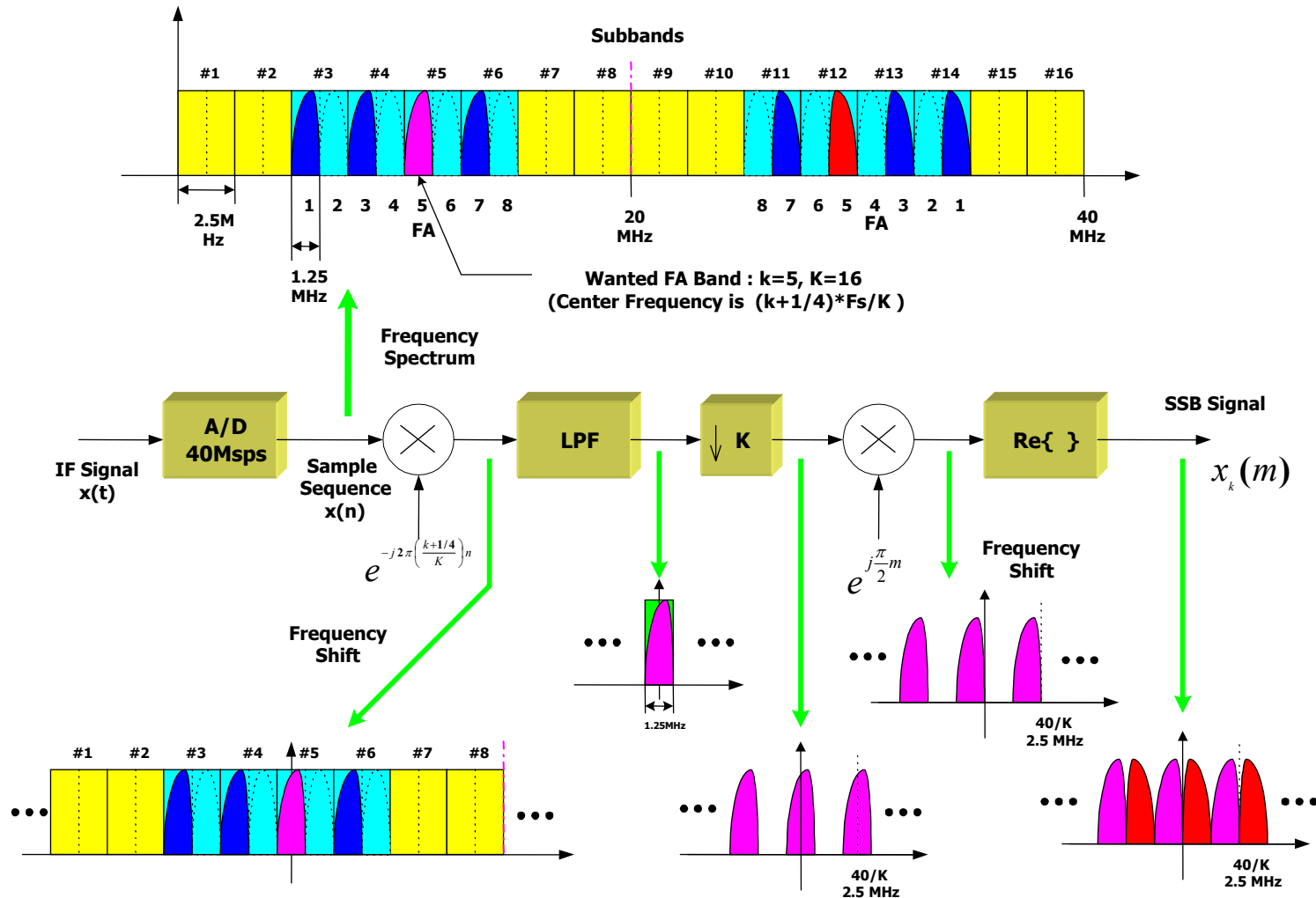


Conventional Multi-hardware Radio



Software Defined Radio

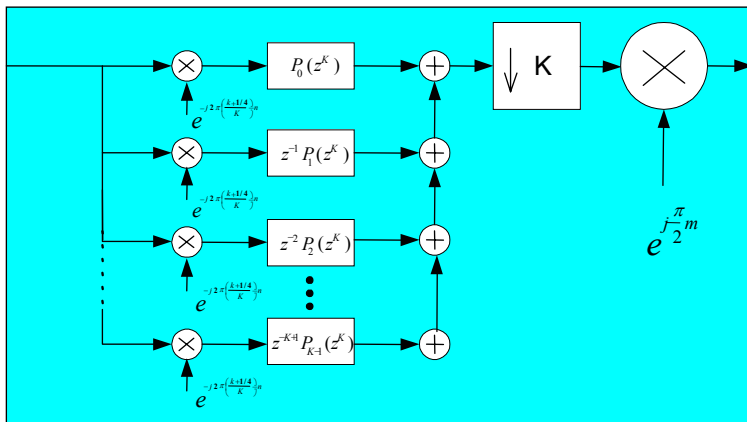
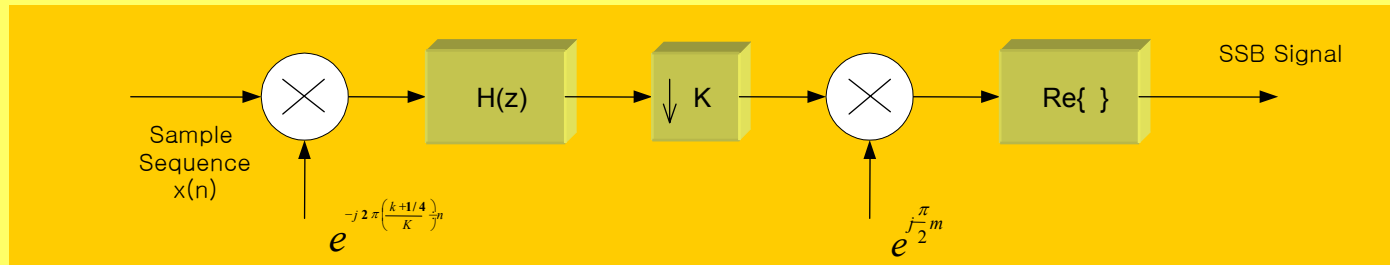
Functionality of Digital IF Channelizer



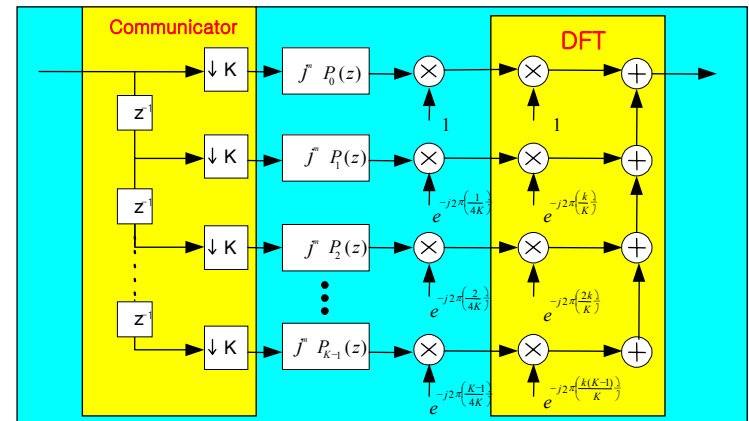
Channelizer using Polyphase Filter Bank

**Prototype
Lowpass Filter**

$$H(z) = P_0(z^K) + z^{-1}P_1(z^K) + z^{-2}P_2(z^K) + \dots + z^{-K+1}P_{K-1}(z^K)$$



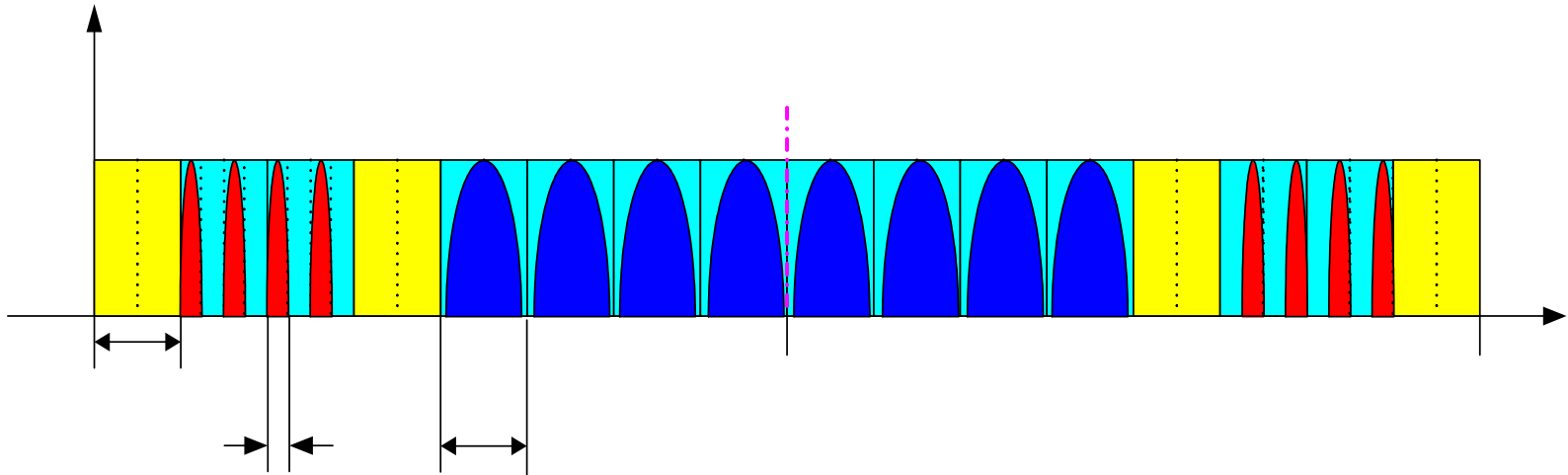
≡



The above models are equivalent.

An Example : IS-95 and W-CDMA

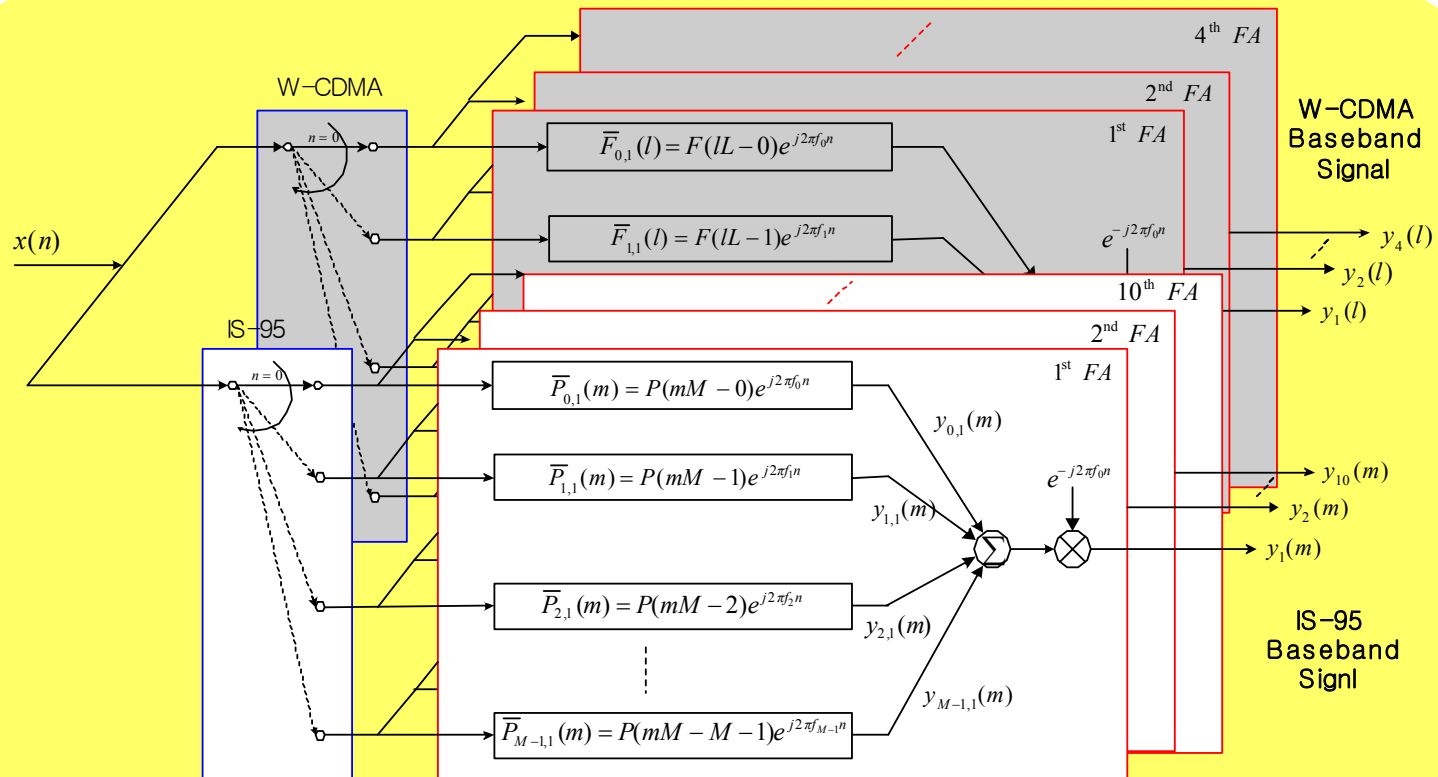
- Sampling Frequency : 80 MHz
- FA BW : 5MHz
- IS-95 : FA BW 1.25MHz



Multiband Channelizer for IS-95 & W-CDMA

■ Characteristics :

- Polyphase filter bank structure performed with low processing clock
- Each communicator is employed for each multi-FA standard.



Conclusions

- For future mobile communication systems, the development of multi-mode and multi-band SDR platform is necessary.
- For multi-mode and multi-band transceiver, the development of Digital IF technology is necessary.
- To realize multi-mode and multi-band SDR-based Digital IF module, reconfigurable RF devices and digital processors with high speed and low power consumption are required.
- More flexible and sophisticated digital signal processing algorithms must be employed onto SDR platform to improve the performance of future mobile communication systems.