5G 비전을 실현하기 위한 5G 무선통신기술 웹 세미나

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Agenda

– Modeling and evaluating multiple waveform techniques

– What do you need for mmWave MIMO radio channel study?

– Multi-Antenna Techniques

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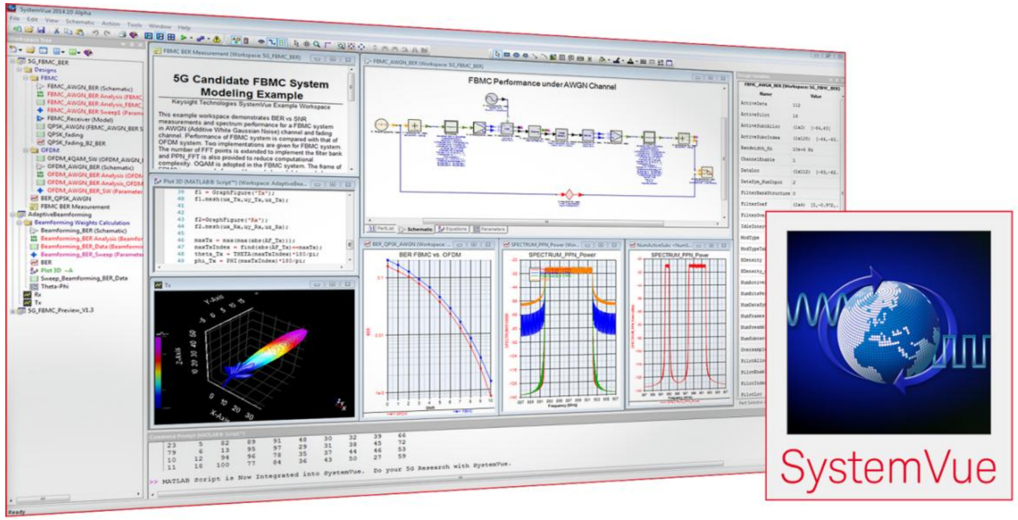

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Part I.
Modeling and evaluating multiple waveform techniques

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5G Enabling Devices >> Research Challenges

Advanced signal processing
- Multiple MIMO modes and beamforming
- Network interference suppression
- Adaptive channel estimation / equalization

New waveforms
- Legacy OFDM enhancement
- FBMC, GFDM, UFMC

Full duplex communications
- Self interference cancellation
- Dual polarization antenna
- Real time operation

- 1-10Gbps connections to end points
- 1 millisecond delay
- 1000x bandwidth
- 10-100x connected devices
- 99.999% availability
- 100% coverage
- 90% reduction in energy
- 10 year battery life for MTD

Amplifier
- Envelope tracking
- Digital predistortion
- Wide, multi bands

Multi-antenna
- Impedance matching
- Mutual coupling
- Multi-band, multi-RAT port sharing
- FD / Massive MIMO

Multiple Access
- Non-orthogonal multiple access
- Random / scheduled / hybrid

Multiple radio technologies
- GSM/EDGE/WCDMA/HSPA/LTE
- WiFi/BT/WiGig/GNSS/5G

Multi-band
- Traditional cellular bands <6GH
- WiFi, BT, GNSS bands
- 5G mmWave bands

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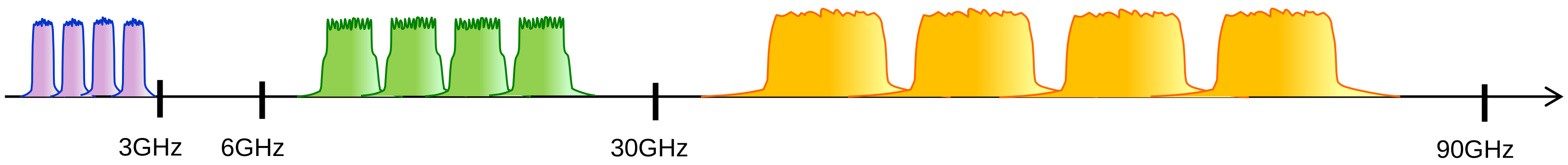
Waveform Design Considerations for 5G

Waveform

Advanced Multi-Carrier Waveforms[1]		
OFDM	FBMC / UFMC / Others	Single carrier

Bandwidth / Frequency



>> Wider BW, Higher Fc, much sensitive at phase noise

New RAT

OFDMA NOMA SCMA

Note[1]:
- Orthogonal Frequency Division Multiplexing(OFDM)
- Filter Bank Multicarrier(FBMC)
- Universal Filtered Multicarrier(UFMC)
- Generalized Frequency Division Multiplexing(GFDM)
- Frequency Quadrature Amplitude Modulation(FQAM)

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Waveform Requirements

- Efficiently support high density users
- Optimized multiple access
- Carrier assignment schemes in asynchronous context

- Efficient usage of the allocated spectrum
- Robustness to narrow-band jammers and impulse noise
- High performance spectrum sensing

- Low computational complexity
- Compatibility OFDM vs. NEW

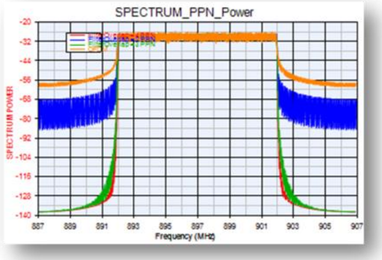

Figure 1.

– OFDM vs. FBMC Spectrum Using different filter overlap factor

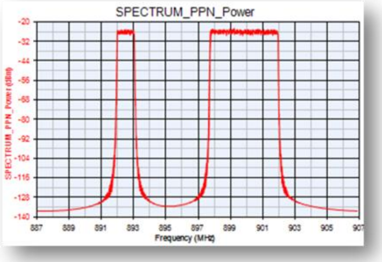

Figure 2.

– FBMC Fragmented Spectrum

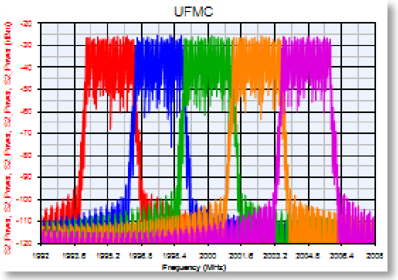

Figure 3.

– UFMC multiplex of sub-bands

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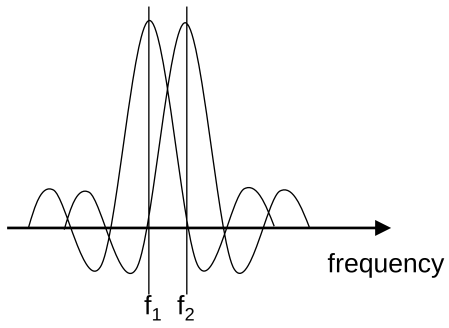
OFDM

Advantage

- Good spectral efficiency
- Resistance against multipath interference
- Efficiently implemented using FFTs and IFFTs
- Subcarrier nulls correspond to peaks of adjacent subcarriers for zero inter-carrier-interference



Drawback

- Some loss of spectral efficiency due to Cyclic Prefix insertion
- Imperfect synchronization cause loss of orthogonality
- Subcarrier intermodulation must be reduced
- High out-of-band power
- Large peak to average power ratio(PAR) leads to amplifier inefficiency

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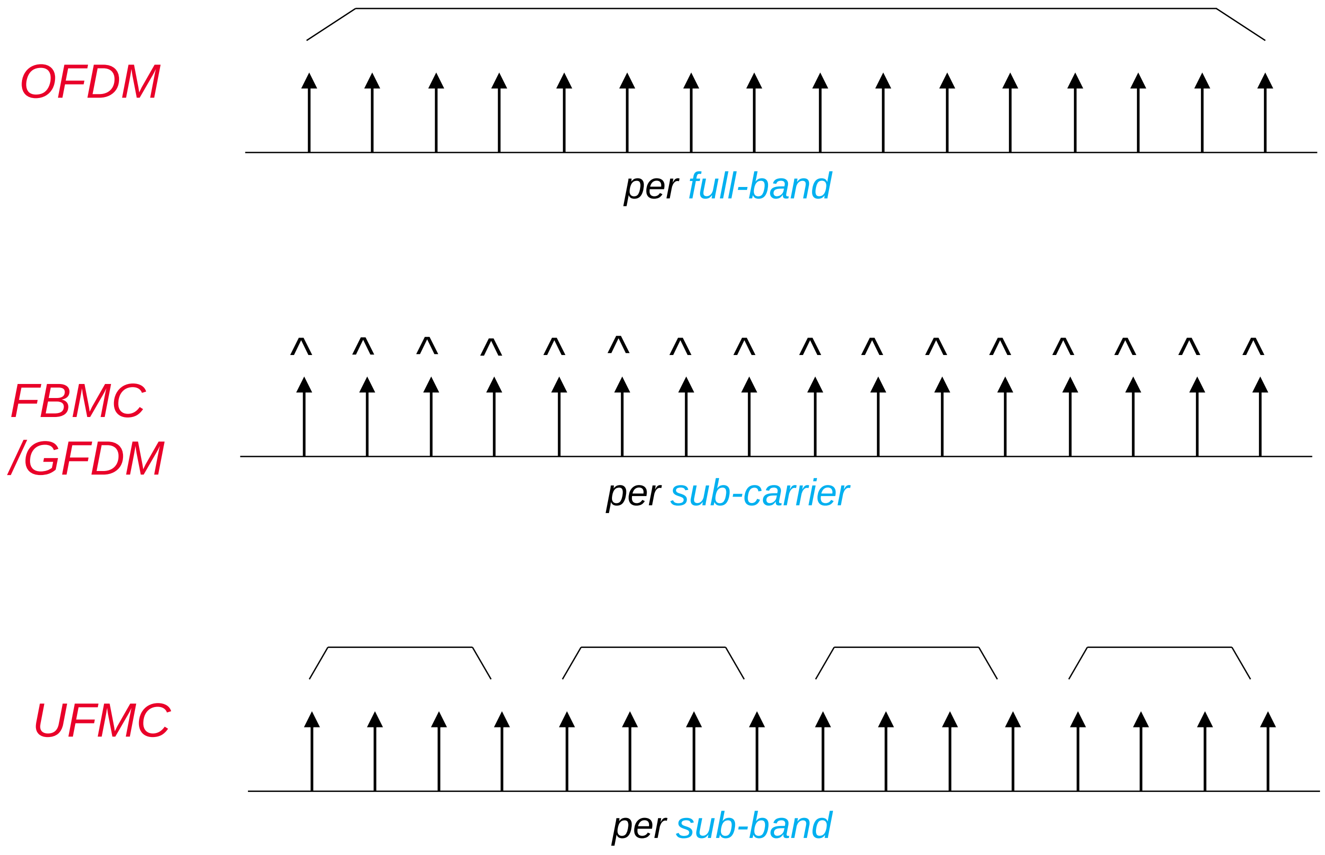
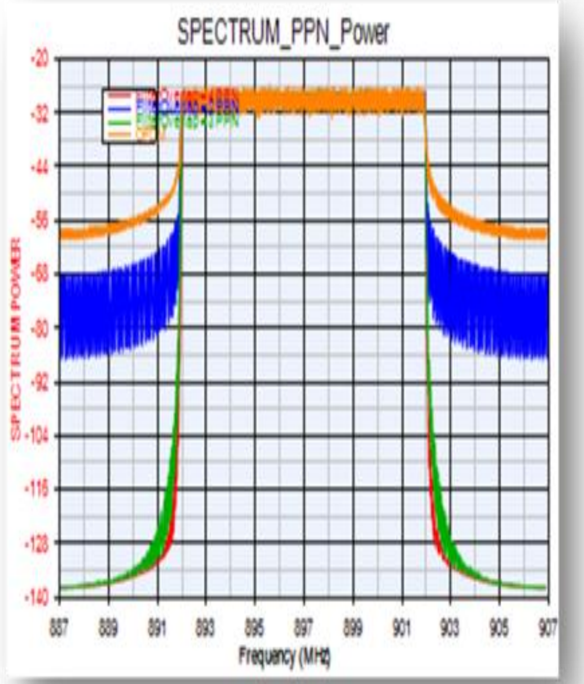
Different Type of Waveforms and Filter Operation





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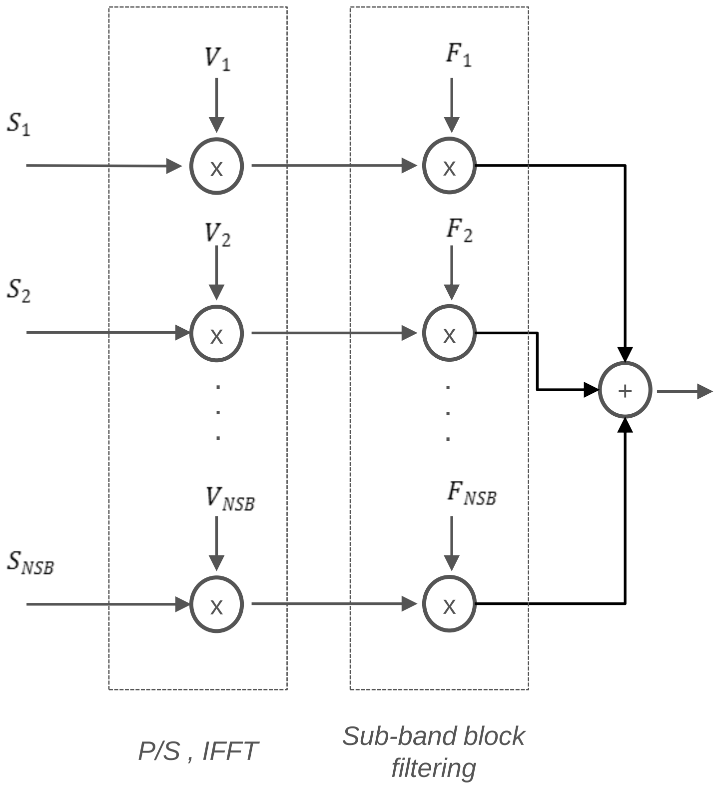
UFMC - Universal Filtered Multi-Carrier



$$\underset{[(N+L-1),1]}{X_k} = \sum_{i=1}^{N_{SB}} \underset{[(N+L-1),N]}{F_{i,k}} \; \underset{[N,n_i]}{V_{i,k}} \; \underset{[n,1]}{S_{i,k}}$$

where:
- N : FFT size, L : Filter length, ni : Complex QAM symbol
- $F_{i,k}$ is a Toeplitz matrix, composed of the filter impulse response
- $V_{i,k}$ is a IDFT matrix, according to the respective sub − band position
- $S_{i,k}$ is a symbol matrix

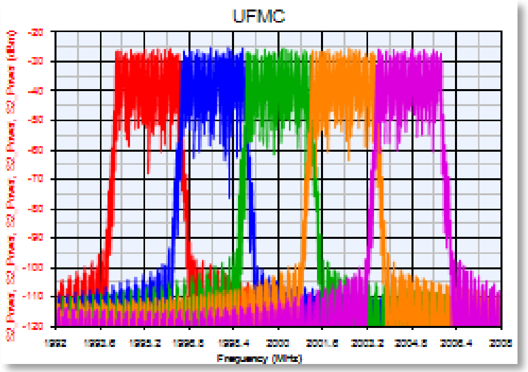


Figure 1.
Five sub-band multiplexed

* OFDM can be implemented by set L as 1

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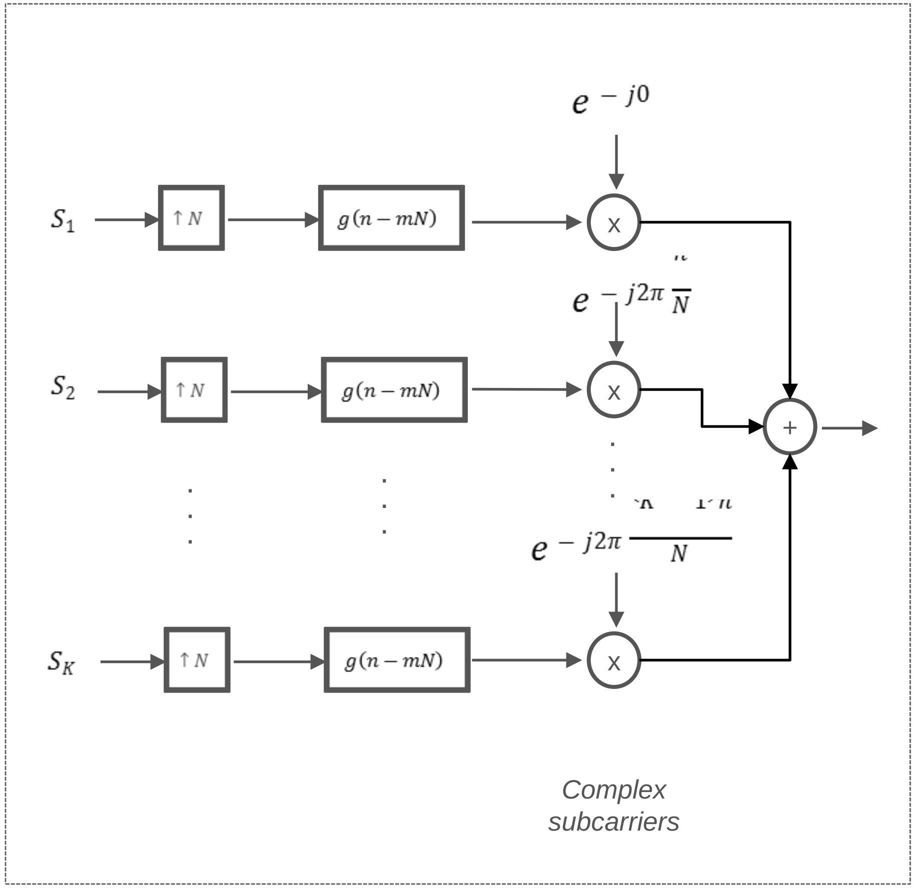
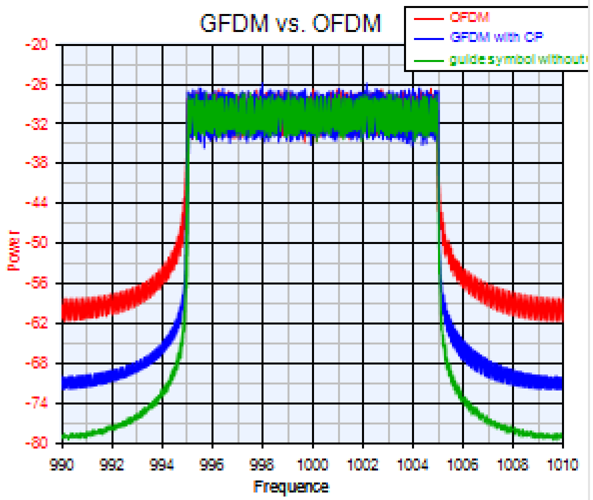
GFDM – Generalized Frequency Division Multiplexing



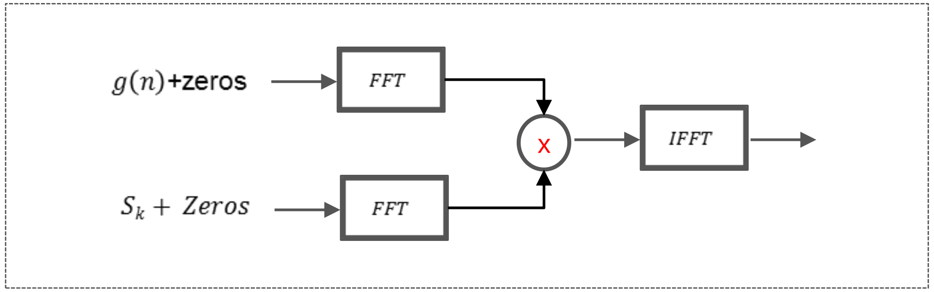
$$X_n = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} S_{k,m}\, \delta(n-mN) * g(n-mN) e^{-j2\pi \frac{k}{N} n}$$

where:

- $S_{k,m}$ *is a symbol sequence*
- K *: number of subcarriers,*
- M *: number of symbols per subcarrier*
- g(n) *is a transmit filter*
- * *: circular convolution*



Circular convolution implementation in frequency domain



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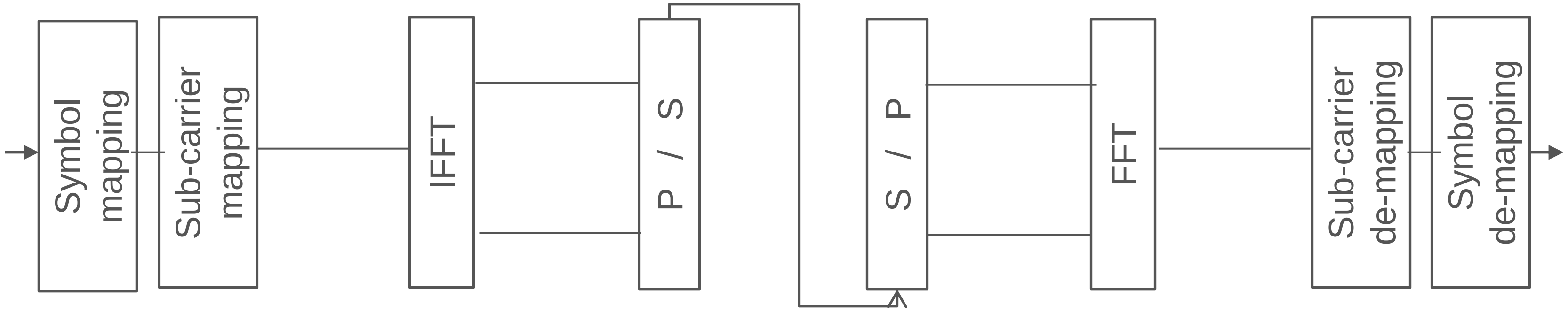
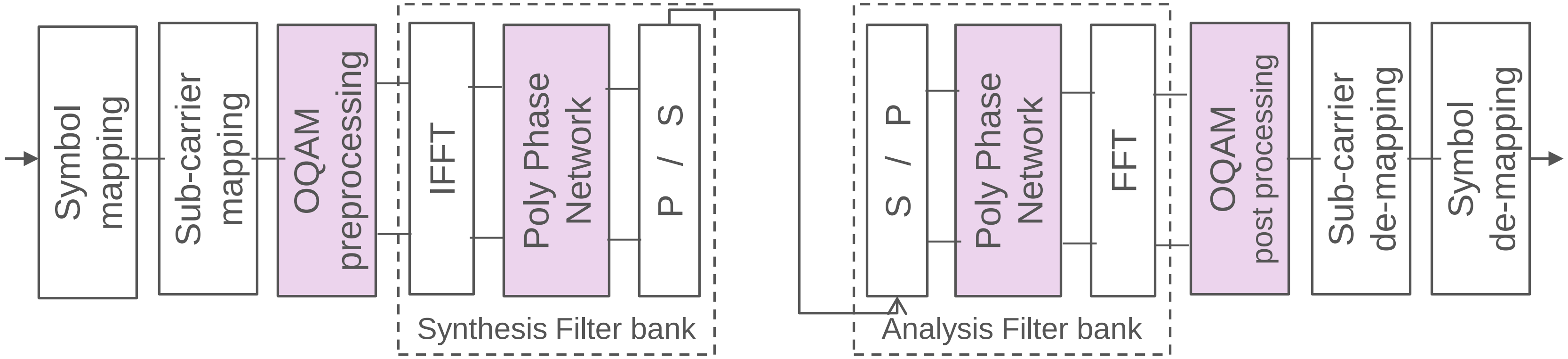
What is Problem Being Solved?

High adjacent channel power ratio(ACPR)



OFDM baseband signal processing blocks

High peak-to-average power ratio(PAPR)



FBMC baseband signal processing blocks

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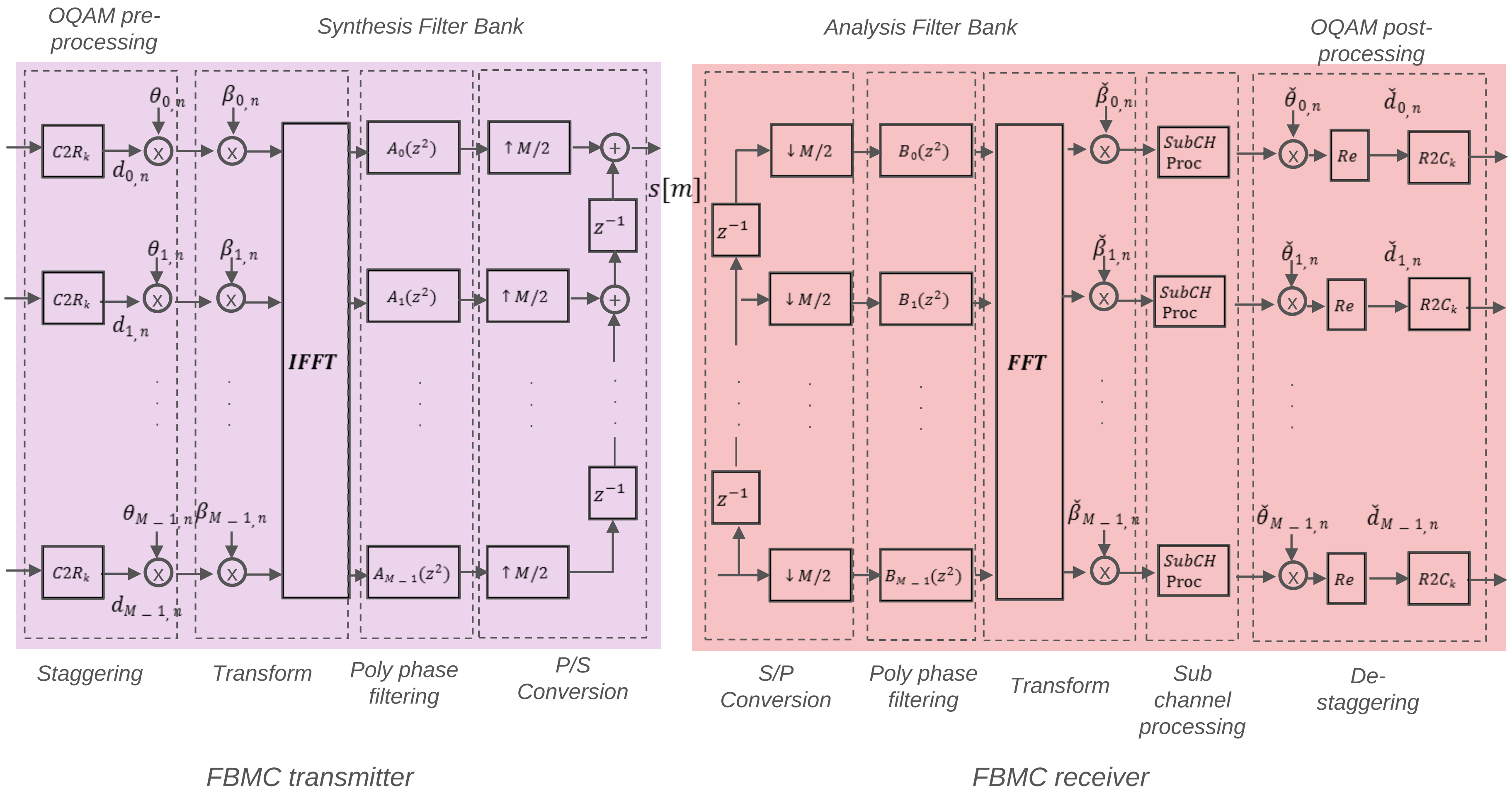
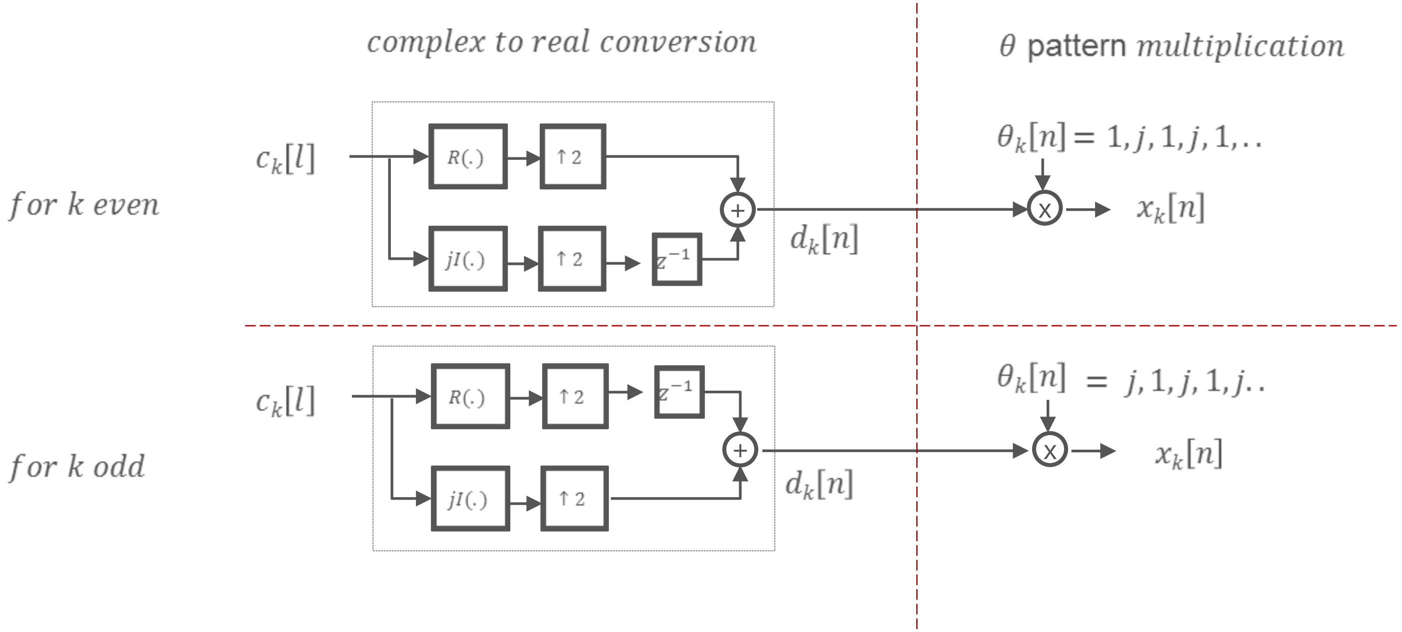
FBMC Signal Processing Block



OQAM Preprocessing



- A time offset of half a QAM symbol period(T/2) is applied to either the real part or the imaginary part of the QAM symbol
- For two successive sub-channels, say m and m+1, the offset are applied to the real part of the QAM symbol in sub-channel , while it is applied to the imaginary part of the QAM symbol in sub-channel m+1.

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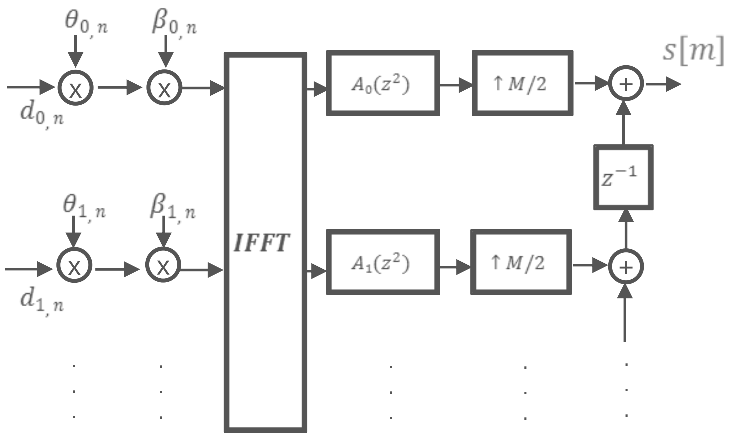
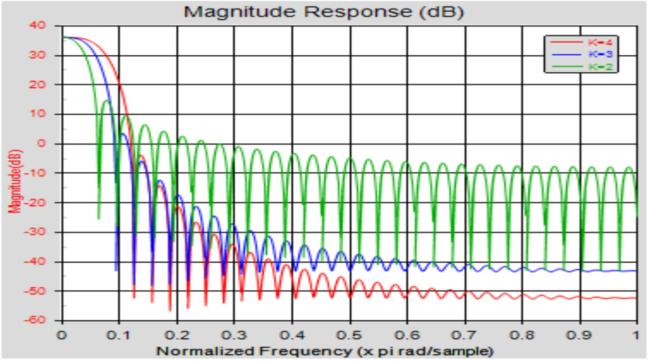
Synthesis Filter Bank

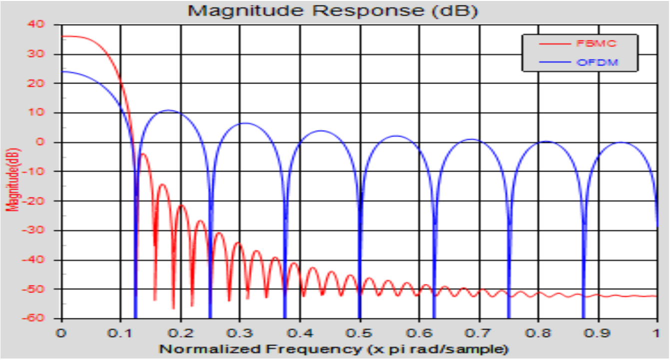


$$s[m] = \sum_{k=0}^{M-1} \sum_{n=-\infty}^{\infty} d_{k,n}\, \theta_{k,n}\, g_k[m - nM/2]$$

where:

- *M is number of subcarriers*
- $d_{k,n}$ *is the real valued symbol*
- $\theta_{k,n}$ *is* $j^{(k+n)}$
- $g_k(m)$ *is impulse response of the filters*





* Filter overlap factor K : number of multicarrier symbols which overlap in the time domain.

* OFDM can be implemented by set K as 1

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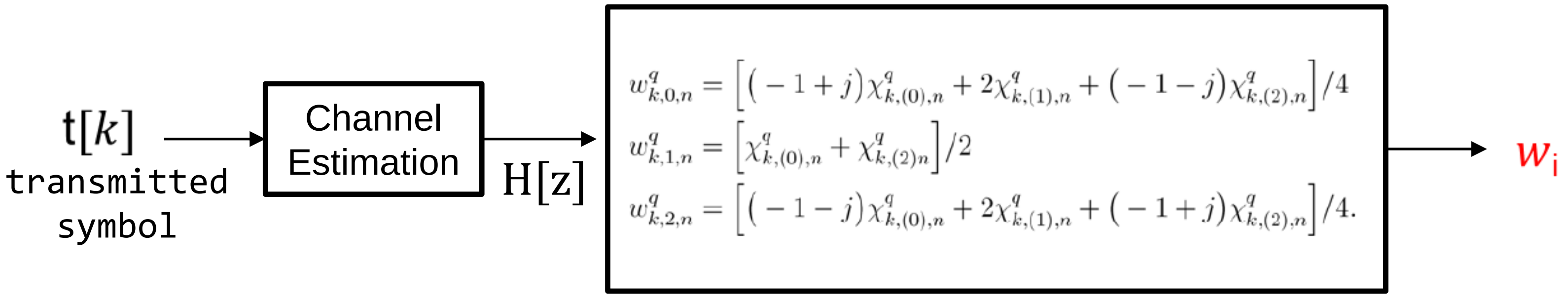
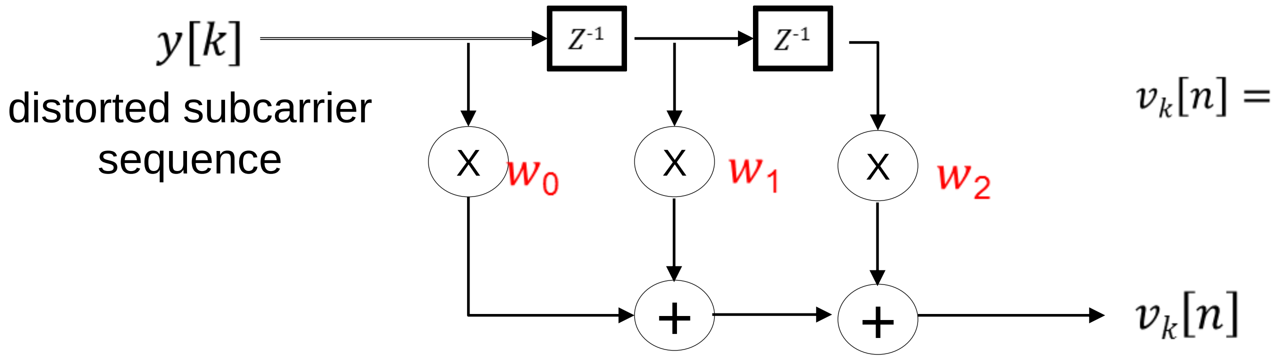
Sub-channel Equalization

Maximal ratio combined diversity reception



Evaluation of MRC weighted target values



$$v_k[n] = \sum_{l=0}^{2} w_{k,l,n}\, y_k[n-l]$$

l = number of tap

3-tap Complex FIR frequency sampling-design

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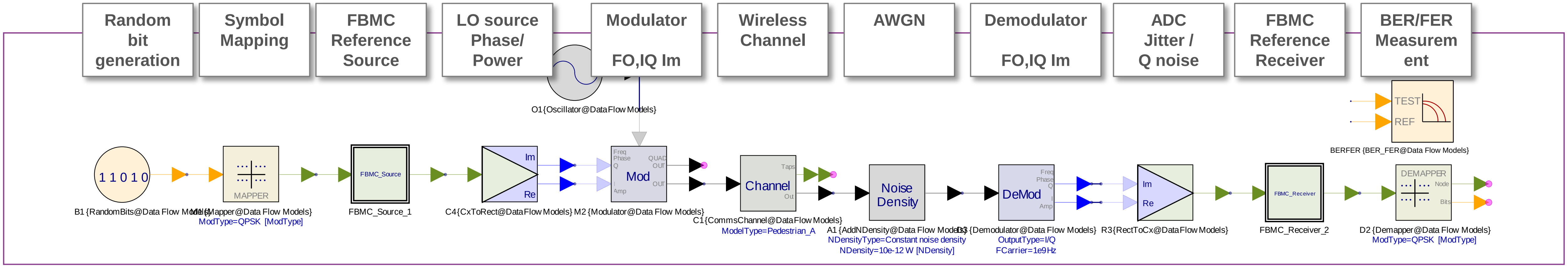
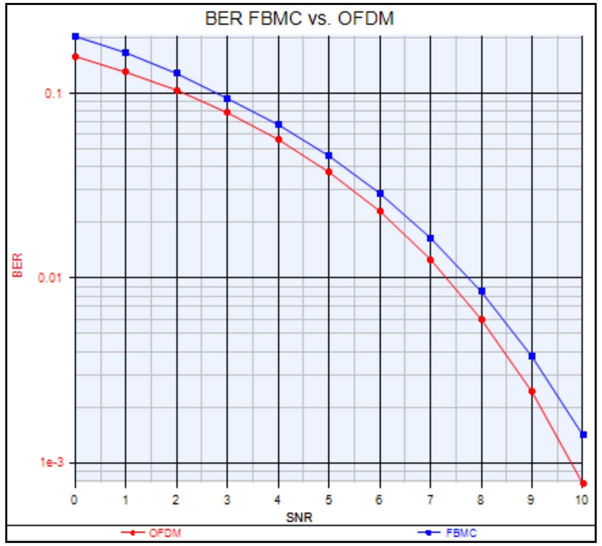
End to End Performance Simulation Model



Simulation parameters

Name	Description	Default Value	Units
SignalPower	Signal power of FBMC signal	0.01	W
SNR	Signal to noise ratio	20	( )
SampleRate	Basic sample rate without oversampling	10e+6	Hz
OversampleRatio	Oversampling ratio	1:Ratio 2	( )
IdleInterval	Idle time at the begining of each frame	0	s
NumPreambleSyms	Number of preamble symbols in one frame	6	( )
NumDataSyms	Number of data symbols in one frame	20	( )
NumSubcarriers	Number of total subcarriers in one symbol	128	( )
ActiveSubcAlloc	Allocation of active subcarriers	[-64,63]	( )
PilotEnable	Whether pilot is inserted into data symbols	1:YES	( )
PilotSequence	Pilot data sequence	[1; 1; 1; 1;-1;-1;-1; 1;-1;-1;-	( )
PilotIndex	Subcarrier index allocated to pilot	[-64:8:63]	( )
FilterOverlapFactor	Filter overlap factor	4	( )
FilterCoef	Filter Coefficient	[1,-0.971960,1/sqrt(2),-0.2	( )
FilterBankStructure	Filter bank structure. Extended IFFT or PPN IFFT	0:Extended_IFFT	( )
ZC_RootIndex1	Root index of ZC sequence 1in preamble	7	( )
ZC_RootIndex2	Root index of ZC sequence 2 in preamble	3	( )
ModType	Modulation type	1:QPSK	( )
NumFrames	Number of frames for simulation	10000	( )
ChannelEnable	Fading channel or awgn channel	1:FadingChannel	( )
Tmax	Time interval of the longest multipath	2e-6	s



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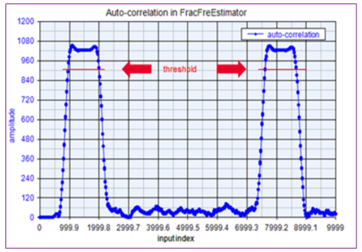
C++ Models for Faster Simulation

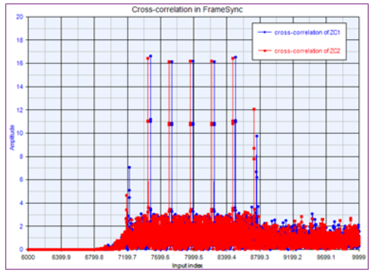
Fractional Frequency Estimation

```
//The peak of auto-correlation is chosen by the midpoint of the inputs which exceed the threshold
//FFO is gotten by the angle of the peak
std::vector<double> AutoCorr(m_FrameSizeWithIdle,0);
double maxV = 0;
for (int i = 0; i < m_FrameSizeWithIdle; ++i)
{
        AutoCorr[i] = abs(corr(m_Buffer.begin()+m_FrameSizeWithIdle-2*m_SymSize+i+1,m_Buffer.begin()+m_FrameSizeWithIdle-m_SymSize+i+1,m_SymSize));
        if (AutoCorr[i] > maxV)
                maxV = AutoCorr[i];
}
double threshold = maxV*0.75;
int low_idx = 0;
int upper_idx = 0;
for (int i = 0; i < m_FrameSizeWithIdle; ++i)
{
        if (AutoCorr[i] > threshold)
        {
                low_idx = i;
                break;
        }
}
for (int i = 0; i < m_FrameSizeWithIdle; ++i)
{
        if (AutoCorr[i] > threshold)
                upper_idx = i;
}
int peak_idx = (low_idx + upper_idx)/2;
std::complex<double> peak_corr;
peak_corr = corr(m_Buffer.begin()+m_FrameSizeWithIdle-2*m_SymSize+peak_idx+1,m_Buffer.begin()+m_FrameSizeWithIdle-m_SymSize+peak_idx+1,m_SymSize);
m_FFOEst = atan2(peak_corr.imag(),peak_corr.real())/(2*PI);
```



Frame Synchronization

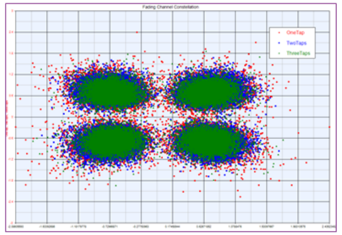
```
//Timing synchronization is achieved by the cross-correlation between local ZC sequences and received Preamble
//The number of peak is relative with the number of preamble symbols per frame
//IFO and timing estimate are gotten by the difference of peaks of two ZC sequences


std::copy(m_Buffer.begin()+m_FrameSizeWithIdle,m_Buffer.end(),m_Buffer.begin());
for (int i = 0; i < m_FrameSizeWithIdle; ++i)
        m_Buffer[i+m_FrameSizeWithIdle] = Input[i];
        std::vector<double> CrossCorr1(m_FrameSizeWithIdle);
        std::vector<double> CrossCorr2(m_FrameSizeWithIdle);
for (int i = 0; i < m_FrameSizeWithIdle; ++i)
{
        CrossCorr1[i] = abs(corr(m_Buffer.begin()+m_FrameSizeWithIdle-
m_SymSize+i+1,m_ZC_ifft1.begin(),m_SymSize));
        CrossCorr2[i] = abs(corr(m_Buffer.begin()+m_FrameSizeWithIdle-
m_SymSize+i+1,m_ZC_ifft2.begin(),m_SymSize));
}

// Variable definition intentionally removed

IFOEst[0] = (idx2-idx1)/(m_ZC_RootIndex1-m_ZC_RootIndex2)/m_OversampleRatio;
TimingEst[0] = (idx2*m_ZC_RootIndex1-idx1*m_ZC_RootIndex2)/(m_ZC_RootIndex1-m_ZC_RootIndex2)-
(m_FilterOverlapFactor-1)*m_SymSize+1;
```



IFO and Timing Estimation

Channel Estimation and Equalization

```
//The repeated structure of preamble symbols formed cyclic prefix that make it
robust to multipath. Preamble symbol is chosen to do channel estimation as pilot.
//One Tap, Two Taps and Three Taps equalization could be done by changing the
parameter NumEqualizerTaps.
//Example code is partial of the entire source
for (int i = 0; i< ActiveSubcAllocArraySize/2; i++)
{
        std::vector<std::complex<double> > A, ANeg, APos;
        A.resize(ActiveSubcAlloc[2*i+1]-ActiveSubcAlloc[2*i]+1);
        ANeg.resize(ActiveSubcAlloc[2*i+1]-ActiveSubcAlloc[2*i]+1);
        APos.resize(ActiveSubcAlloc[2*i+1]-ActiveSubcAlloc[2*i]+1);
        for (int k = 0; k < ActiveSubcAlloc[2*i+1]-ActiveSubcAlloc[2*i]+1; k++)
                A[k] = tmp[ActiveSubcAlloc[2*i]+NumSubcarriers/2+k];
        ANeg[0] = 0.5*(A[ActiveSubcAlloc[2*i+1]-ActiveSubcAlloc[2*i]] + A[0]);
        for (int k = 1; k < ActiveSubcAlloc[2*i+1]-ActiveSubcAlloc[2*i]+1; k++)
        {
                ANeg[k] = 0.5*(A[k-1] + A[k]);
        }
        for (int k = 0; k < ActiveSubcAlloc[2*i+1]-ActiveSubcAlloc[2*i]; k++)
        {
                APos[k] = 0.5*(A[k+1] + A[k]);
        }
        APos[ActiveSubcAlloc[2*i+1]-ActiveSubcAlloc[2*i]] = 0.5*(A[ActiveSubcAlloc[2*i+1]-ActiveSubcAlloc[2*i]] + A[0]);
        for (int k = 0; k < ActiveSubcAlloc[2*i+1]-ActiveSubcAlloc[2*i]+1; k++)
        {
                m_WNeg[ActiveSubcAlloc[2*i]+NumSubcarriers/2+k] = ANeg[k];
                m_WPos[ActiveSubcAlloc[2*i]+NumSubcarriers/2+k] = APos[k];
                m_W[ActiveSubcAlloc[2*i]+NumSubcarriers/2+k] = A[k];
        }
`
```



Constellation of Pedestrian_A Channel with SNR= 20dB

Algorithmic reference to convert synthesizable fixed point model

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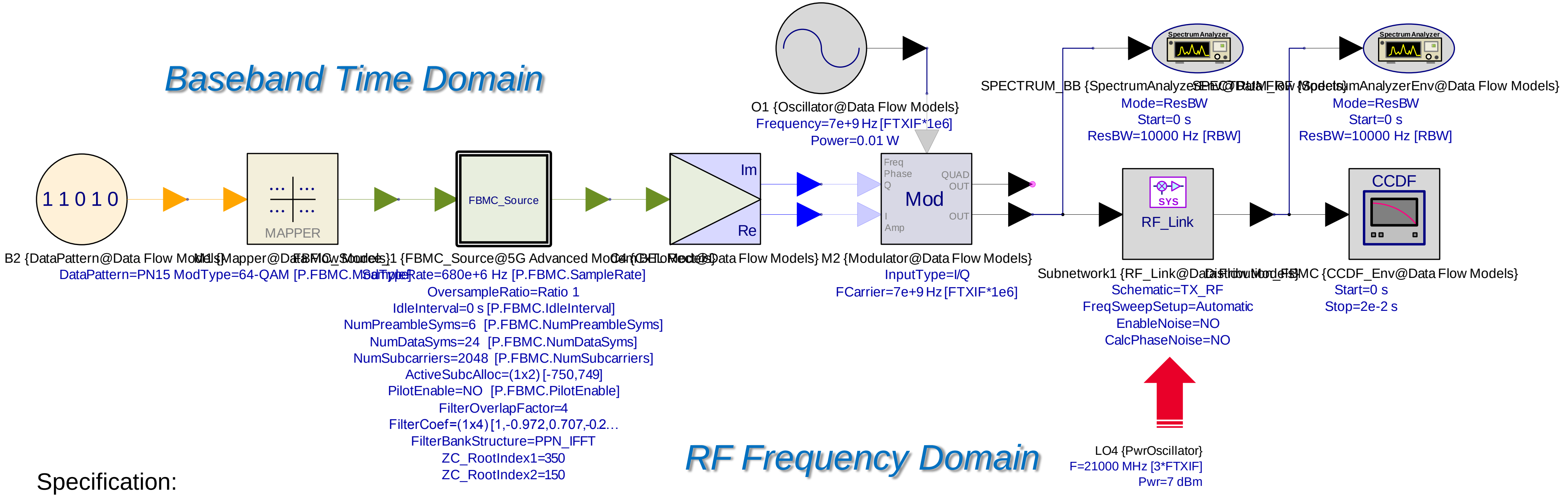
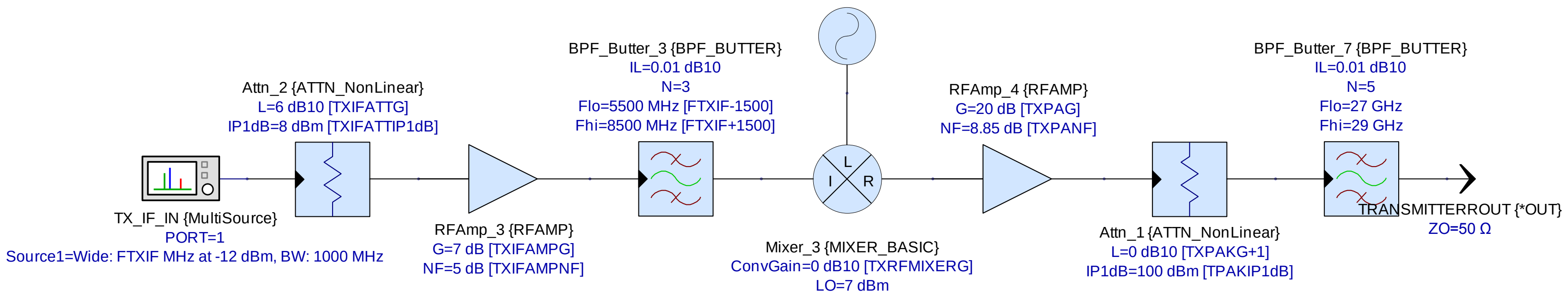
Case Study: Cross Domain Modeling & Simulation



Specification:

- Fc = 28GHz
- Fs = 680MHz
- nFFT = 2048
- BW = 500MHz
- Mod = 64QAM



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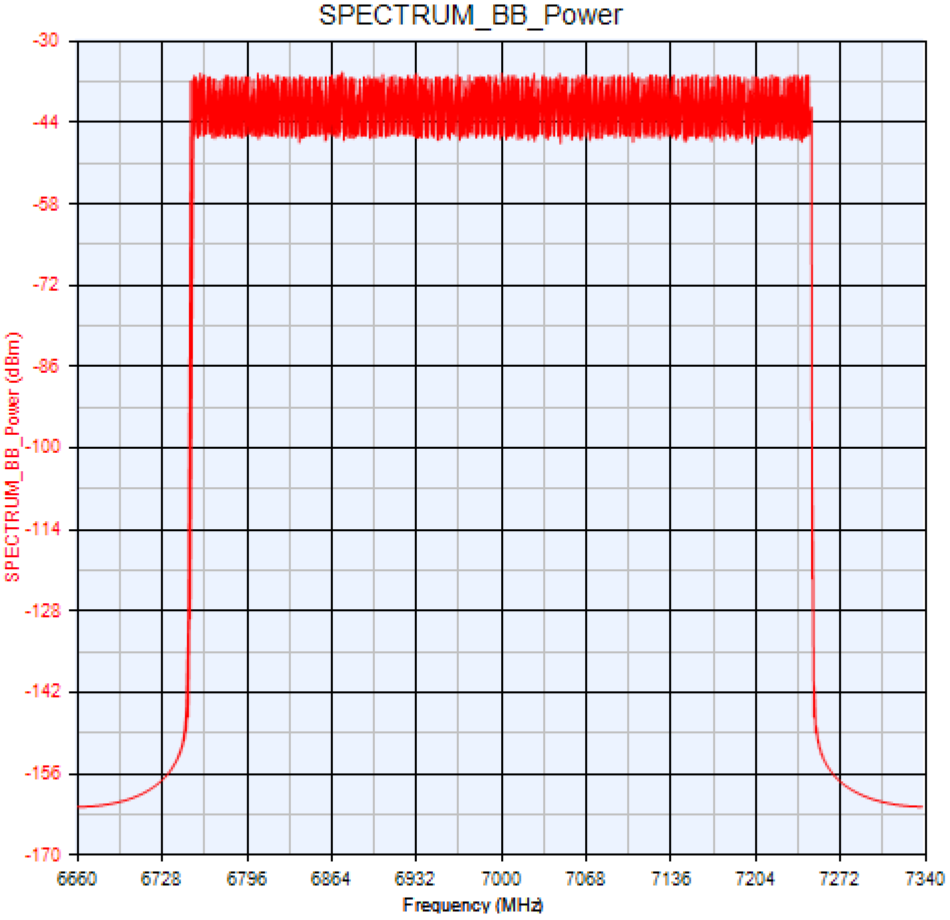
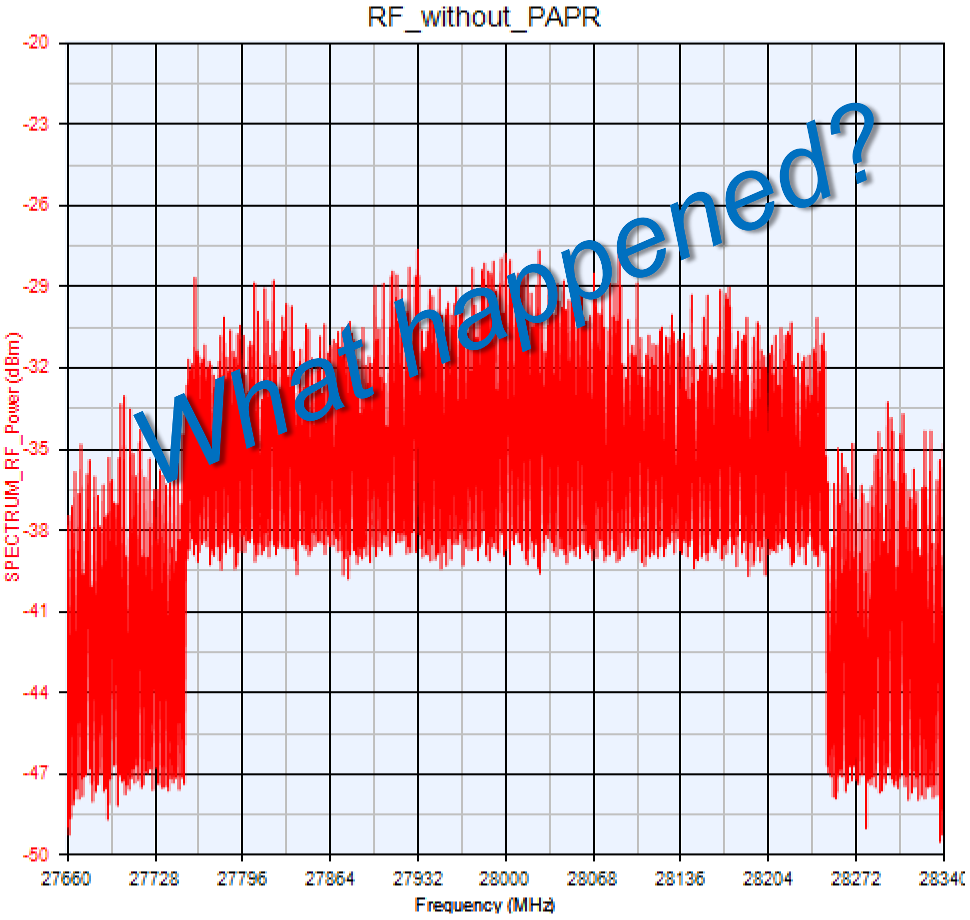
Case Study Continue:

Develop New Clipping Techniques using Realistic RF Models



FBMC Baseband Spectrum



FBMC RF Spectrum without PAPR Reduction

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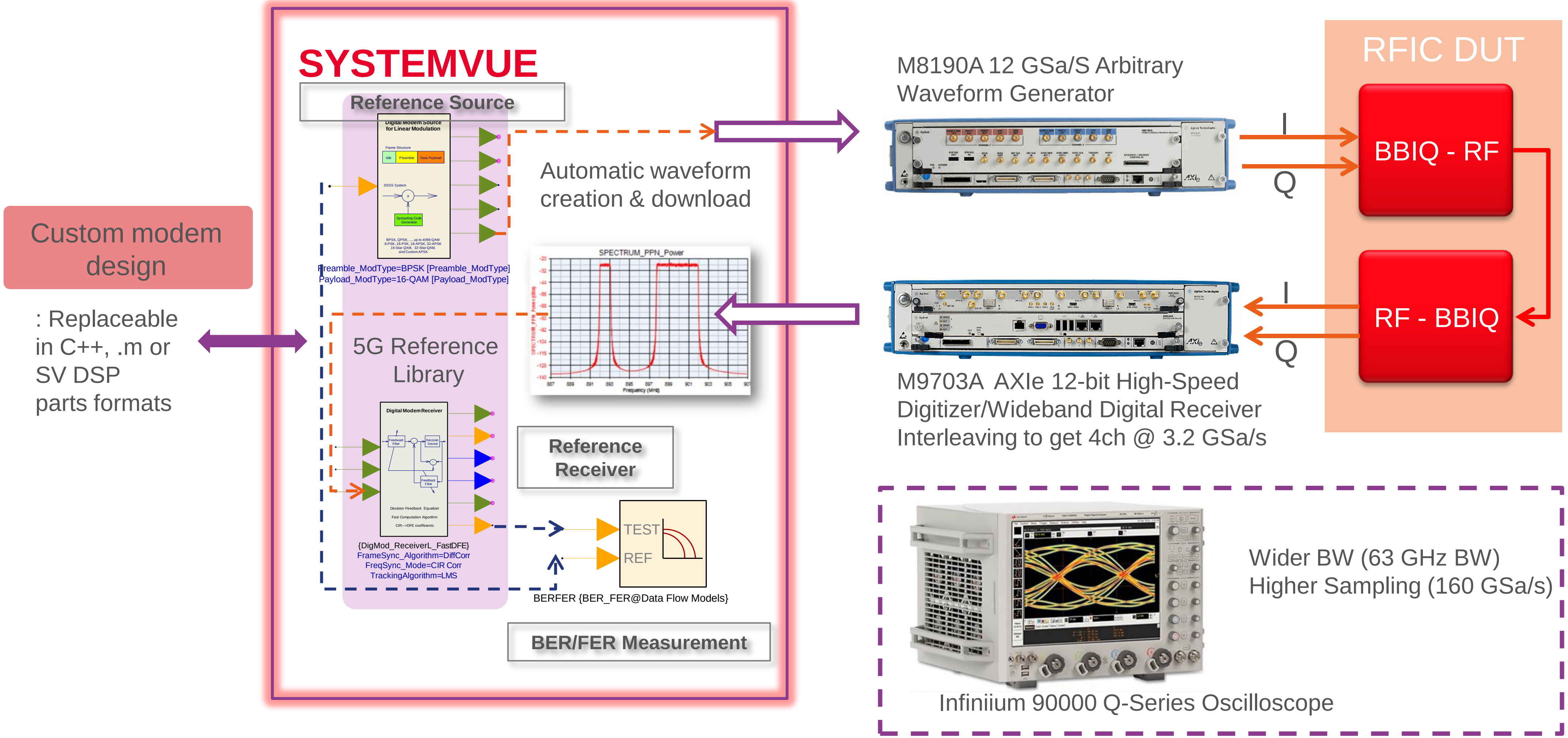
Moving from Simulation to Hardware in the loop



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Part II.
What do you need for mmWave MIMO radio channel study?

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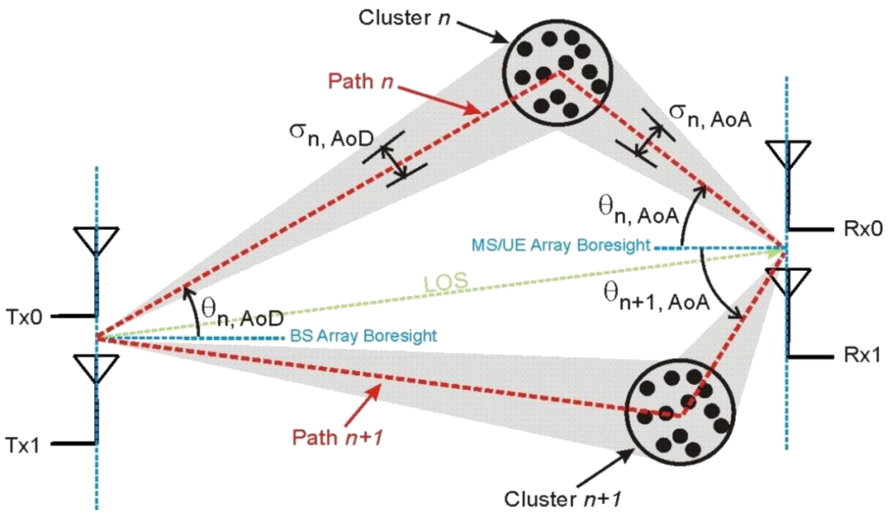
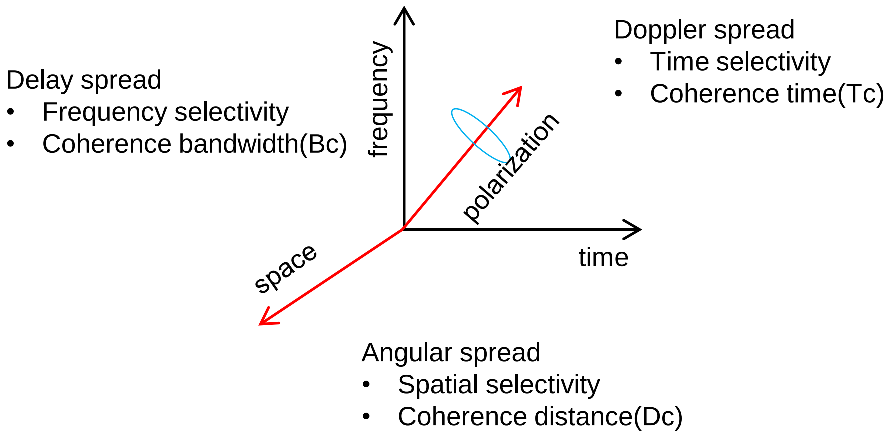
MIMO Fading Channel

How much we know this in higher frequency?





$$H_{u,s,n}(t;\tau)=\sum_{m=1}^{M}\begin{bmatrix}F_{rx,u,V}(\varphi_{n,m})\\F_{rx,u,H}(\varphi_{n,m})\end{bmatrix}^{T}\begin{bmatrix}\alpha_{n,m,VV} & \alpha_{n,m,VH}\\ \alpha_{n,m,HV} & a_{n,m,HH}\end{bmatrix}\begin{bmatrix}F_{tx,s,V}(\phi_{n,m})\\F_{tx,s,H}(\phi_{n,m})\end{bmatrix}$$
$$\times\exp\left(j2\pi\lambda_0^{-1}(\bar{\varphi}_{n,m}\cdot\bar{r}_{rx,u})\right)\exp\left(j2\pi\lambda_0^{-1}(\bar{\phi}_{n,m}\cdot\bar{r}_{tx,s})\right)$$
$$\times\exp\left(j2\pi\upsilon_{n,m}t\right)\delta(\tau-\tau_{n,m})$$

* *Tx antenna element **s** to Rx element **u** for cluster **n***

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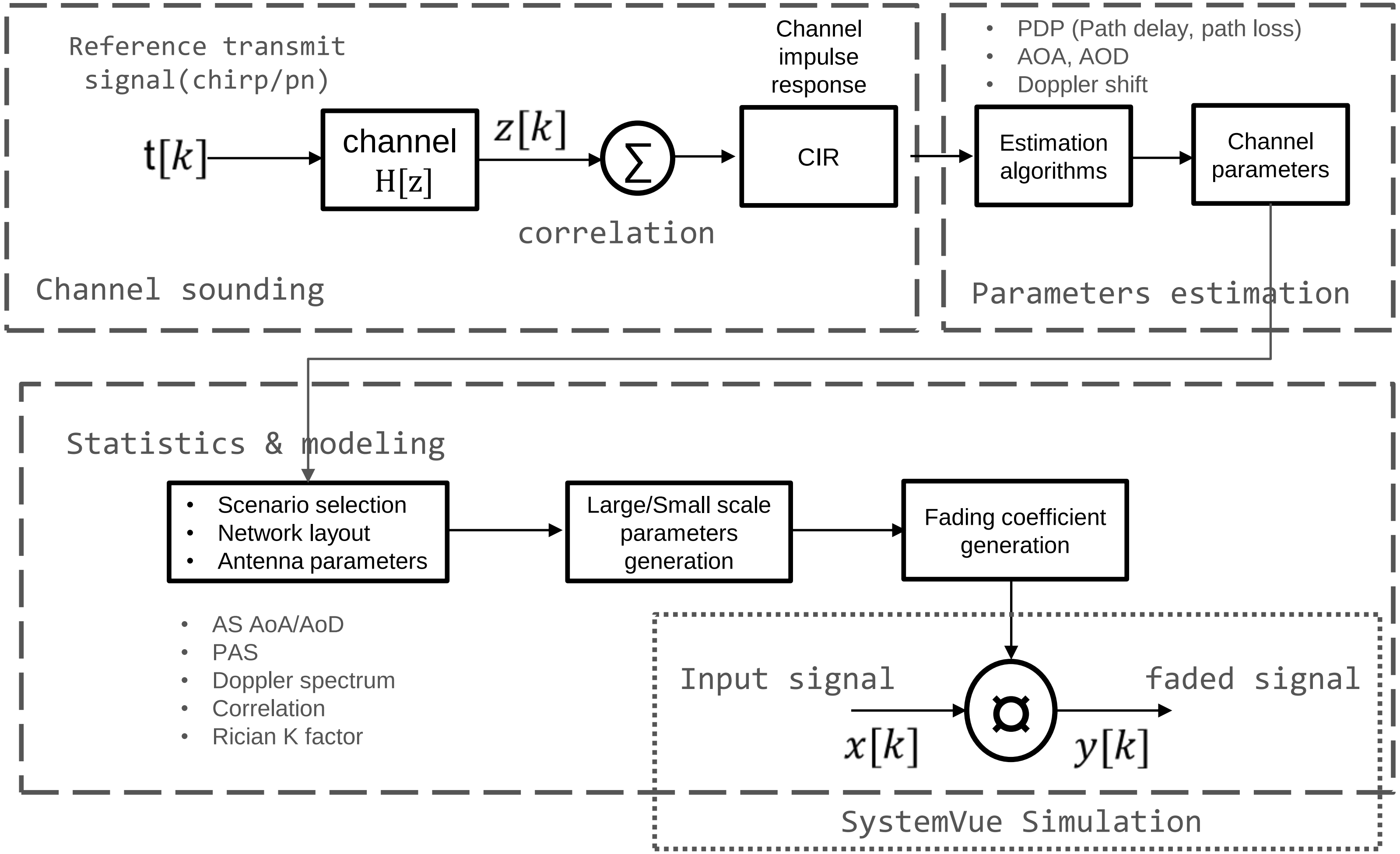
Channel Sounding / Parameter Extraction / Simulation



ESPRIT
Subspace based algorithm
✖ Maximum estimating number of path is limited by number of Rx, will be fail under NLOS scenario
✖ cannot estimate path loss and path delay
✓ small computing amount

SAGE
Maximum likelihood estimation algorithm
✓ No limitation for number of path, suitable for both LOS and NLOS scenarios
✓ Can estimate all the channel parameters including path loss and path delay of each path
✖ Iteration needed, large computing amount

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Requirements and Challenges

System Requirements

– Spatial consistency and mobility

– Diffuse versus specular scattering

– Very large antenna arrays

– Frequency range

– Complexity vs. Accuracy

– Applicability of the existing and proposed models on the 5G requirements

Technical Challenges

– Channel measurement methodology

– High frequency instrumentation

– Ultra-broad band signal

– Synchronization and calibration

– Data streaming

– Channel parameter estimation process

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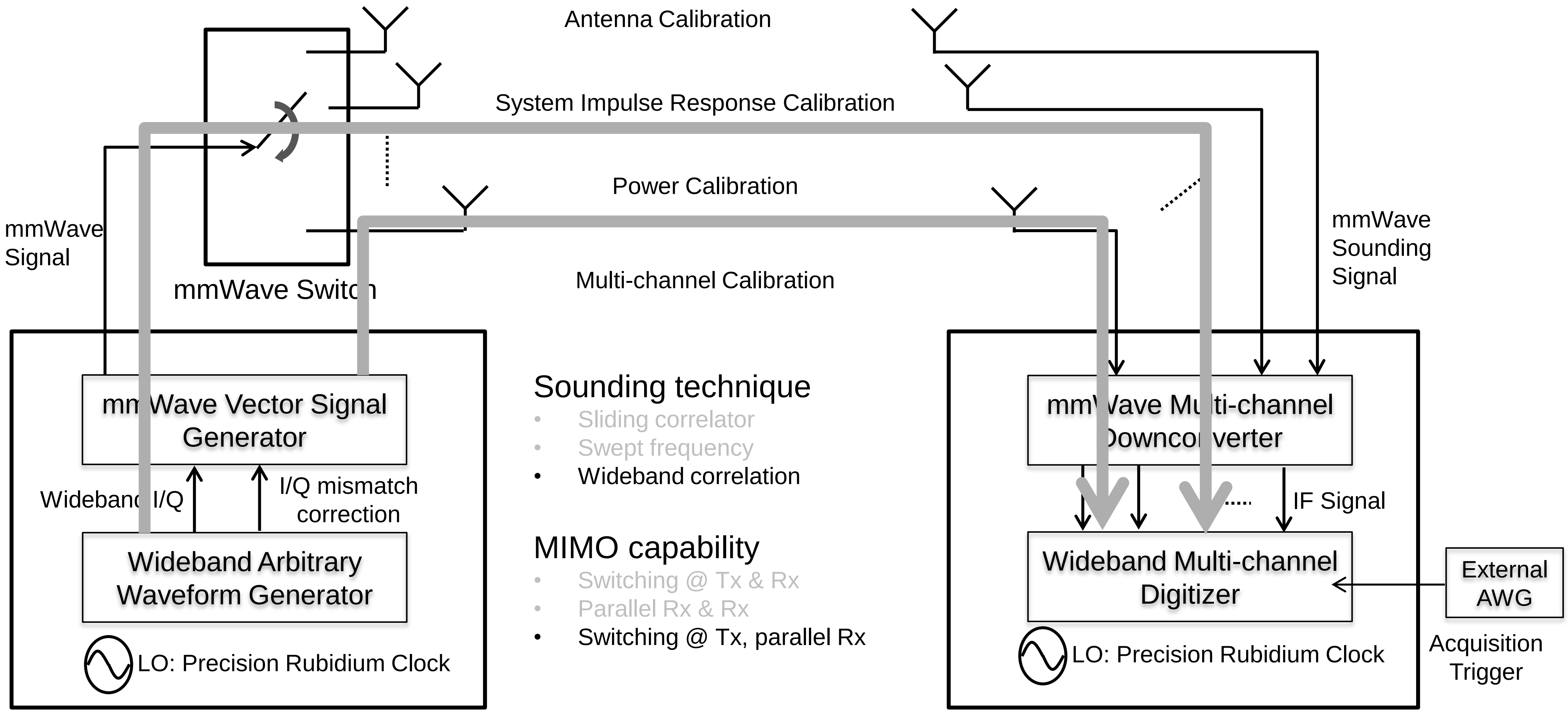
Proposed Architecture / System Considerations



Sounding technique

- Sliding correlator
- Swept frequency
- Wideband correlation

MIMO capability

- Switching @ Tx & Rx
- Parallel Rx & Rx
- Switching @ Tx, parallel Rx

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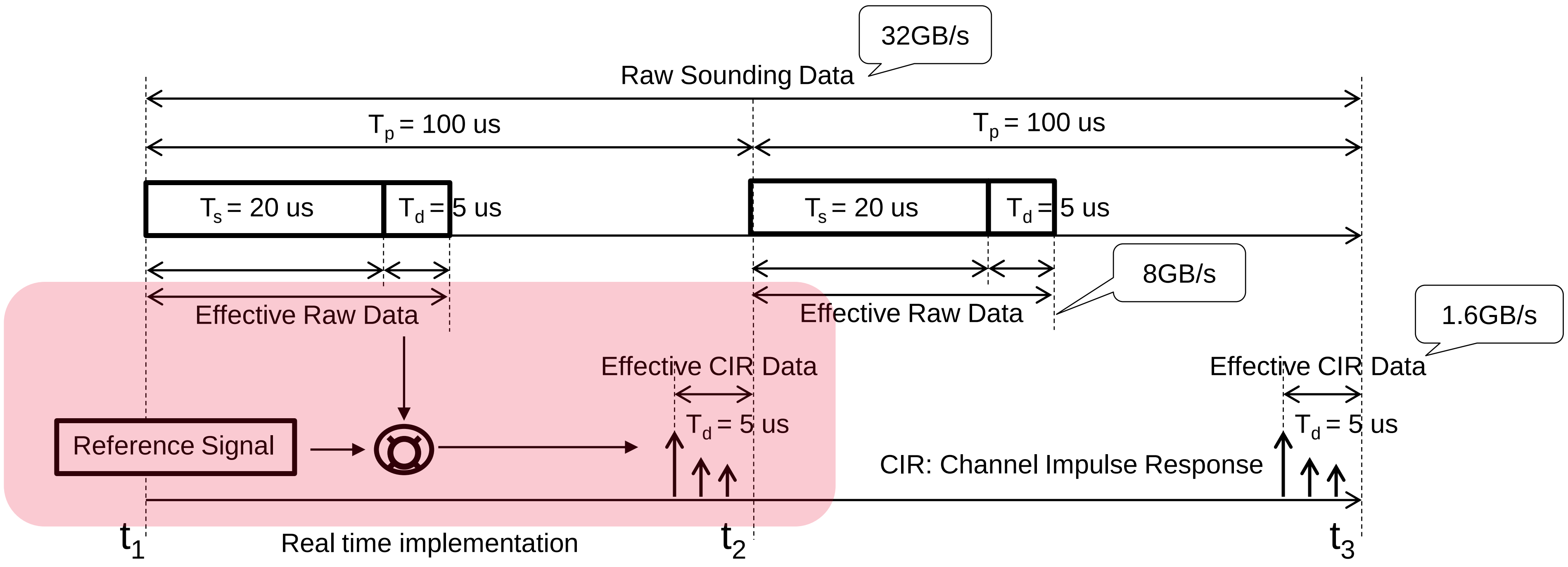
Data Capture and Streaming Considerations



Note:

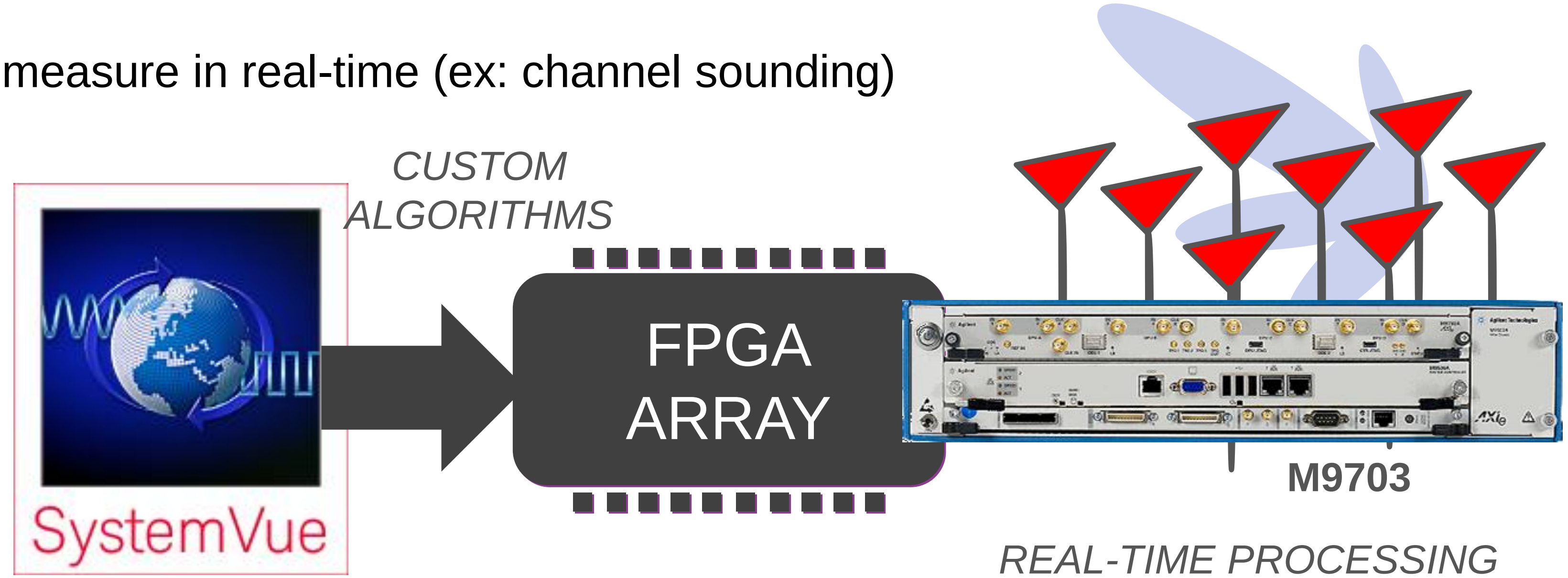
- 1GSa/s sampling rate,
- T_p = transmitting period, T_s = transmitting signal length, T_d = max delay spread
- PCI express 2.0 bandwidth(x16 lane) = 64Gbit/s(8GB/s)

Prototyping and Testing in Real Time Hardware

– Move forward from largely theoretical massive MIMO research to real hardware implementation and test

– Open FPGA and download custom algorithms for MIMO and Beamforming

– Test and measure in real-time (ex: channel sounding)



REAL-TIME PROCESSING
Up to 40 Channels x 1GHz wide

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Parameter Estimation Algorithms

Algorithm		Consistency	Coherent Signals	Estimation Performance	Computations	Max Num. of Path
Beamforming Based	Bartlett	L=1	No	Poor	1-D search	
	Capon	No	No	Poor	1-D search	
Subspace Based	MUSIC[1]	Yes	No; Yes for ROOT-MUSIC	Good	EVD, 1-D search	**< Num. of Rx**
	ESPRIT[2]	Yes	No; Yes for TLS-ESPRIT and Unitary-ESPRIT	Good	EVD	**< Num. of Rx**
ML Based	**SAGE[3]**	**Yes**	**Yes**	**Good**	**Iterative, 1-D search**	**No limitation**

[1]**MUSIC**: **MU**ltiple **SI**gnal **C**lassification
[2]**ESPRIT**: **E**stimating **S**ignal **P**arameter via **R**otation **I**nvariance
[3]**SAGE**: **S**pace-**A**lternating **G**eneralized **E**xpectation maximization
[4]**EVD**: **E**igen-**V**alue **D**ecomposition

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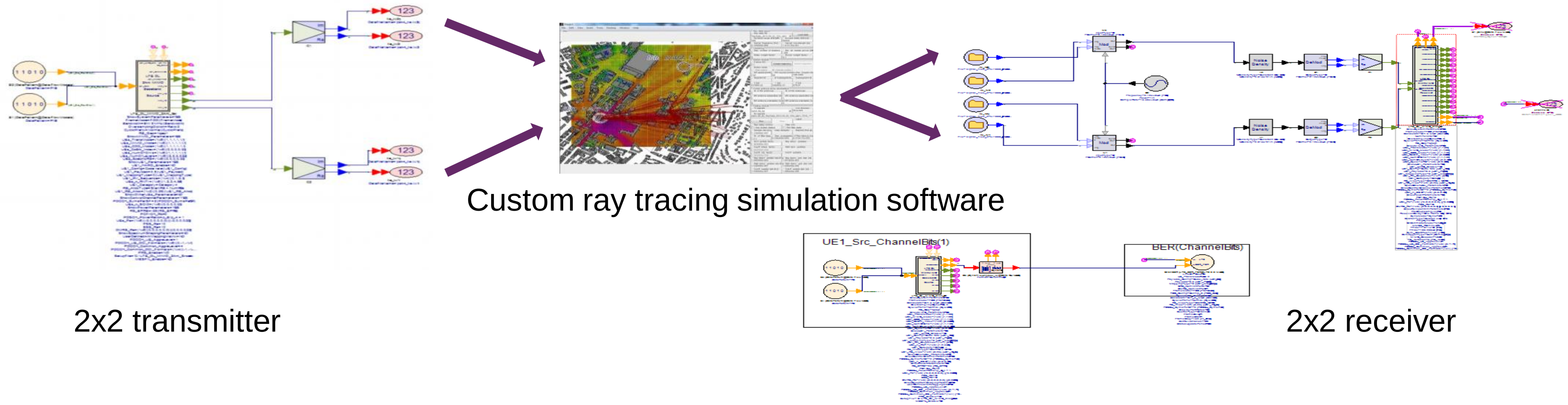
Case Study: Interact between Ray Tracing Fading Engine

- Stochastic channel models **fail to accurately represent real-world environments**
- Idea: **replicate real-world scenes** in lab. The scenes originate from
  - Measurements (sounder, scanner, UE);
  - Ray-tracing simulation software integration.
- System model



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Part III.
Multi-Antenna Techniques

Keysight EEsof EDA

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Motivation

- Higher requirement for system capacity and spectral efficiency(bits/s/Hz)
- To overcome traditional approaches (expand bandwidth, higher modulation order, multiple access)
- The MIMO for better use the spatial resource
  - The capacity is increased by a multiplication of the number of antennas

$$C = B \times \log_2\left(1 + \frac{S}{N}\right)(bit/s) \times M$$

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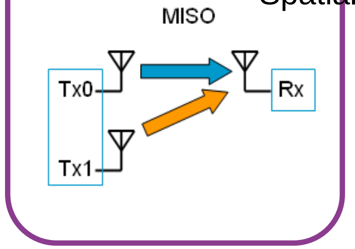
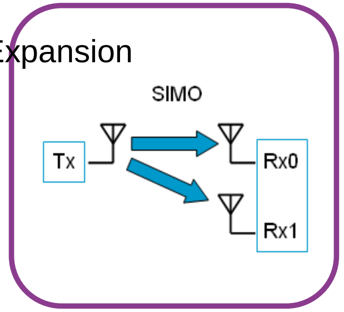
Classification

Spatial diversity

Improve robustness

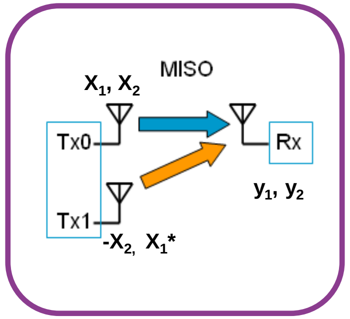


Spatial Expansion



Transmit Diversity

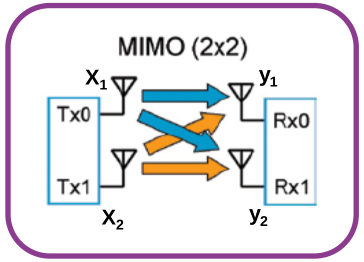
Receive Diversity



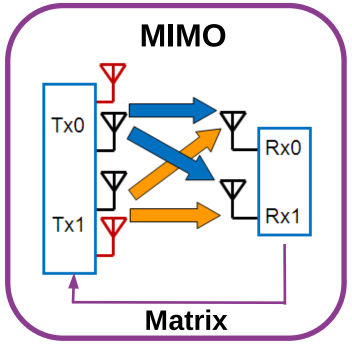
Space-time block coding (STBC)

Spatial multiplexing

Improve user throughput



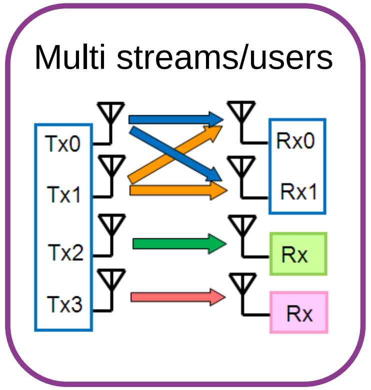
Spatial division multiplexing



Transmit Beamforming

Multi-user

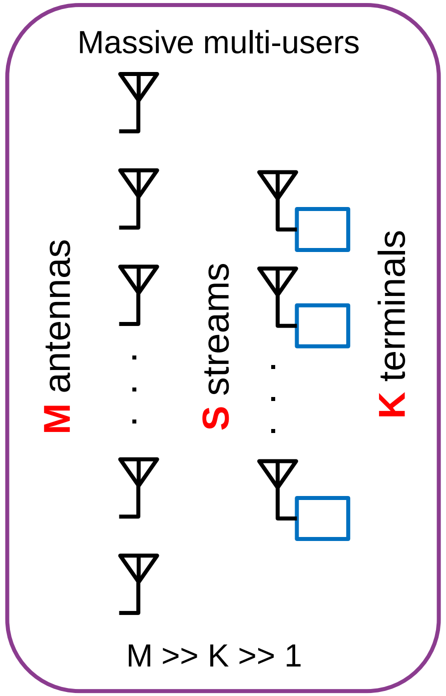
Increase system efficiency



Multi-user MIMO

Use spatial channel information?

- Open-loop MIMO
- Closed-loop MIMO



Massive MIMO

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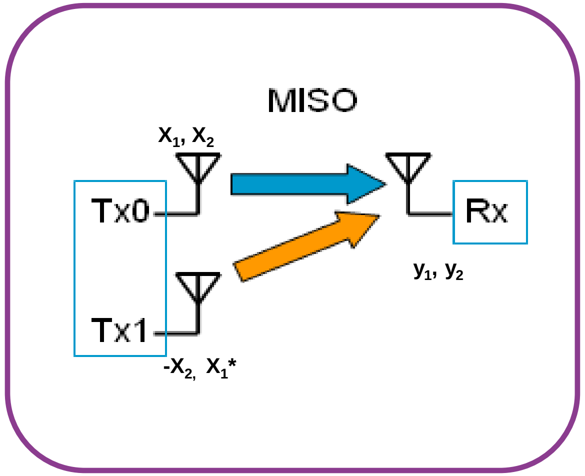
Transmit Diversity

- Use transmit diversity to diminish the effects of fading by *transmitting the same information from two different antennas*
- The data from the second antenna is *encoded differently* to distinguish it from the primary antenna
- The transmit diversity feature uses *ST(space-time)* or *SF(space-frequency)* block encoding to differentiate the signals between Antenna 1 and Antenna 2
- The user equipment (UE) must be able to recognize that the information is coming from two different locations and properly decode the data.



SFBC: f_1 f_2

$$\begin{matrix} Tx_0 \\ Tx_1 \end{matrix} \downarrow \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix}$$

STBC: t_1 t_2

* complex conjugate

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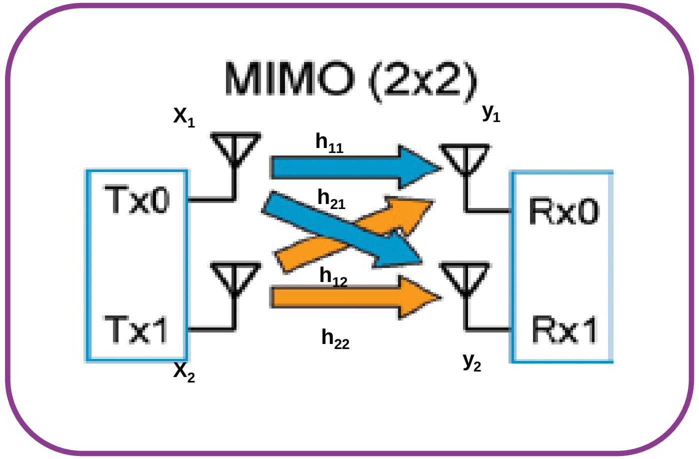
Spatial Multiplexing

– Operation Concept

- *Transmission of multiple spatial data streams over different antennas* in the same RB
- The dimension of spatial channels is increased and *system capacity increased*

– Relevant signal processing

- Perform *Layer mapping* and *Pre-coding* to lower the receiver complexity and reduce the signal interference between antennas
- Statistic correlation between vector(h_{11},h_{12}) and vector(h_{21},h_{22})



x: transmitted signal,
y: received signal,
H: spatial channel matrix,
H_{ij}: channel coefficient from the j^{th} transmit antenna and the i^{th} receive antenna.
$y=Hx$
$y_1=h_{11}x_1+h_{12}x_2+n_1$
$y_2=h_{21}x_1+h_{22}x_2+n_2$

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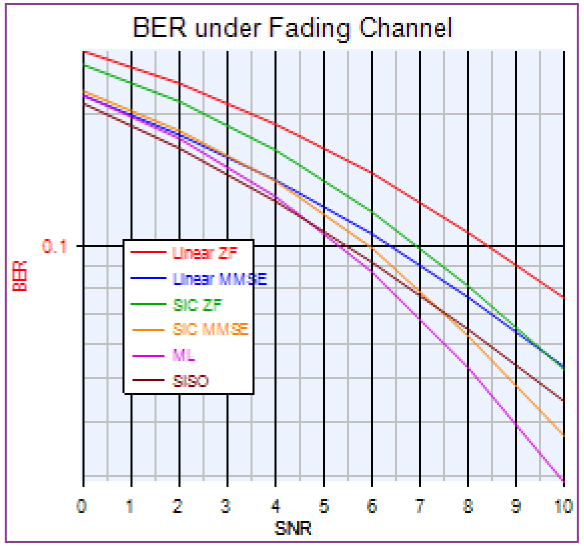
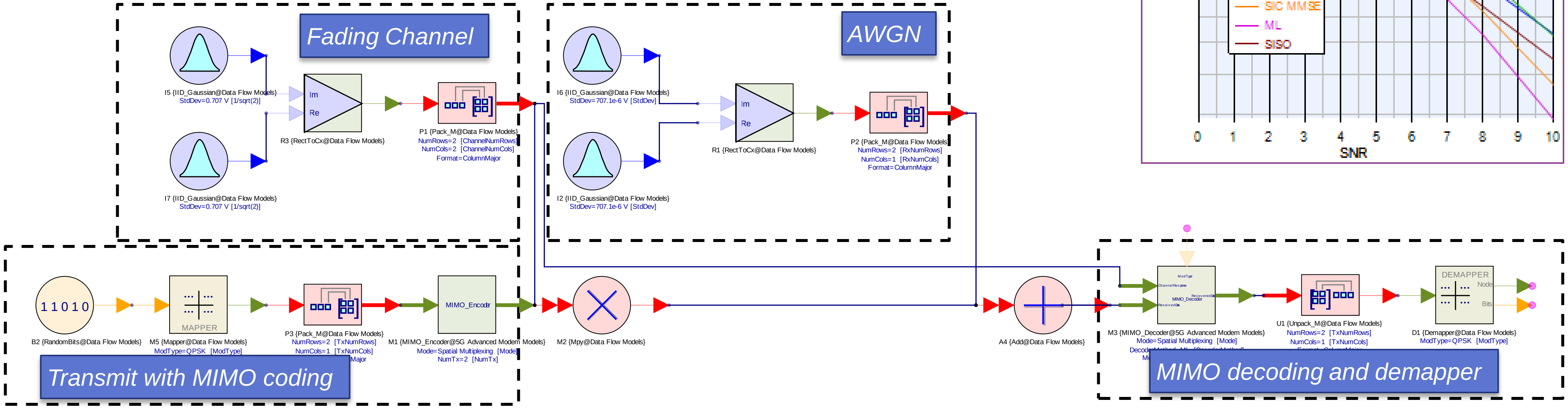
Modeling and Simulation for MIMO

– MIMO Tx/Rx simulation under Rayleigh fading and AWGN channel

– Explore different decoding algorithms and performance evaluation

- ML, MMSE-SIC, ZF-SIC, MMSE-Linear, ZF-Linear





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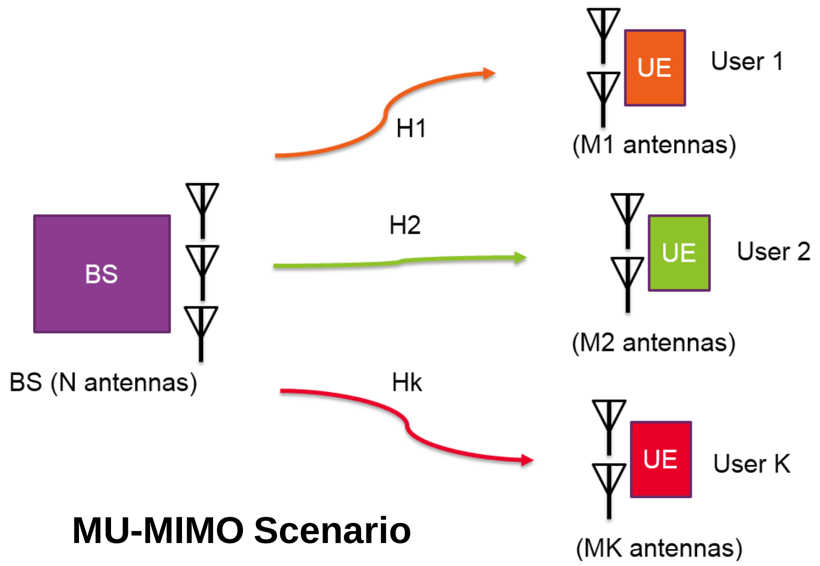
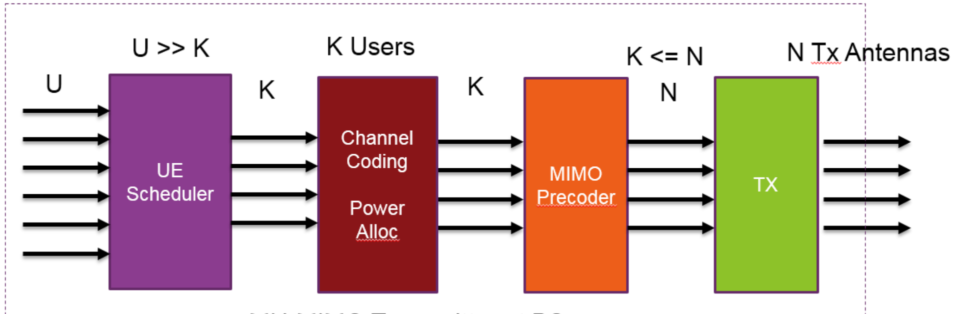
Multi-User MIMO



MU-MIMO Scenario



MU-MIMO Transmitter at BS

Capacity Comparison

SU-MIMO: $Mlog(1+SNR)$

MU-MIMO: $Mlog\left(1+\frac{SNR}{M}logU\right), U \rightarrow \infty$

M: TX antenna number, U: Total user number

Received signal at UE k:

$$\mathbf{y}_k = \mathbf{H}_k\mathbf{W}_k\mathbf{s}_k + \mathbf{H}_k \sum_{l=1,l\neq k}^{K} \mathbf{W}_l\mathbf{s}_l + \mathbf{n}_k$$

The challenge for MU-MIMO is to find orthogonal users and design precoding W to minimize the second term with the restrictions of user grouping, power, latency and complexity

H_k: kth user's channel, W_k: weight vector, S_k: data symbol

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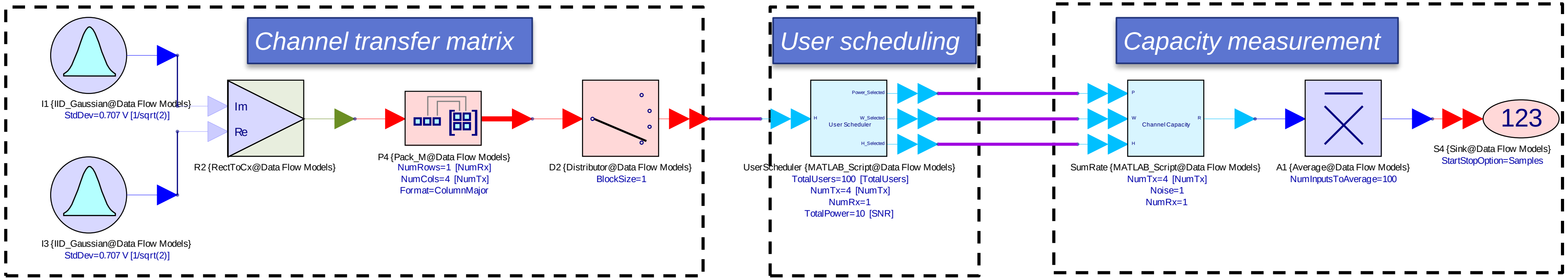
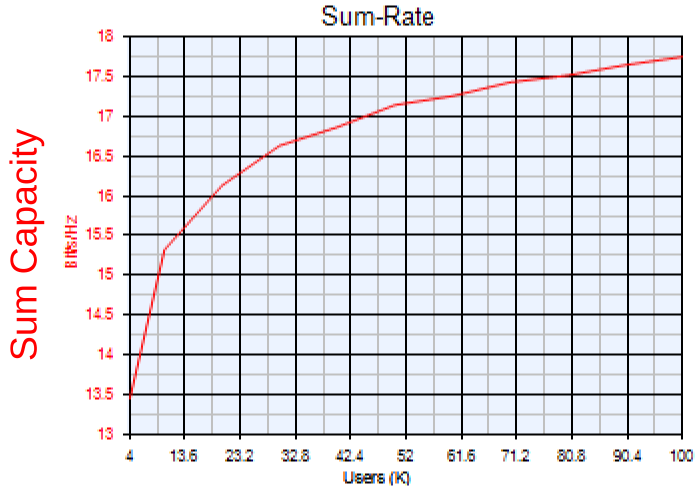
Modeling and Simulation for Capacity Estimation





User K: 4->100

Simulation condition

– Transmit antenna number (M) : 4

– Total number of user : from 4 to 100

– SNR=10dB

– Power allocation by waterfilling algorithm

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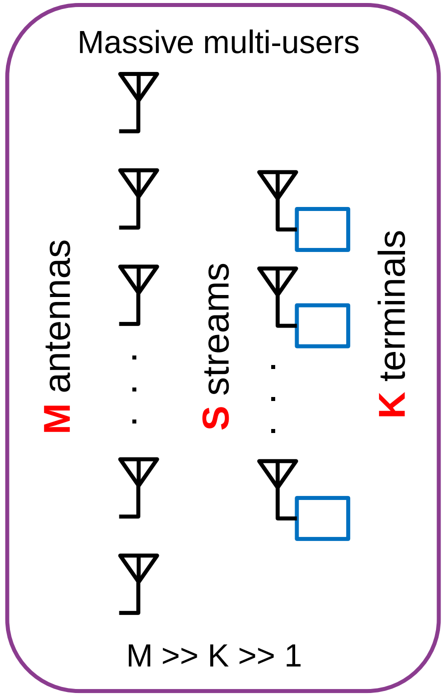
Massive MIMO

- The use of a very large number of service antennas operated fully coherent and adaptive
- Brings huge improvements in throughput and energy efficiency when combined with simultaneous scheduling of a large number of UEs
- System Model : **M** transmit antenna with maximum **S** streams, **K** users each with a single antenna
- Originally envisioned for time division duplex(TDD[1]), but can potentially be applied in frequency division duplex(FDD)



Massive MIMO

Note[1] : Prefer TDD as not enough resources for pilots and CSI feedback.

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Massive MIMO Operation and Challenges

Operation

- Acquire Channel State Information from uplink Pilots / Data
- Reciprocity calibration and adjustment
- Pre-coding[1] to support multi-stream transmission
- MMSE receiver with beamforming
  - Maximum ratio combining(MRC) : interference and noise are both white in the space
  - Interference rejection combining(IRC): colored interference

Challenges

- Pilot contamination: interference from other cells
  - Blind channel estimation?
  - Coordination and planning?
- New pre-coder with low-complexity, low-PAPR
- Hardware performance
  - I/Q imbalance, A/D resolution, PA linearity
  - Phase noise, clock distribution
- Synchronization at low SNR

Note[1] : Linear pre-coding [maximum ratio transmission(MRT), zero-forcing(ZF)].
Non-linear pre-coding [Dirty paper coding(DPC)], full CSI required

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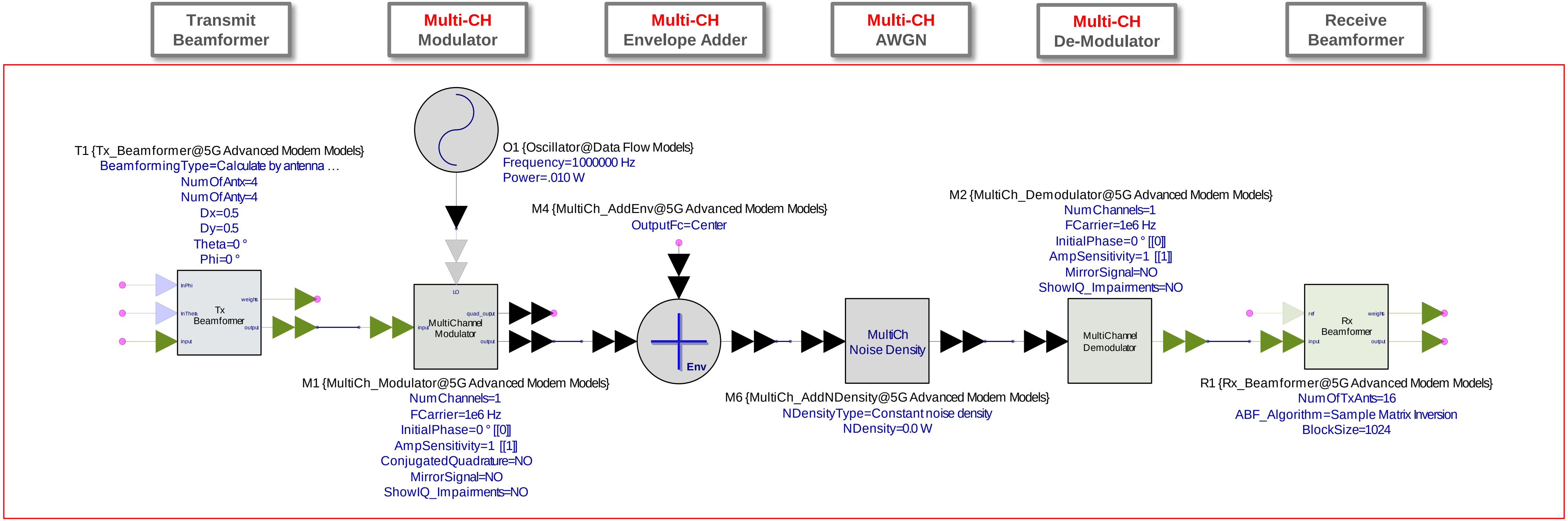
Modeling and Simulation for Large Number of Antennas



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Summary: What you need for your 5G research is…

Transition naturally from Design to Test with a single “cockpit”

- ✓ *Model Based Design*
- ✓ *Mixed Simulation Technologies*
- ✓ *5G Reference IP*

IP Reference Libraries
4G *LTE-Advanced, LTE ,**5G***
3G *HSPA+, WCDMA, EDGE, GSM*
WLAN *802.11ac/n/a/b/g*
WPAN *802.11ad, 802.15.3c*

- ✓ Quickly capture “system level” design concepts
- ✓ Model implementation-level impairments

BB Algorithm Modeling
MATLAB .m
FixedPoint, HDL/FPGA
Embedded C++
Filtering, EQ, Modem

Unified Platform Software

RF / Analog Channel Modeling
MIMO Channel (OTA)
Digital Pre-Distortion (DPD)
RF System Design

RF EDA Platforms

Test Software
I/O Lib, ComExpert
89600 VSA
Signal Studio
3rd Party

Test Equipment
RF Sources & Analyzers
AWG & Digitizers
Scopes, Logic, Modular

- ✓ Connect BB, RF, and T&M for rapid validation
- ✓ Rapid prototyping with integrated measurement

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Thank you!

– Resources

- SystemVue : www.keysight.com/find/eesof-systemvue
- 5G Library: www.keysight.com/find/eesof-systemvue-5g-exploration

– **Try SystemVue!** Obtain a "FREE" 45-day evaluation copy of SystemVue and explore how SystemVue can help with early 5G systems exploration and evaluation

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