


Fundamentals of LTE

Presented by:
Agilent Technologies, Inc.

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Agenda

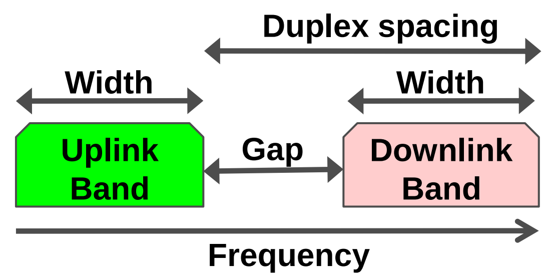
- **Introduction to LTE**
  - Major features and requirements
  - Frequency bands
  - Channel bandwidths
  - OFDM/OFDMA/SCFDMA
  - Structure – frame, slots, resource blocks & elements
  - Physical signals and channels
- **Transmitter & Receiver Test Fundamentals**
- **LTE-Advanced Topics**
  - Carrier Aggregation
  - MIMO

LTE Major Features

<table>
<tr><th>Feature</th><th colspan="6">Capability</th></tr>
<tr><td>Access modes</td><td colspan="6">FDD & TDD</td></tr>
<tr><td rowspan="2">Channel BW
1RB = 12 subcarriers = 180 kHz</td><td>1.4 MHz</td><td>3 MHz</td><td>5 MHz</td><td>10 MHz</td><td>15 MHz</td><td>20 MHz</td></tr>
<tr><td>6 RB</td><td>15 RB</td><td>25 RB</td><td>50 RB</td><td>75 RB</td><td>100 RB</td></tr>
<tr><td>Transmission Scheme</td><td colspan="6">Downlink: OFDMA (Orthogonal Frequency Division Multiple Access)
Uplink: SC-FDMA (Single Carrier Frequency Division Multiple Access</td></tr>
<tr><td>Modulation Formats</td><td colspan="6">QPSK, 16QAM, 64QAM</td></tr>
<tr><td>MIMO Technology</td><td colspan="6">Downlink: Tx diversity, Rx diversity, Single-User MIMO (up to 4x4), beamforming
Uplink: Multi-User MIMO</td></tr>
<tr><td>Peak Data Rates</td><td colspan="6">Downlink: 300 Mbps (4x4 MIMO, 20 MHz, 64QAM)
Uplink: 75 Mbps (20 MHz BW, 64QAM)</td></tr>
<tr><td>Bearer services</td><td colspan="6">Packet only – no circuit switched voice or data services are supported ➔ voice must use VoIP</td></tr>
<tr><td>Transmission Time Interval (TTI)</td><td colspan="6">1 ms</td></tr>
</table>

LTE FDD Frequency bands (36.101 table 5.5-1)

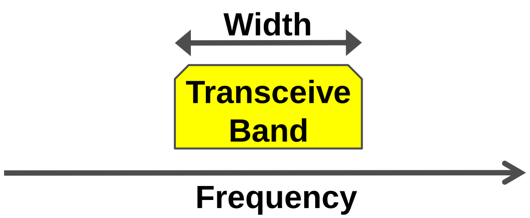
Band	Uplink MHz		Downlink MHz		Width	Duplex	Gap
1	1920	1980	2110	2170	60	190	130
2	1850	1910	1930	1990	60	80	20
3	1710	1785	1805	1880	75	95	20
4	1710	1755	2110	2155	45	400	355
5	824	849	869	894	25	45	20
6	830	840	865	875-	10	35	25
7	2500	2570	2620	2690	70	120	50
8	880	915	925	960	35	45	10
9	1749.9	1784.9	1844.9	1879.9	35	95	60
10	1710	1770	2110	2170	60	400	340
11	1427.9	1447.9	1475.9	1495.9	20	48	28
12	698	716	728	746	18	30	12
13	777	787	746	756	10	-31	21
14	788	798	758	768	10	-30	20
15*	1900	1920	2600	2620	20	700	680
16*	2010	2025	2585	2600	15	575	560
17	704	716	734	746	12	30	18
18	815	830	860	875	15	45	30
19	830	845	875	890	15	45	30
20	832	862	791	821	30	-41	11
21	1447.9	1462.9	1495.9	1510.9	15	48	33
22	3410	3490	3510	3590	80	100	20
23	2000	2020	2180	2200	20	180	160
24	1626.5	1660.5	1525	1559	34	-101.5	67.5
25	1850	1915	1930	1995	65	80	15
26	814	849	859	894	35	45	10
27	807	824	852	869	17	45	28
28	703	748	758	803	45	55	10



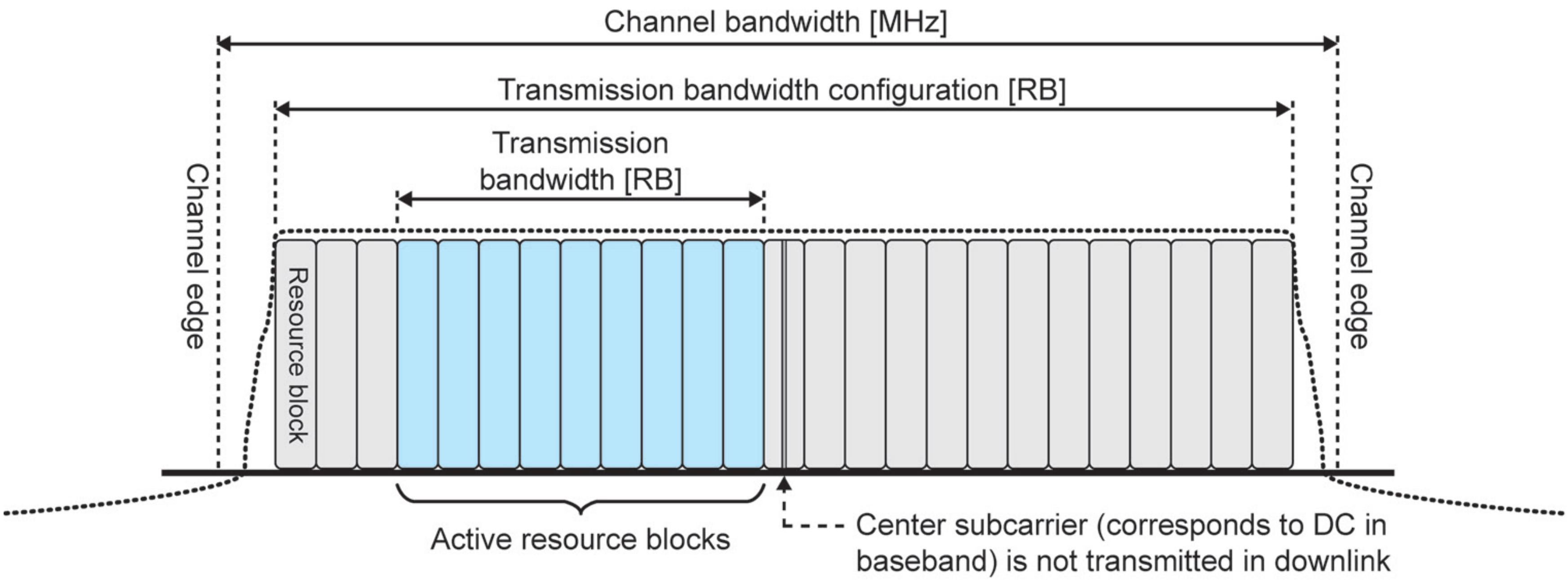
- There is a lot of overlap between band definitions for regional reasons
- The Duplex spacing varies from 30 MHz to 799 MHz
- The gap between downlink and uplink varies from 10 MHz to 680 MHz
- Bands 15 and 16 are specified by ETSI only for use in Europe

LTE TDD Frequency bands

Band	Uplink MHz		Downlink MHz		Width
33	1900	1920	1900	1920	20
34	2010	2025	2010	2025	15
35	1850	1910	1850	1910	60
36	1930	1990	1930	1990	60
37	1910	1930	1910	1930	20
38	2570	2620	2570	2620	50
39	1880	1920	1880	1920	40
40	2300	2400	2300	2400	100
41	2496	2690	2496	2690	194
42	3400	3600	3400	3600	200
43	3600	3800	3600	3800	200
44	703	803	703	803	100

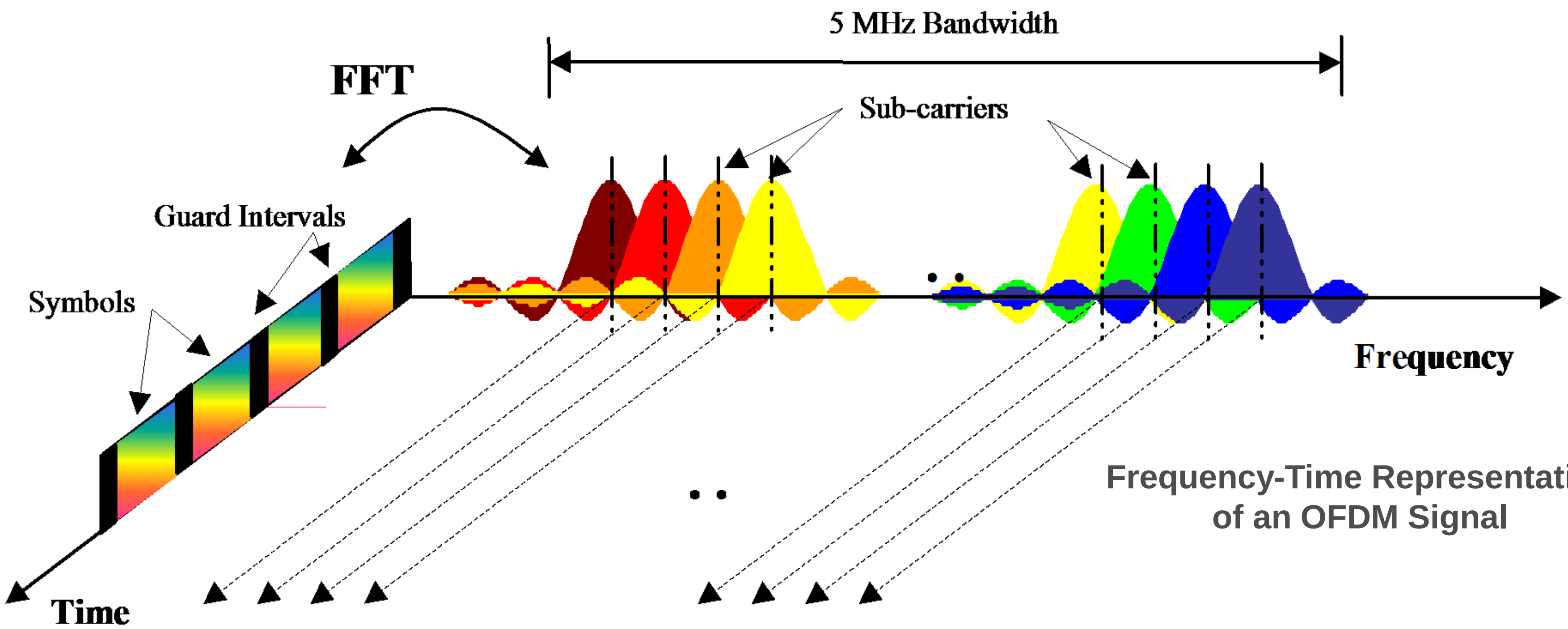


Channel Bandwidths



Channel Bandwidth (MHz)	1.4	3	5	10	15	20
Transmission bandwidth configuration (MHz)	1.06	2.7	4.5	9	13.5	18
Transmission bandwidth configuration (RB)	6	15	25	50	75	100

Orthogonal Frequency Division Multiplexing



Frequency-Time Representation of an OFDM Signal

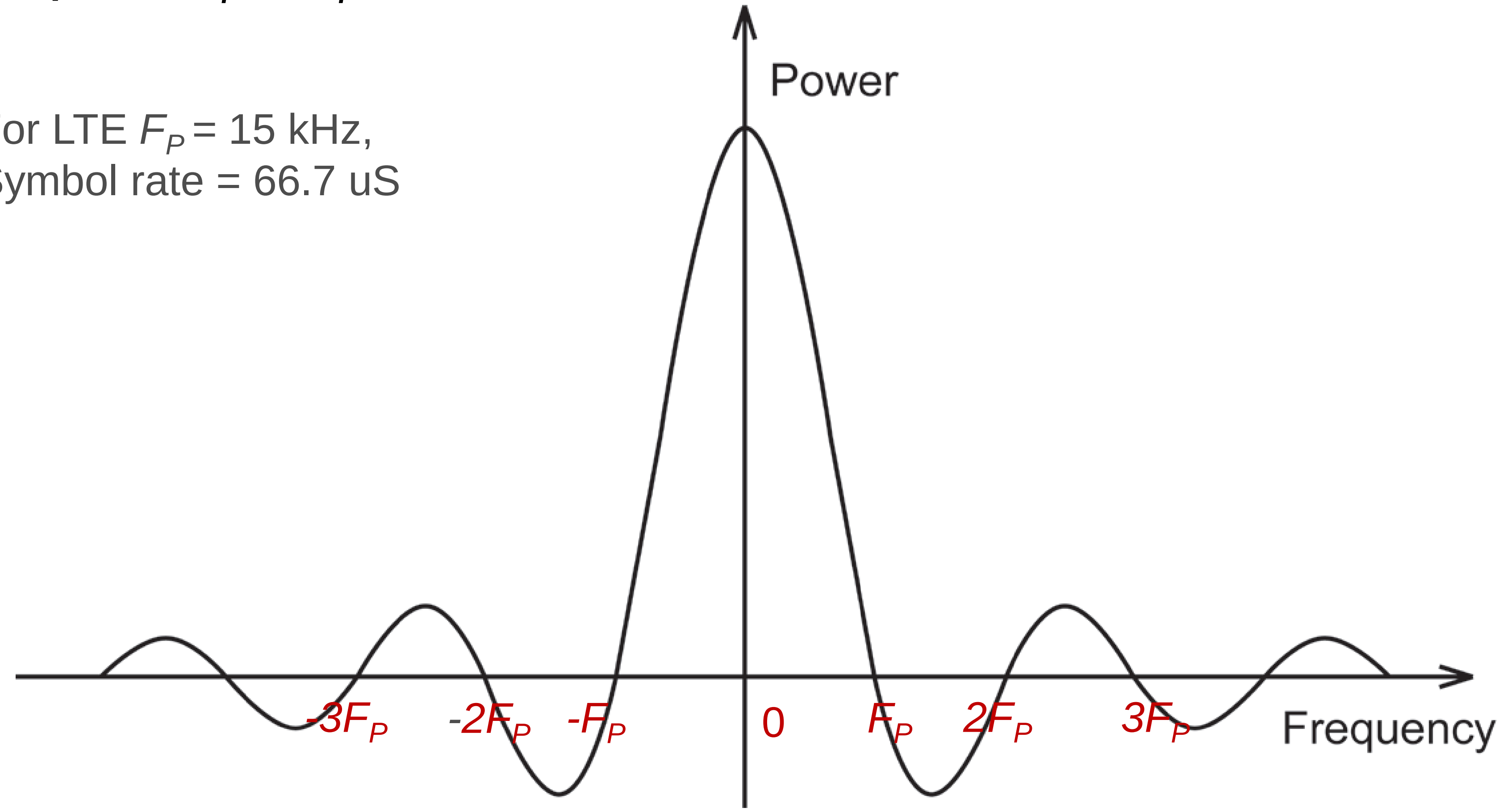
OFDM is a digital multi-carrier modulation scheme

- **large number of closely-spaced orthogonal sub-carriers**
- **sub-carriers modulated with a conventional modulation format (e.g. QPSK, 16/64QAM)**
- **low symbol rate similar to conventional single-carrier modulation schemes in the same bandwidth.**

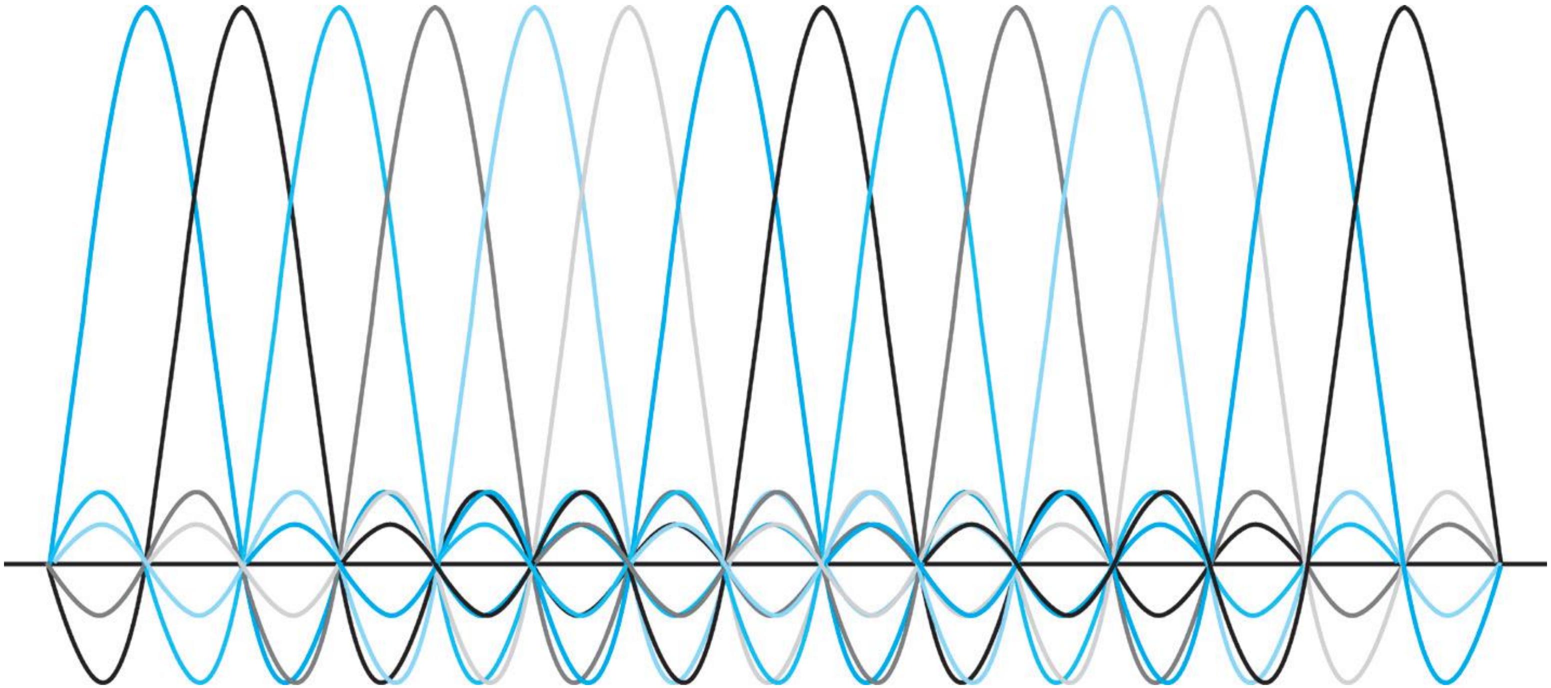
Spectrum of single modulated OFDM subcarrier

The Spectrum of a Complex Tone Pulse is a Sinc or sin(x)/x with Zeros at Multiples of $F_P = 1/T_P$

For LTE F_P = 15 kHz,
Symbol rate = 66.7 uS



Spectrum of multiple OFDM subcarriers



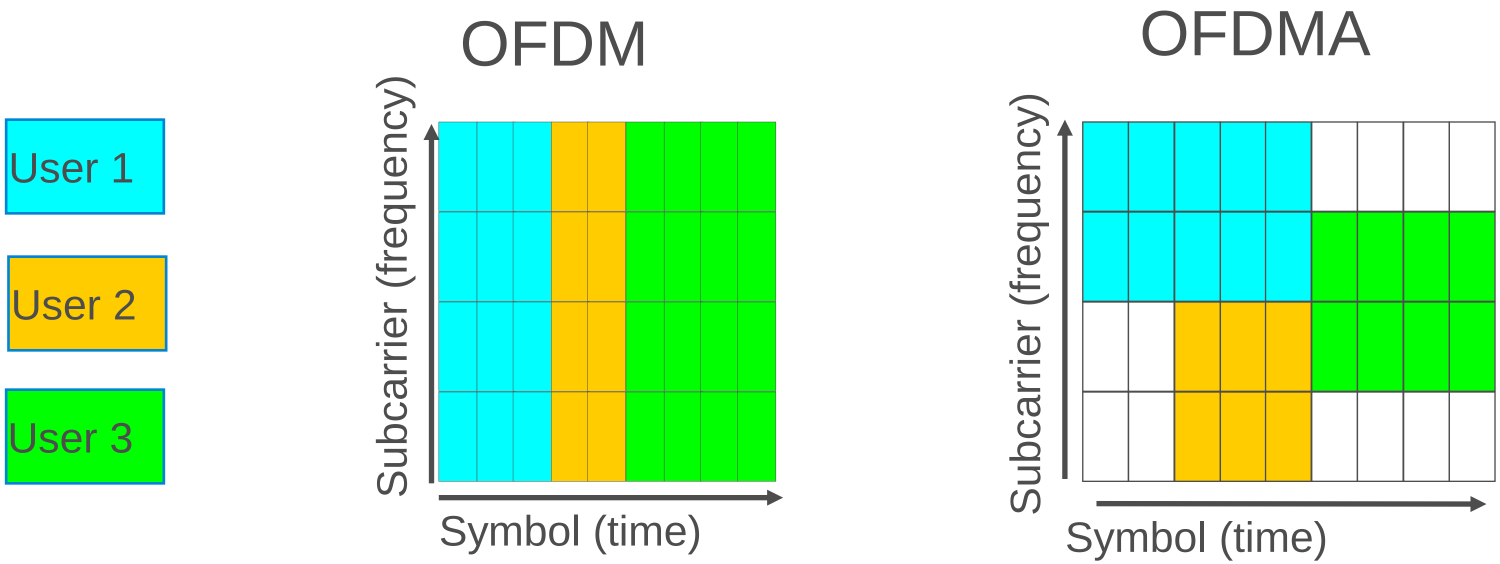
OFDM Operates as a Number of Orthogonal (Non-Interfering) Narrowband Systems

- Carrier spacing creates orthogonality.
- Phase noise, timing and frequency offsets decrease orthogonality.

OFDMA

LTE uses OFDMA (Orthogonal Frequency Division Multiple Access)

- **more advanced form of OFDM where subcarriers are allocated to different users over time**



User allocation in time domain only

User allocation in time and frequency domain

Orthogonal Frequency Division Multiplexing

OFDM advantages

- Multiple subcarriers allows
  - Scalable channel bandwidth
  - Frequency selective scheduling within the channel
- Wide channels are possible which support higher data rates
- Resistance to multi-path due to very long symbols

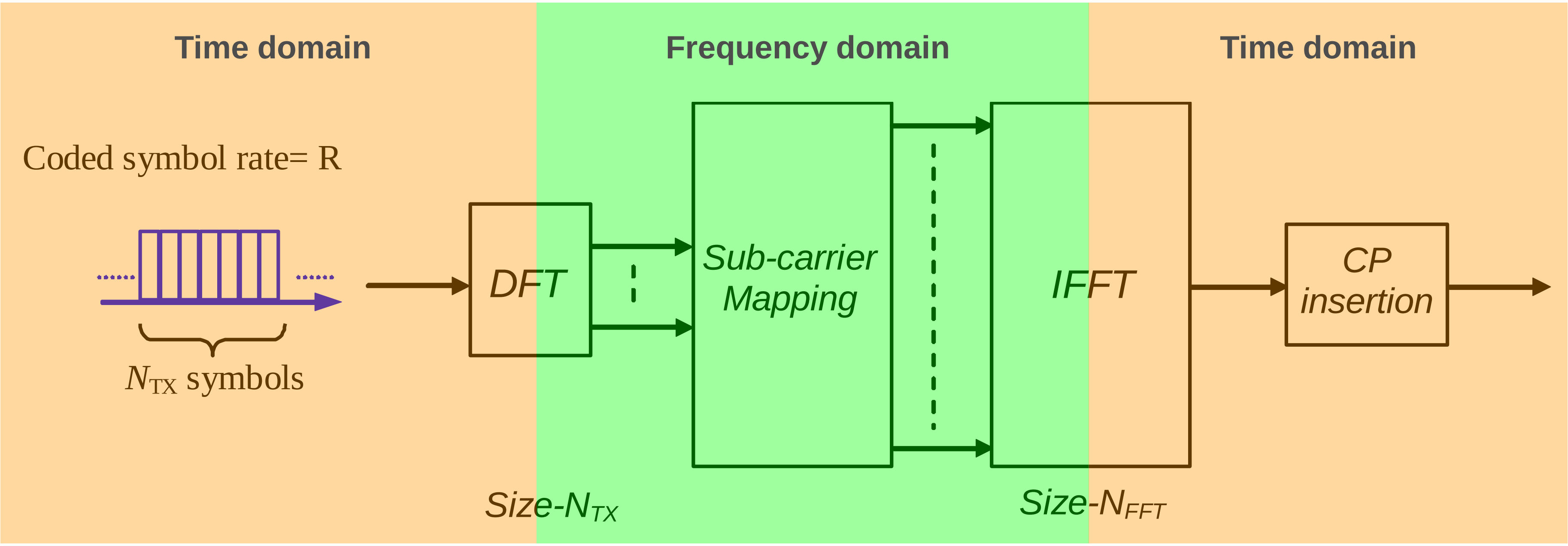
OFDM disadvantages

- Sensitive to frequency errors and phase noise due to close subcarrier spacing
- Sensitive to Doppler shift which creates interference between subcarriers
- Pure OFDM creates high PAR which is why SC-FDMA is used on UL

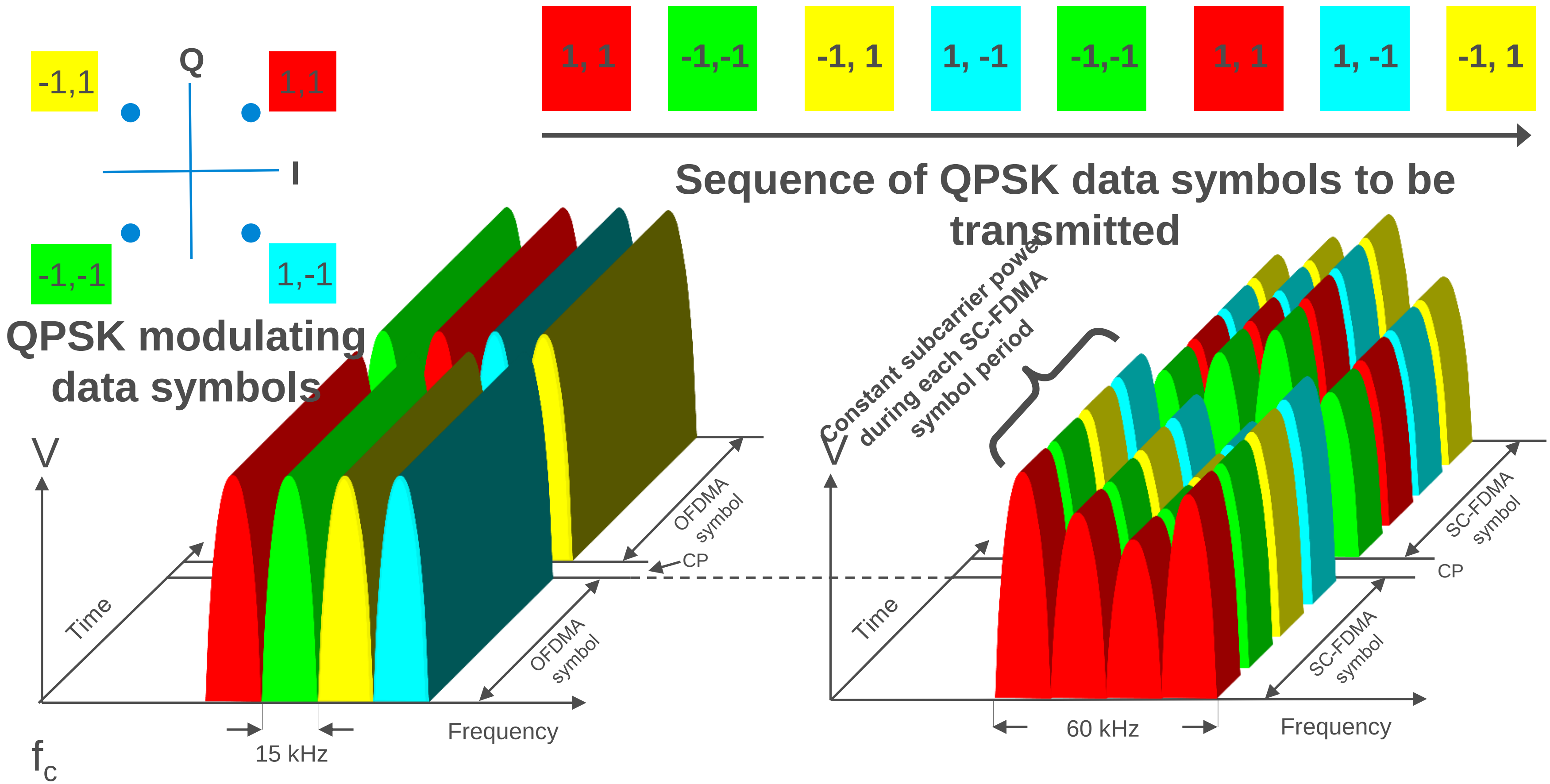
Single Carrier FDMA:
The new LTE uplink transmission scheme

SC-FDMA is a hybrid transmission scheme:

- low peak to average (PAR) of single carrier schemes
- frequency allocation flexibility and multipath protection of OFDMA



Comparing OFDMA and SC-FDMA
QPSK example using M=4 subcarriers



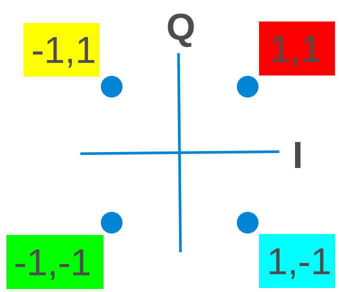
OFDMA
Data symbols occupy 15 kHz for one OFDMA symbol period

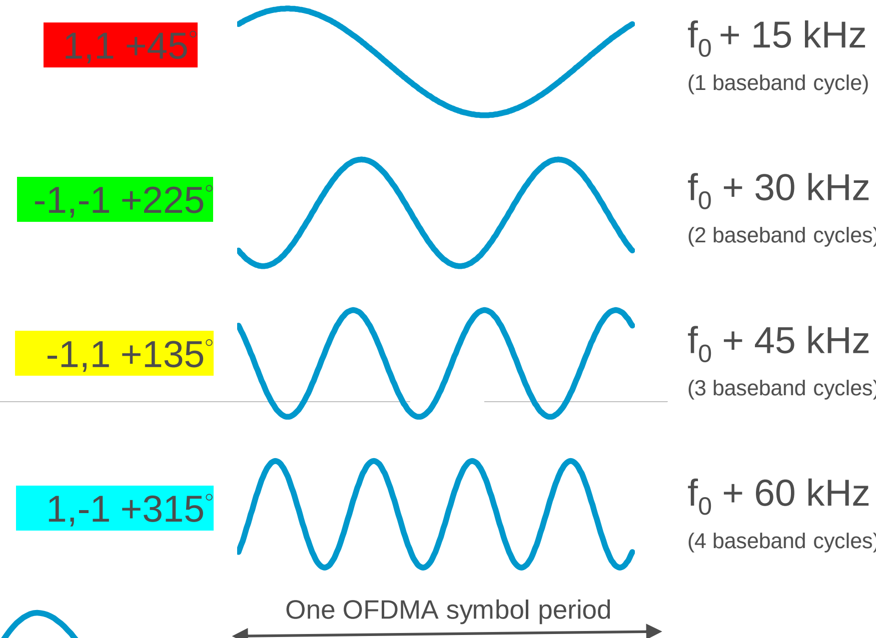
SC-FDMA
Data symbols occupy M*15 kHz for 1/M SC-FDMA symbol periods

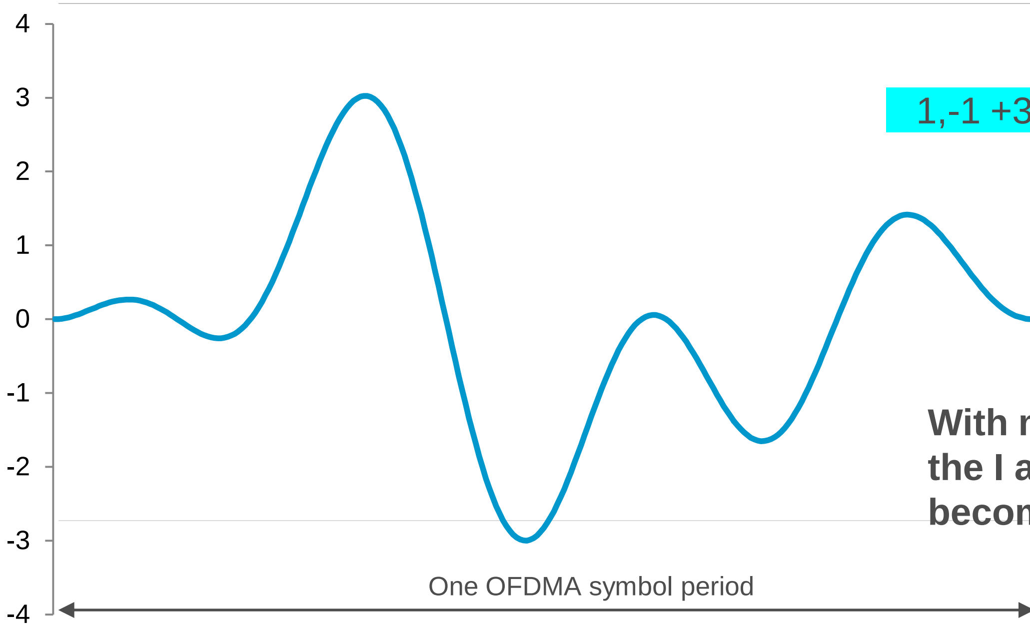
OFDMA modulation
QPSK example using M=4 subcarriers

Each of M subcarriers is encoded with one QPSK symbol

M subcarriers can transmit M QPSK symbols in parallel







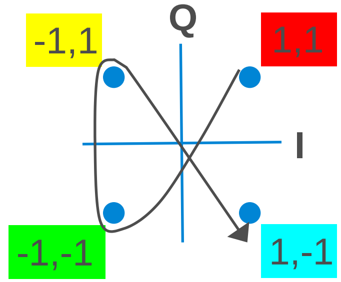
With many subcarriers the I and Q waveforms become Gaussian

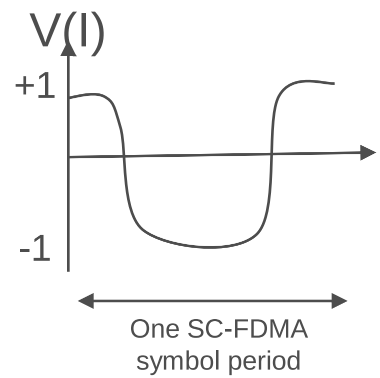
SC-FDMA signal generation
QPSK example using M=4 subcarriers

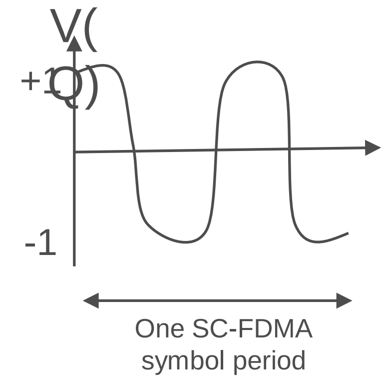
To transmit the sequence:

1, 1 -1,-1 -1, 1 1,-1

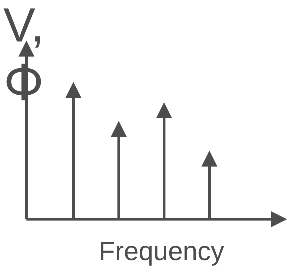
create a time domain representation of the IQ baseband sequence



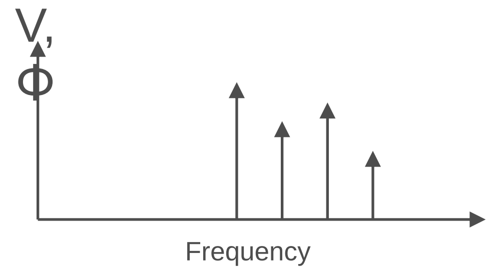




Perform a DFT of length M and sample rate M/(symbol period) to create M FFT bins spaced by 15 kHz

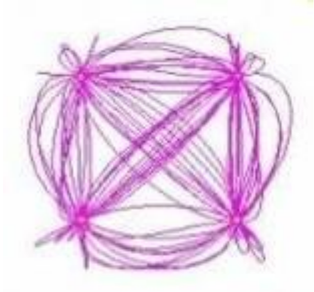


Shift the M subcarriers to the desired allocation within the system bandwidth



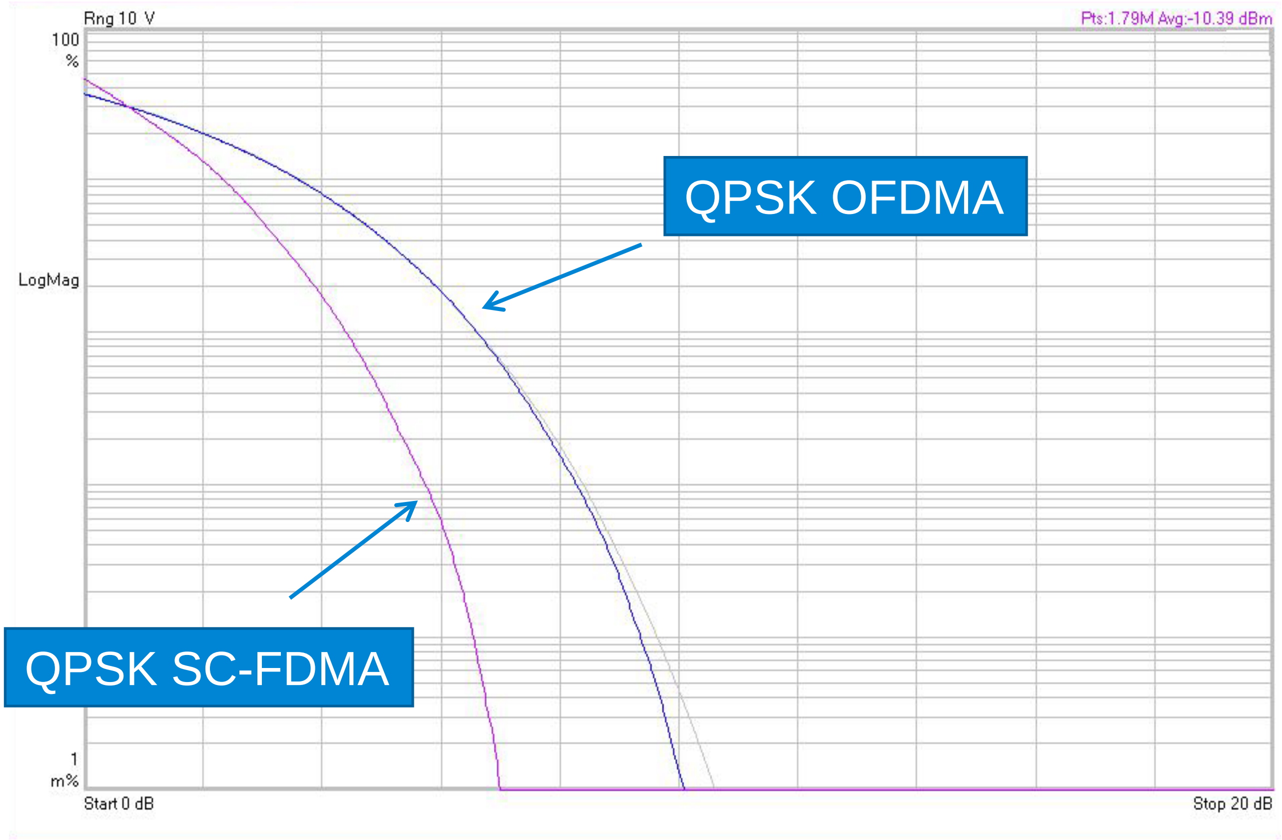
Perform an IFFT to create a time domain signal of the frequency shifted original

Insert the cyclic prefix between SC-FDMA symbols and transmit



Important Note: The PAR is the same as the original QPSK data symbols

Complimentary cumulative distribution function

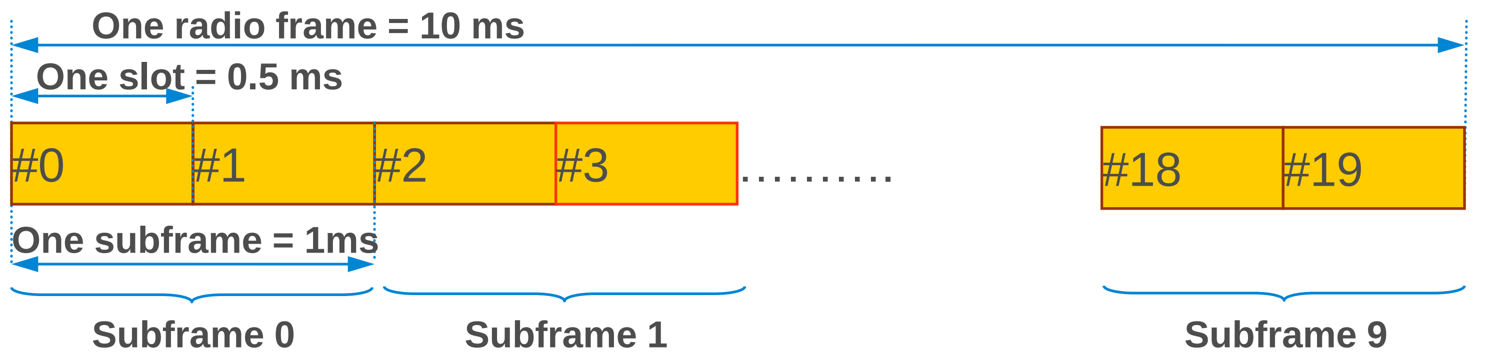


- SC-FDMA has lower PARs
- Extra headroom lowers costs in the power amplifier and reduces battery drain.

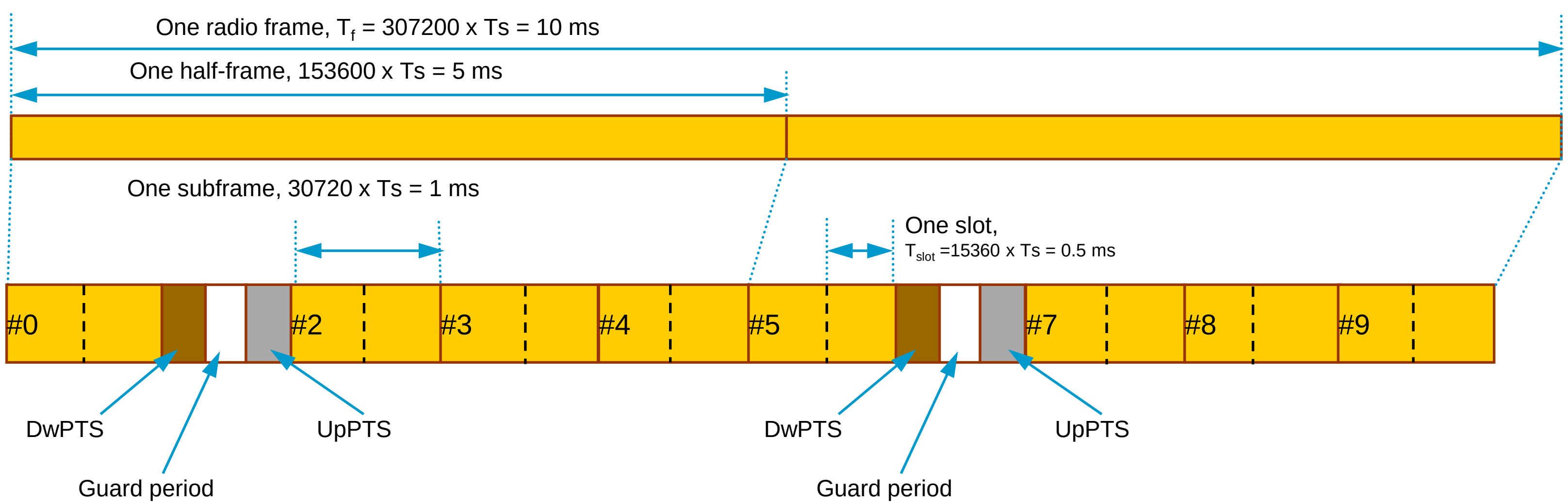
Physical Layer Definitions: Frame Structure

Frame Structure type 1 (FDD)

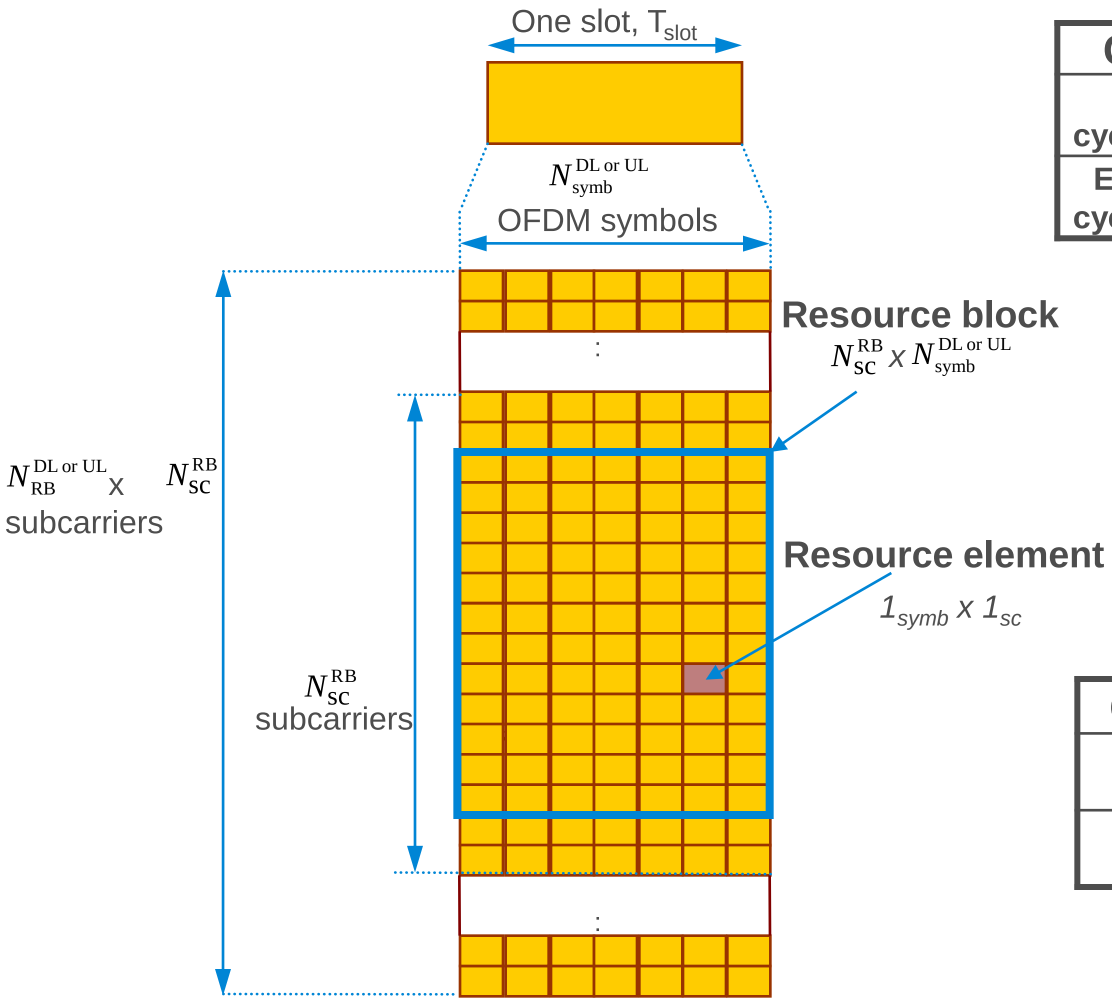
FDD: Uplink and downlink are transmitted separately



Frame Structure type 2 (TDD)



Slot Structure & Physical Resource Elements



Condition (DL)		N^{RB}_{sc}	N^{DL}_{symb}
Normal cyclic prefix	Δf=15kHz	12	7
Extended cyclic prefix	Δf=15kHz	12	6
	Δf=7.5kHz	24	3

Condition (UL)	N^{RB}_{sc}	N^{UL}_{symb}
Normal cyclic prefix	12	7
Extended cyclic prefix	12	6

LTE Physical Layer Signals & Channels

Physical signals

Downlink	Uplink
Primary synchronization signal	Demodulation reference signal (DMRS)
Secondary synchronization signal	Sounding reference signal (SRS)
Reference signals	

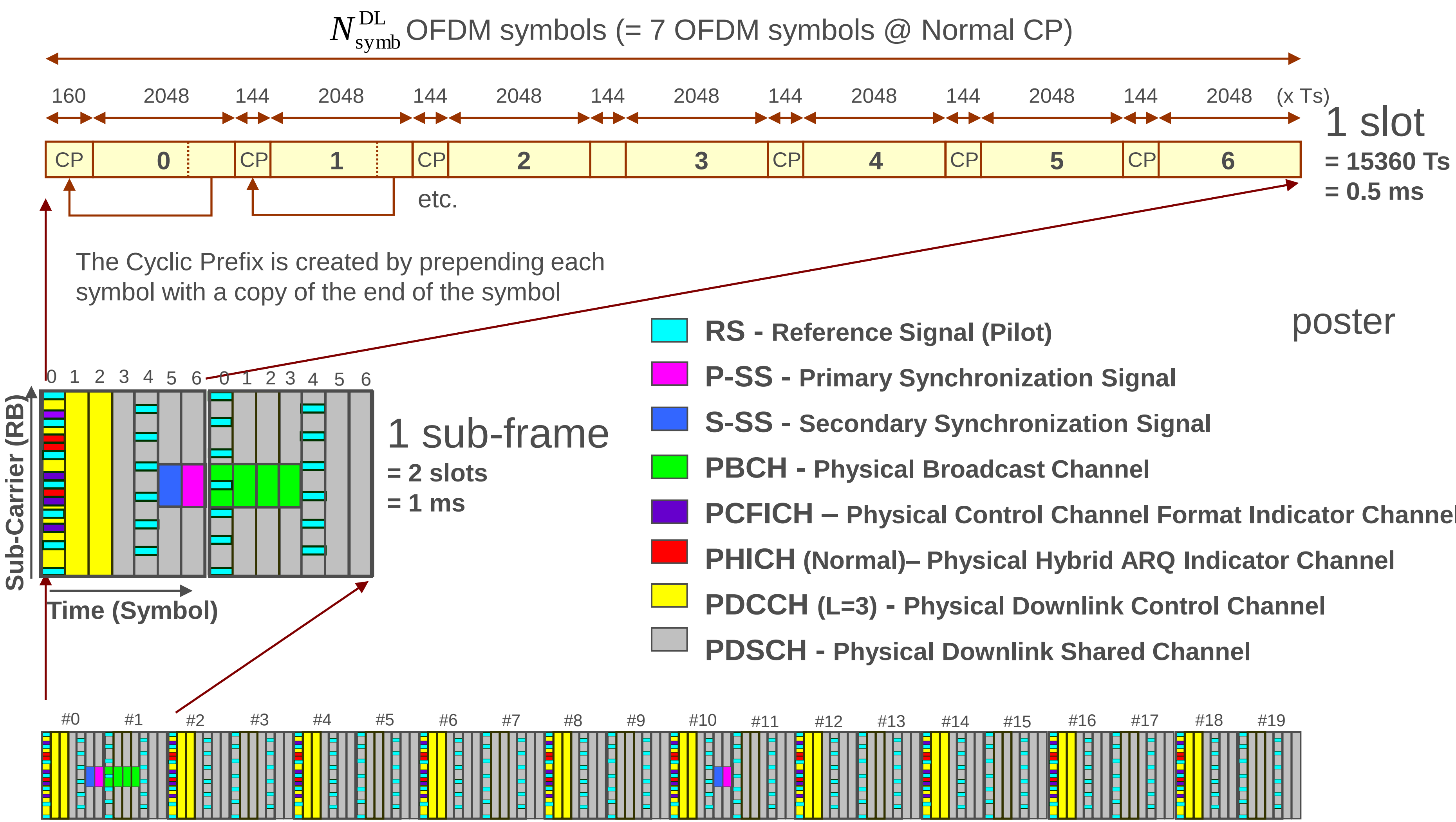
Generated in Layer 1 and are used for system synchronization, cell identification and radio channel estimation

Physical channels

Downlink	Uplink
Physical Downlink Shared Channel (PDSCH)	Physical Uplink Shared Channel (PUSCH)
Physical Broadcast Channel (PBCH)	Physical Uplink Control Channel (PUCCH)
Physical Downlink Control Channel (PDCCH)	Physical Random Access Channel (PRACH)
Physical Multicast Channel (PMCH)	
Physical Control Format Indicator Channel (PCFICH)	
Physical Hybrid Automatic Repeat Request (ARQ) Indicator Channel (PHICH)	

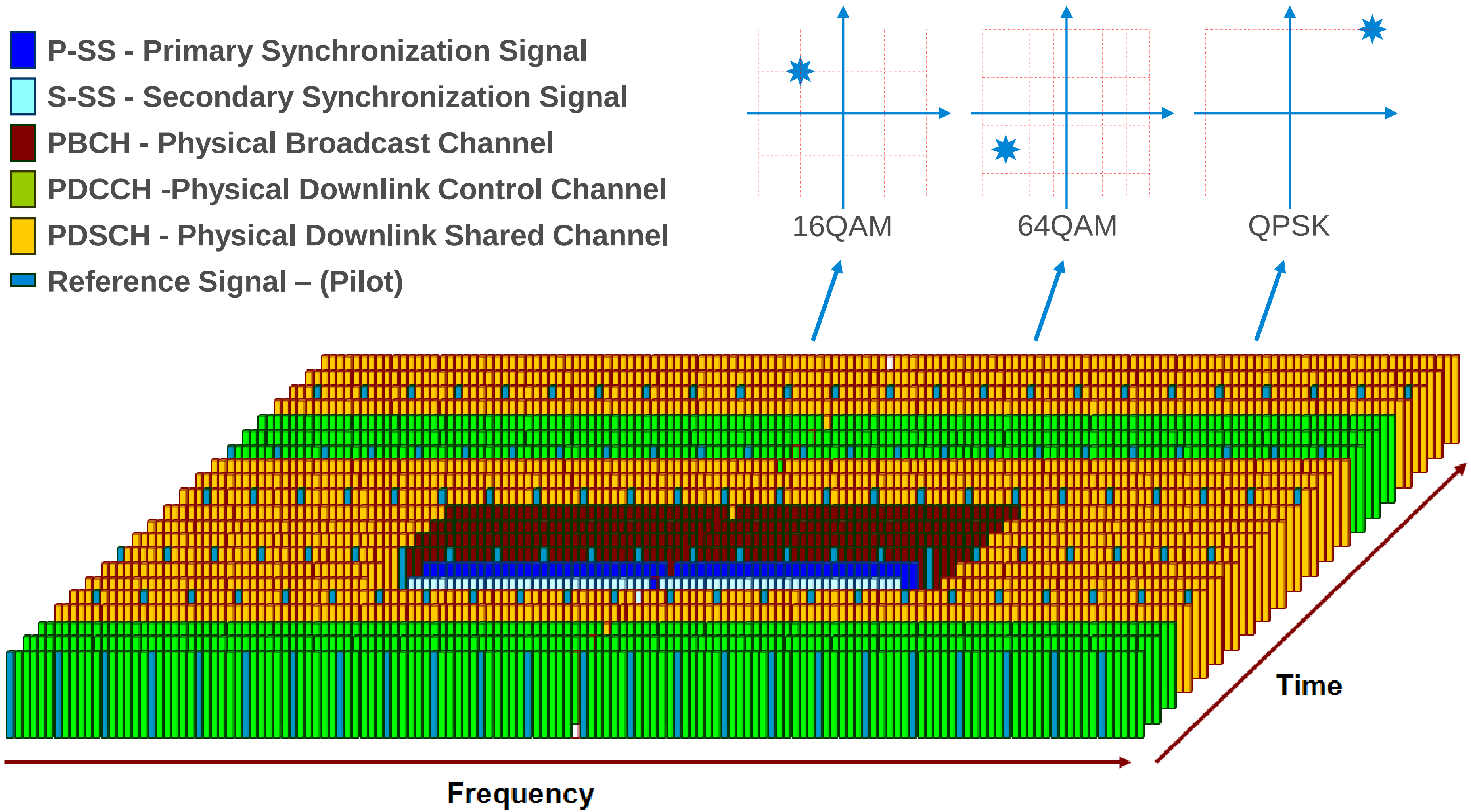
Carry data from higher layers including control, scheduling and user payload

Downlink Frame Structure Type 1



LTE Downlink Mapping

- P-SS - Primary Synchronization Signal
- S-SS - Secondary Synchronization Signal
- PBCH - Physical Broadcast Channel
- PDCCH -Physical Downlink Control Channel
- PDSCH - Physical Downlink Shared Channel
- Reference Signal – (Pilot)



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- **LTE-Advanced Topics**
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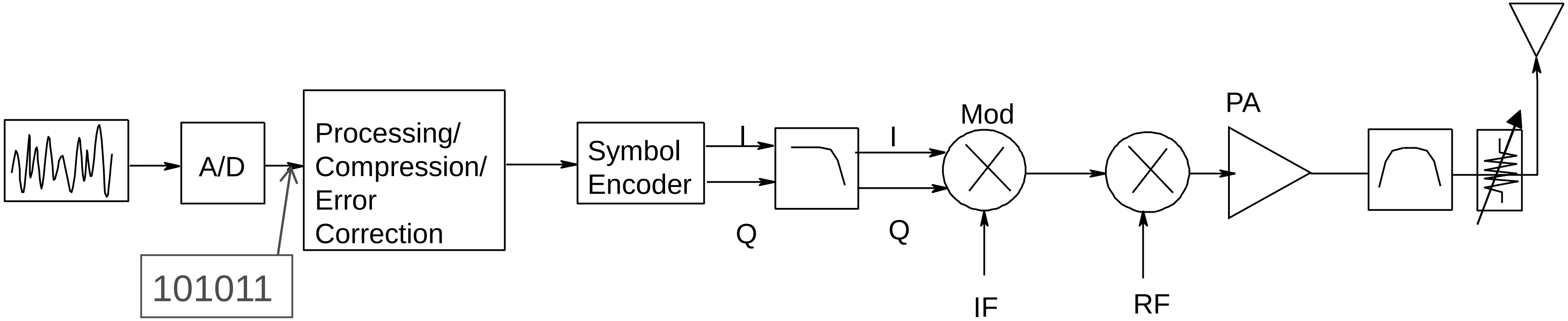
  - MIMO

Transmitter Basics



- Channel Coding
- Map to I & Q
- Modulation Shaping Filter
- Modulate to IF
- Upconvert to RF
- Amplify, Filter, Send to Antenna

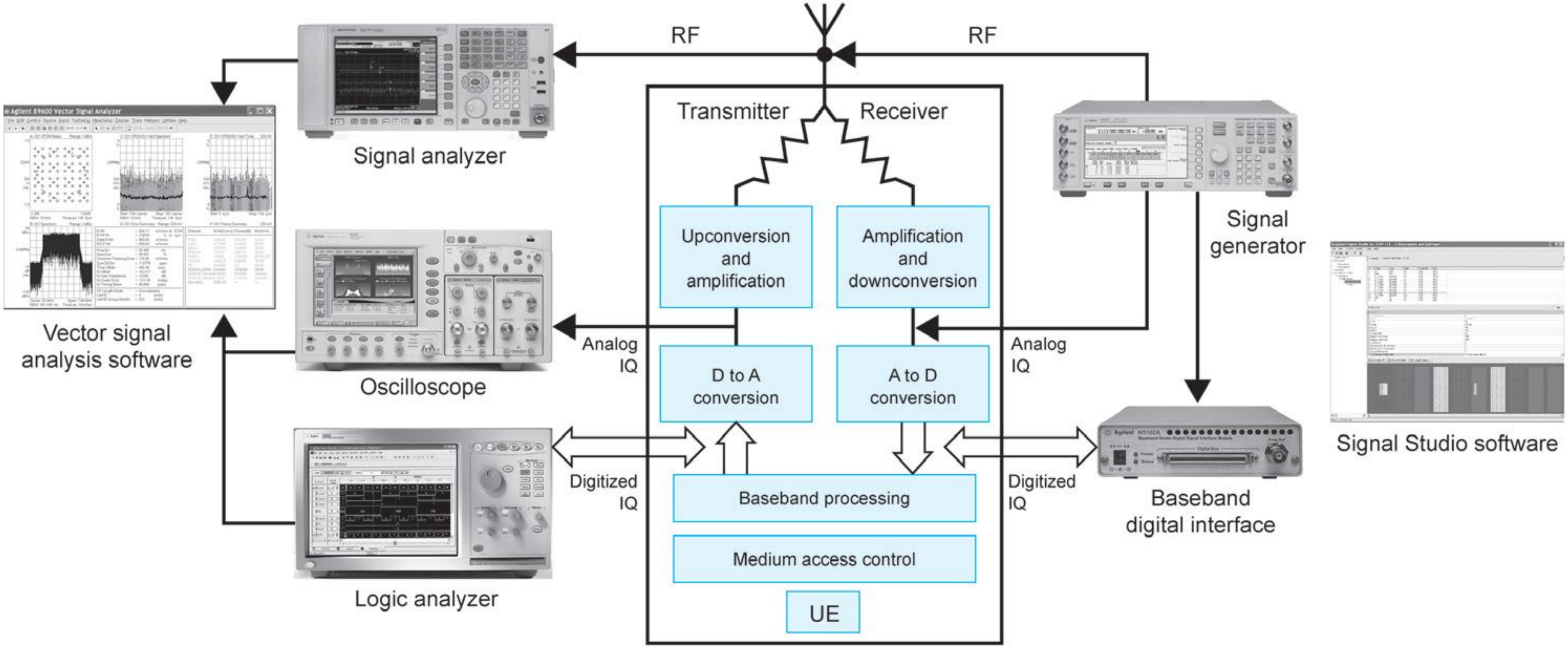
- Characteristics tests
  - Output power
  - Transmitted signal quality
  - Unwanted emissions

Transmitter Testing – Characteristics

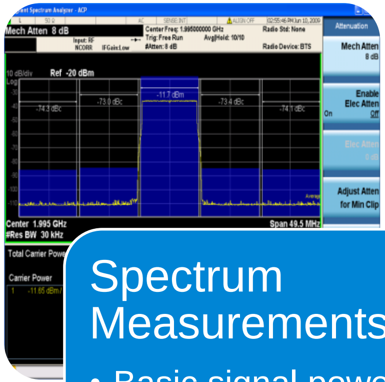
Output power	eNB 36.141	UE 36.521-1
Max output power	6.2	
Transmit power		6.2
Output power dynamics	6.3	6.3
Transmit on/off power	6.4	
Transmitted signal quality		
Frequency error	6.5.1	6.5.1
EVM	6.5.2	
Transmit modulation quality		6.5.2
Time alignment between Tx branches	6.5.3	
DL RS power	6.5.4	

Unwanted emissions	eNB 36.141	UE 36.521-1
ACLR	6.6.2	6.6.2
Spurious emissions	6.6.4	6.6.3
Transmitter intermodulation	6.7	6.7
Occupied BW	6.6.1	6.6.1
Oper. band unwanted emissions	6.6.3	
Spectrum emission mask		6.6.2

Measuring Signals at Different Locations in the Transmitter

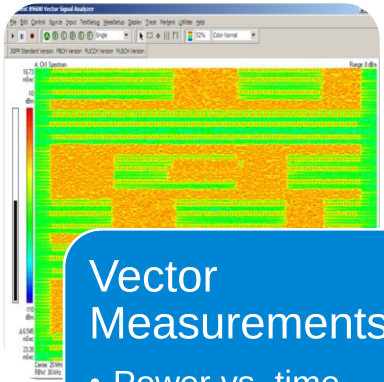


A Systematic & Structured Approach



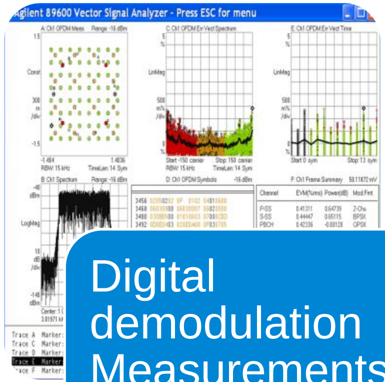
Spectrum Measurements

- Basic signal power and frequency characteristics



Vector Measurements

- Power vs. time, CCDF, spectrograms

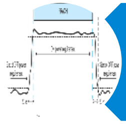


Digital demodulation Measurements

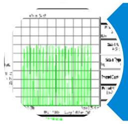
- Constellation and modulation quality analysis, advanced analysis

More productive and efficient to follow a verification sequence when measuring complex signals

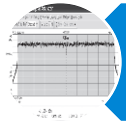
Verifying Transmitter – Spectrum and Vector Measurements



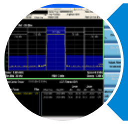
Channel power



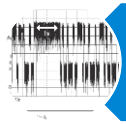
Amplitude flatness



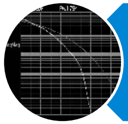
Center frequency



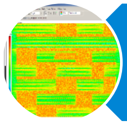
Occupied bandwidth



Power vs time

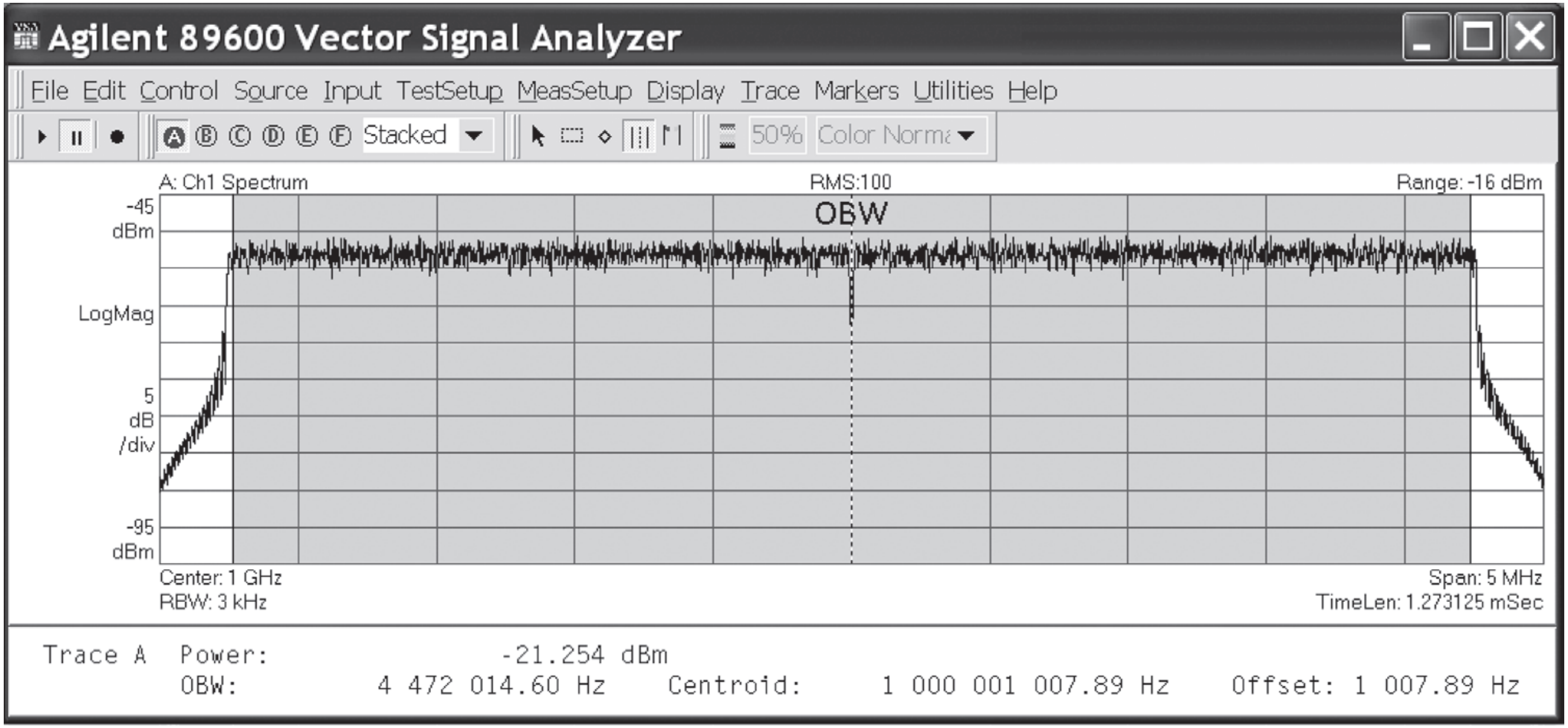


CCDF

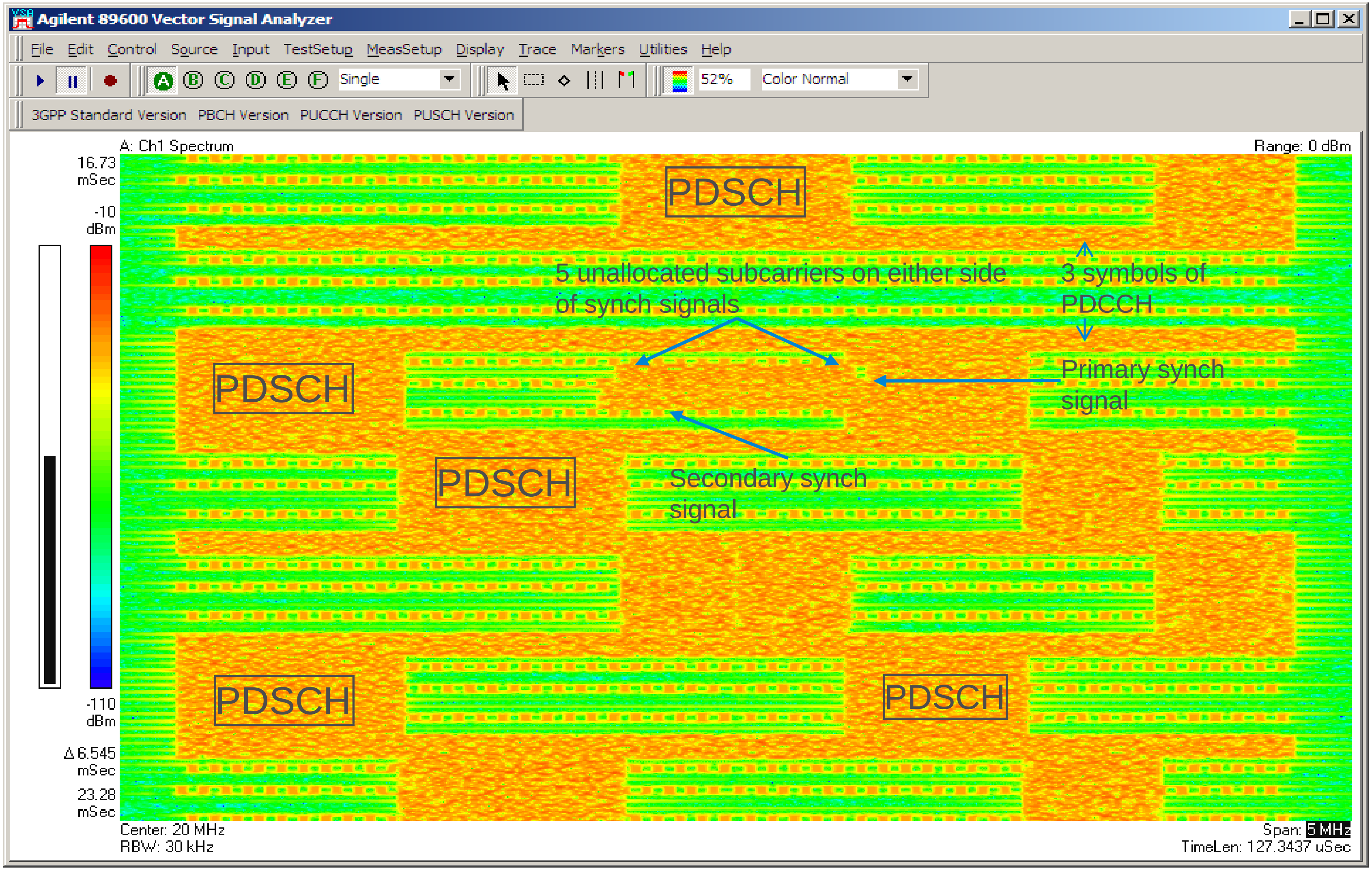


Spectrum vs time

Occupied Bandwidth



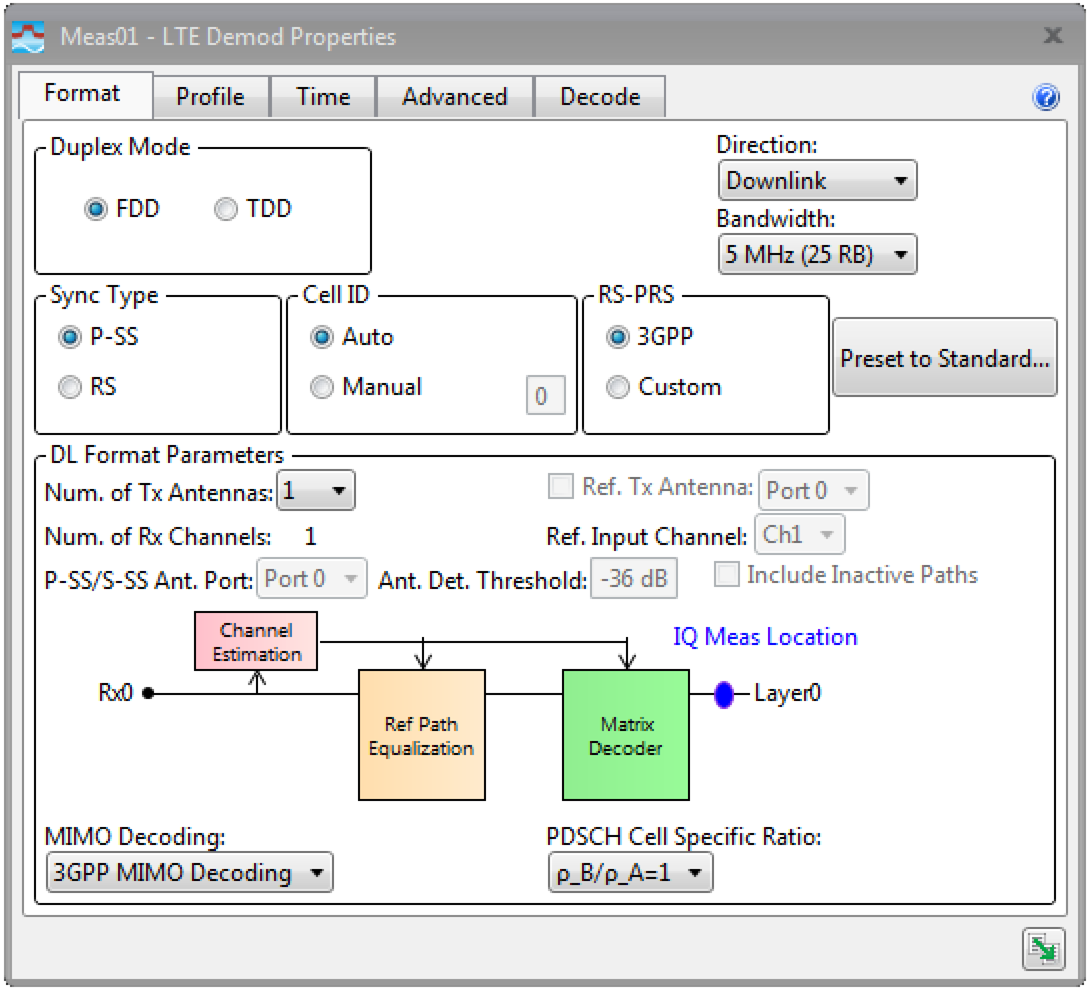
Spectrogram



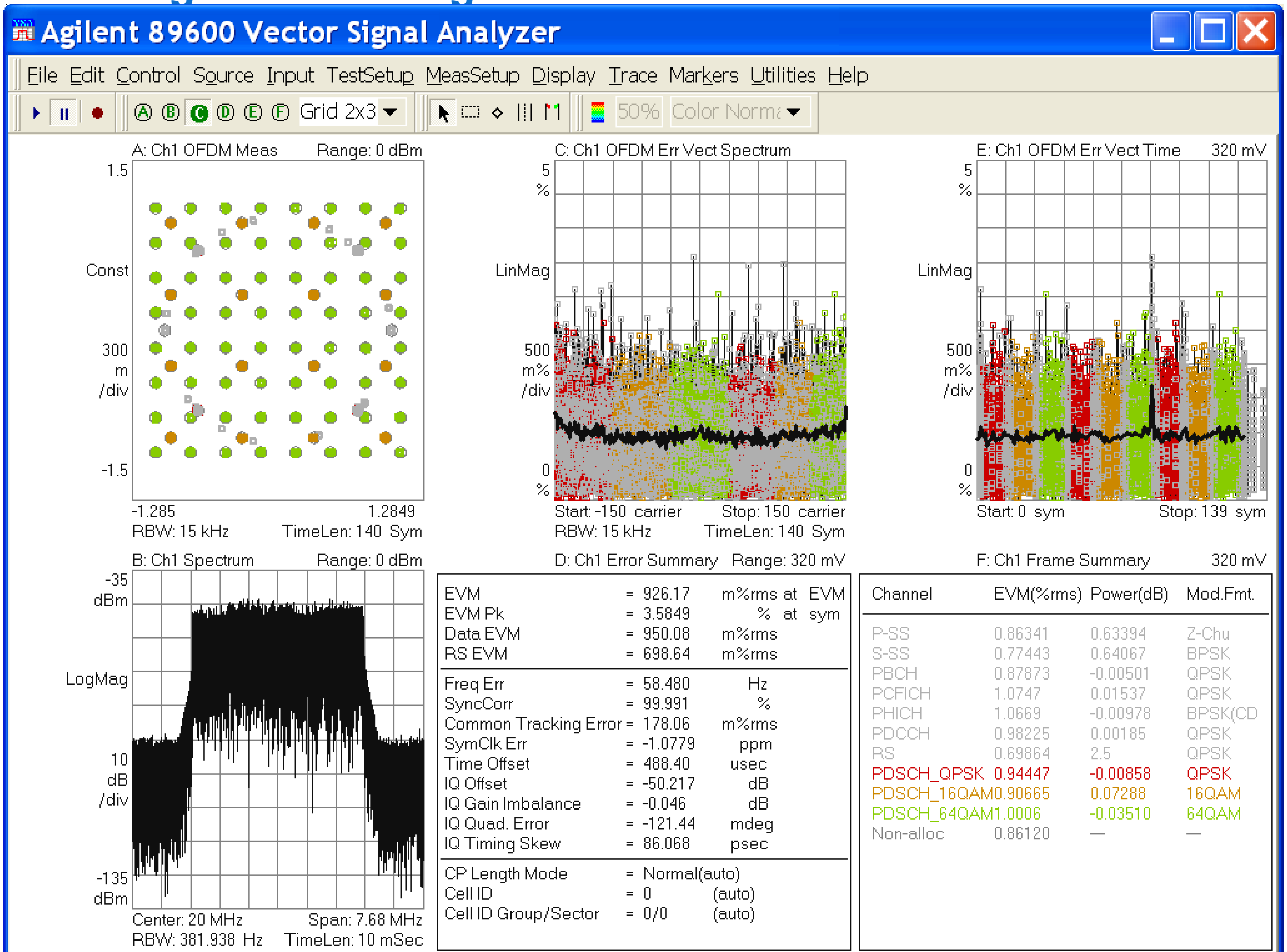
Analysis of Signals After Digital Demodulation

Measurement example for setup, including:

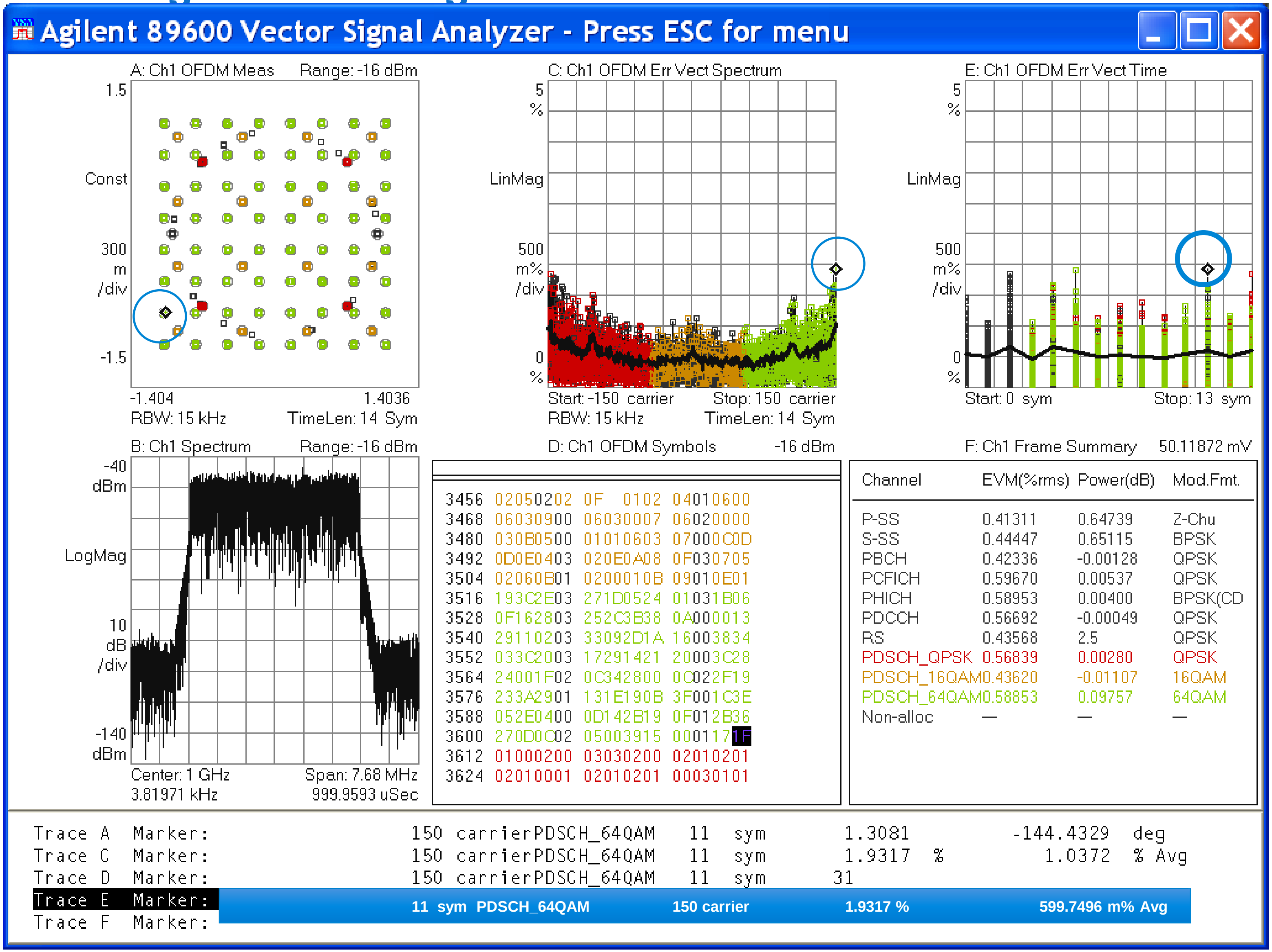
- UL / DL
- FDD / TDD
- Bandwidth & Span
- Sync type



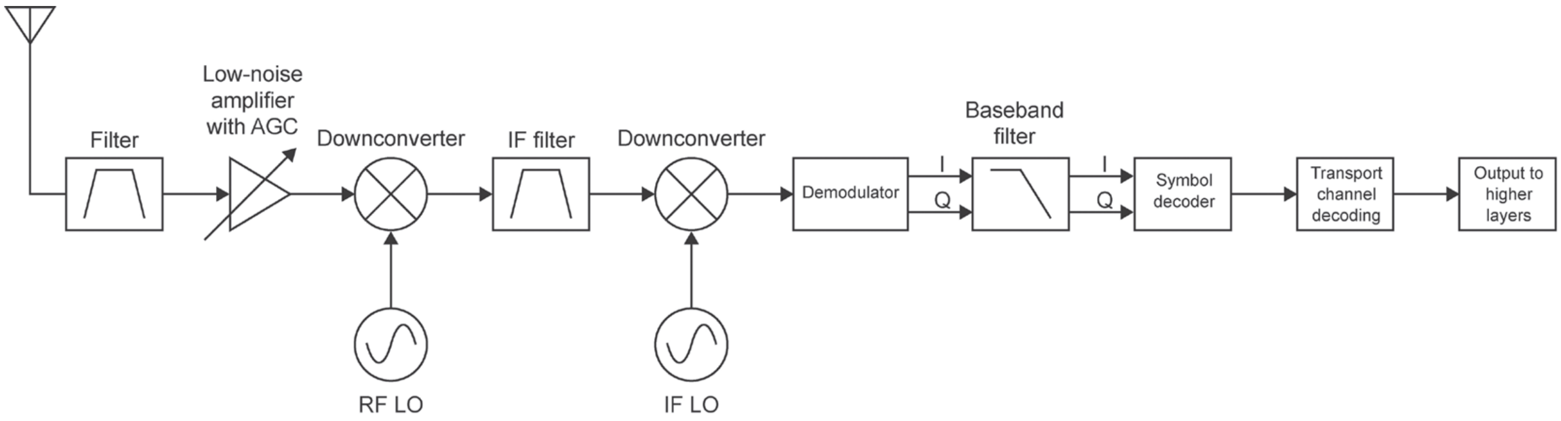
Analysis of Signals After Digital Demodulation



Analysis of Signals After Digital Demodulation



Receiver Basics



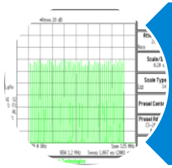
- Downconvert to IF/BB
- Filter
- Demodulate
- Decode and Process Bits
- Convert to Analog (if necessary)

- Characteristics tests - open loop
  - Sensitivity and Dynamic Range
  - Susceptibility to interference
  - Unwanted emissions

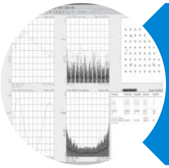
Receiver Testing – Characteristics

Sensitivity and dynamic range	eNB 36.141	UE 36.521.1
Reference sensitivity level	7.2	7.3
Dynamic range	7.3	
In-channel selectivity	7.4	
Max input level		7.4
Susceptibility to interference		
Blocking	7.6	7.6
Adjacent channel selectivity	7.5	7.5
Intermodulation characteristics		7.8
Receiver intermodulation	7.8	
Spurious response		7.7
Unwanted emissions		
Spurious emissions	7.7	7.9

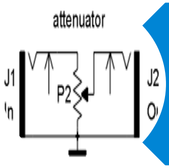
Verifying RF receiver –front end



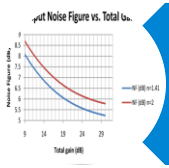
Amplitude flatness



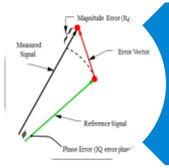
Phase linearity



Automatic gain control



Noise figure



Receiver EVM

Common RF Front End Measurements
Phase Linearity

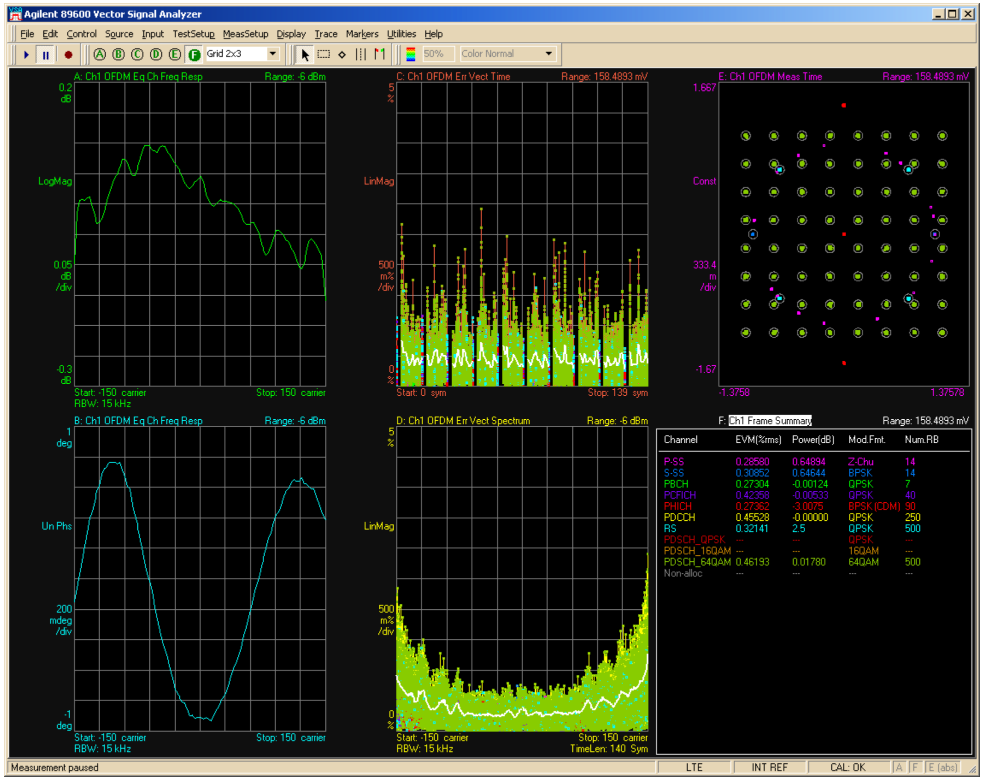
Issues

- LTE can correct some amplitude / phase errors with RS
- Errors will manifest themselves as EVM
- Important because LTE BW is wider than other cellular standards
- Need to test individual components, i.e. Amplifiers, Filters, Mixers, etc

How to test

- VSA can measure phase linearity and also amplitude flatness of modulated LTE signal
- Hard to test with traditional signal generator and spectrum analyzer
- High degree of integration may make network analyzer impractical

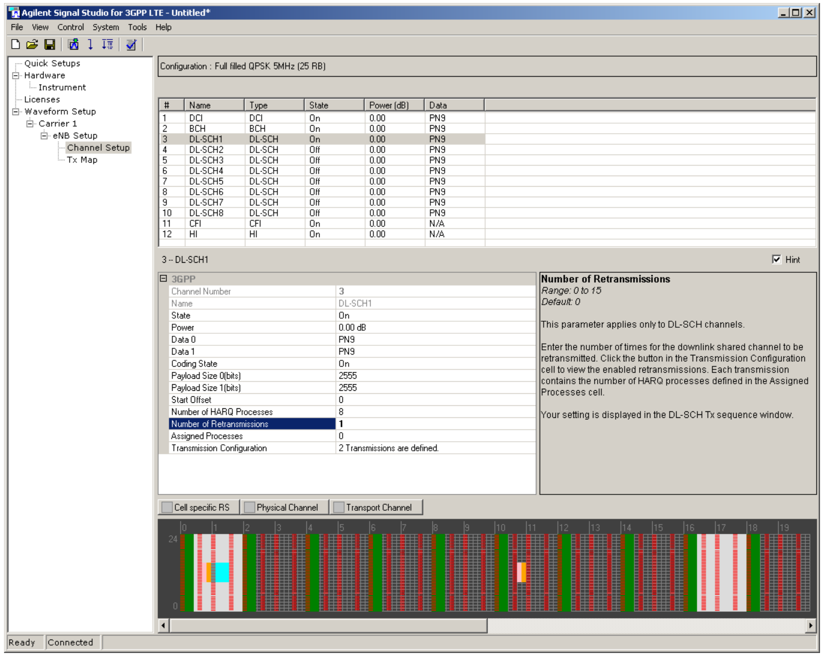
89600A VSA Measurement

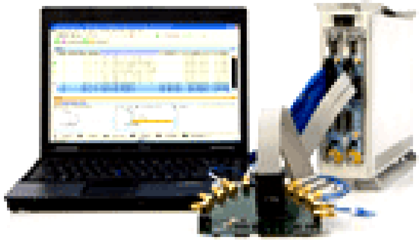


Baseband Measurements

Baseband Measurement Goals

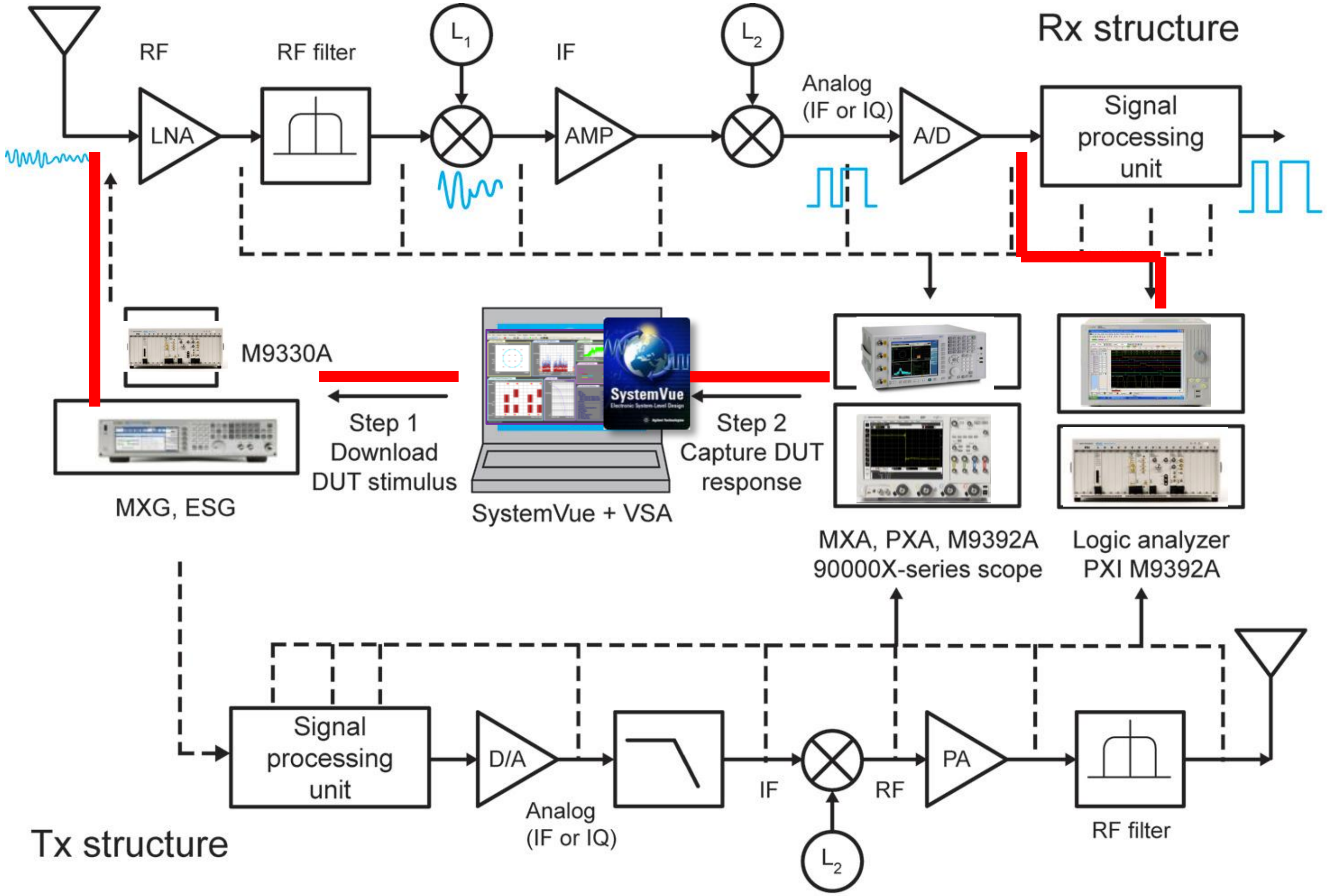
- Determine if RX can correctly demodulate and decode data
  - Different RB allocation
  - Different modulation types
  - Different LTE system BW
- Functional testing of HARQ capability
- Determine performance RX under impaired conditions
- Pre-conformance testing
  - Receiver Characteristics
    - Open Loop
    - Require interfering carriers
  - Performance Requirements
    - Closed Loop
    - Requires fading





RDX for DigRF v4

Combining Simulation and Test to Measure EVM, BER/BLER and throughput at stages in TxRx Chain

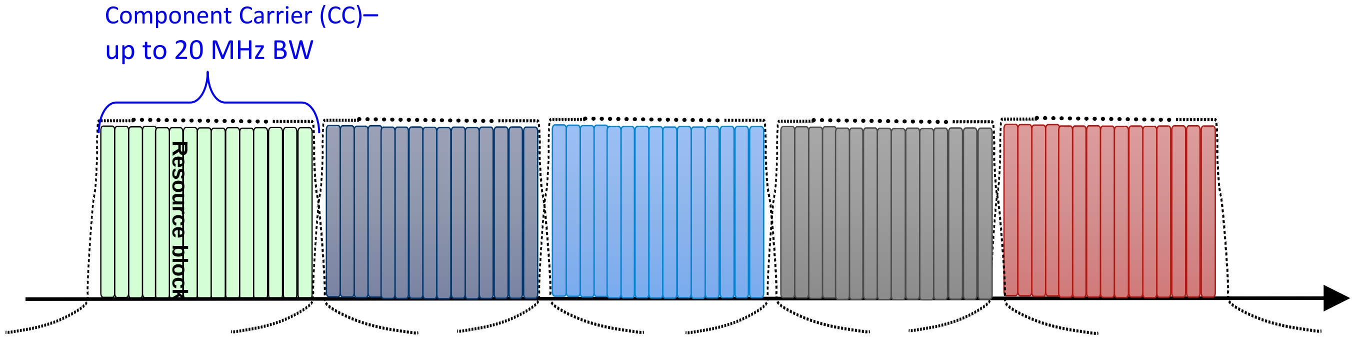


Agenda

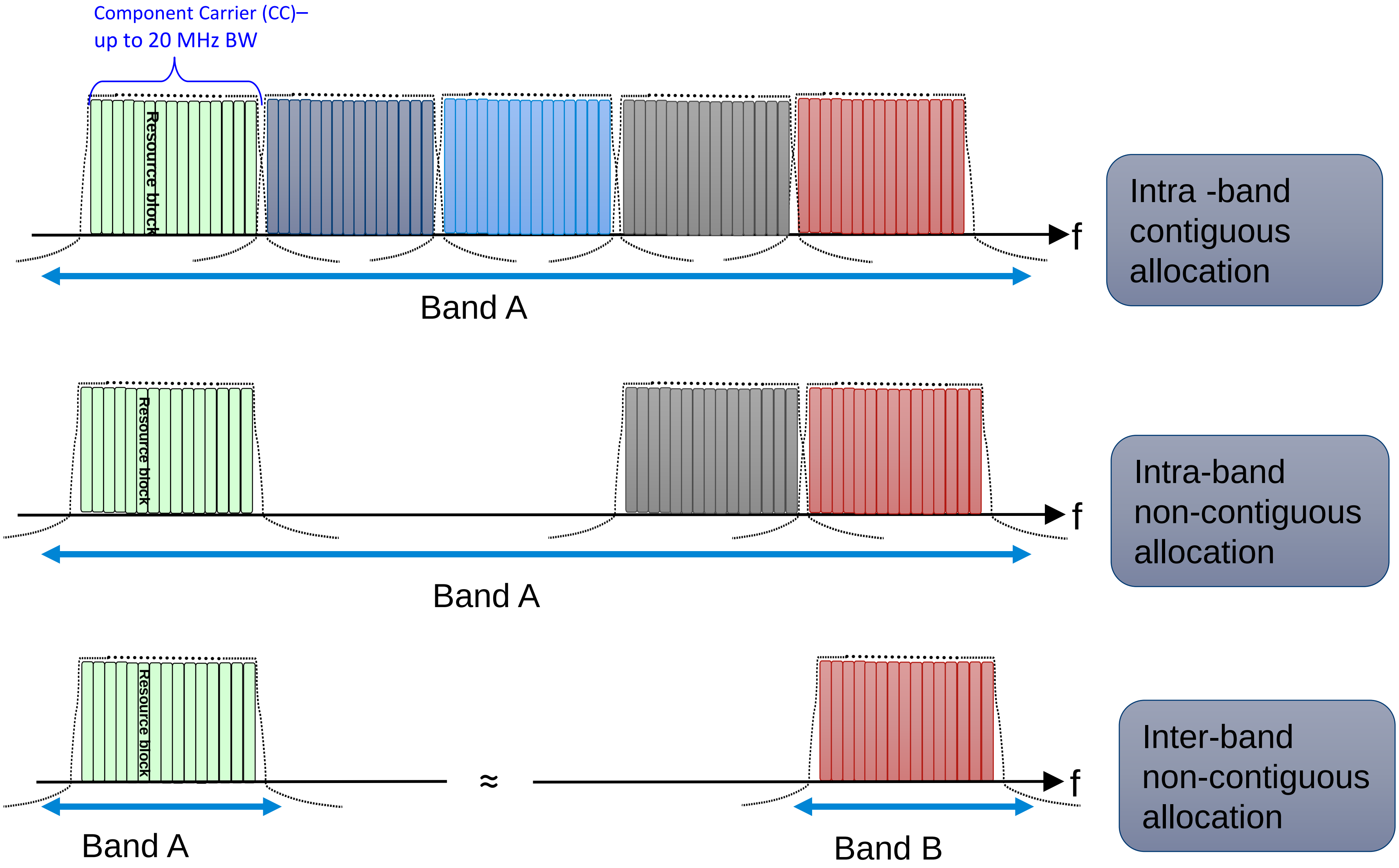
- **Introduction to LTE**
  - Major features and requirements
  - Frequency bands
  - Channel bandwidths
  - OFDM/OFDMA/SCFDMA
  - Structure – frame, slots, resource blocks & elements
  - Physical signals and channels
- **Transmitter & Receiver Test Fundamentals**
- **LTE-Advanced Topics**
  - Carrier Aggregation
  - MIMO

What is Carrier Aggregation?

- Extends the maximum transmission bandwidth, up to 100 MHz, by aggregating up to five LTE carriers – also known as component carriers (CCs)
- Lack of sufficient contiguous spectrum forces use of carrier aggregation to meet peak data rate targets:
  - 1 Gbps in the downlink and 500 Mbps in the uplink
- Motivation:
  - Achieve wide bandwidth transmissions
  - Facilitate efficient use of fragmented spectrum
  - Efficient interference management for control channels in heterogeneous networks



Carrier Aggregation Modes

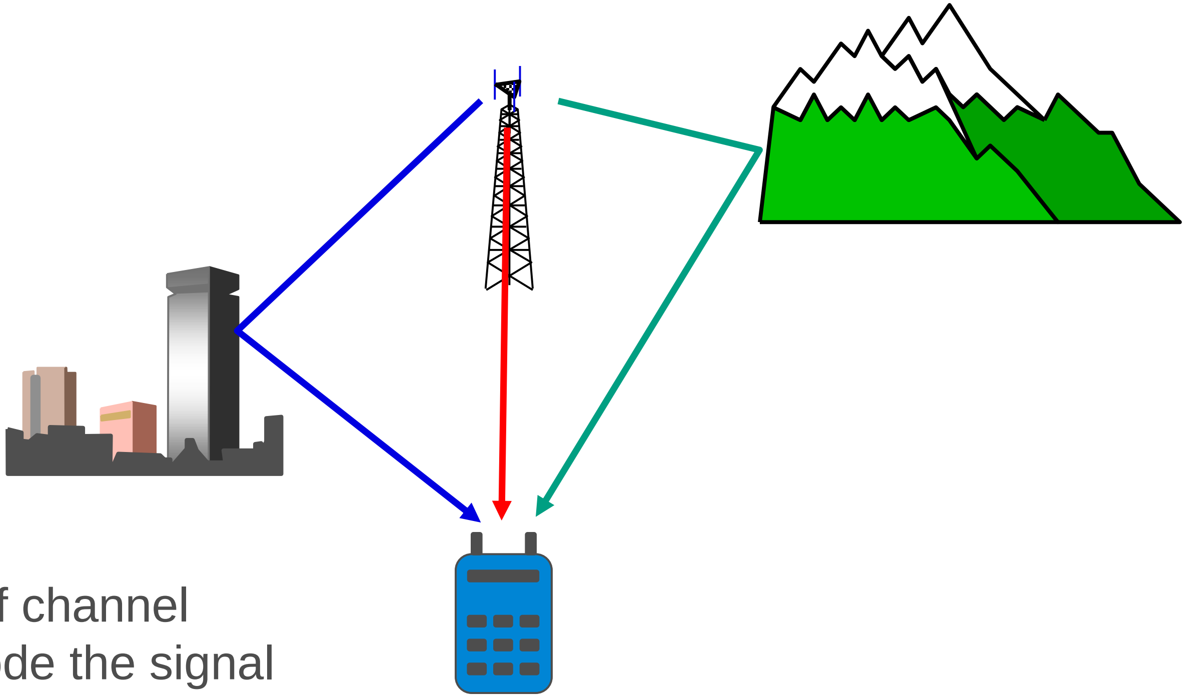


Multi-Antenna Techniques

Objective of Multiple Antennas: To increase coverage and physical layer capacity.

Three kinds of multiple-antenna applications:

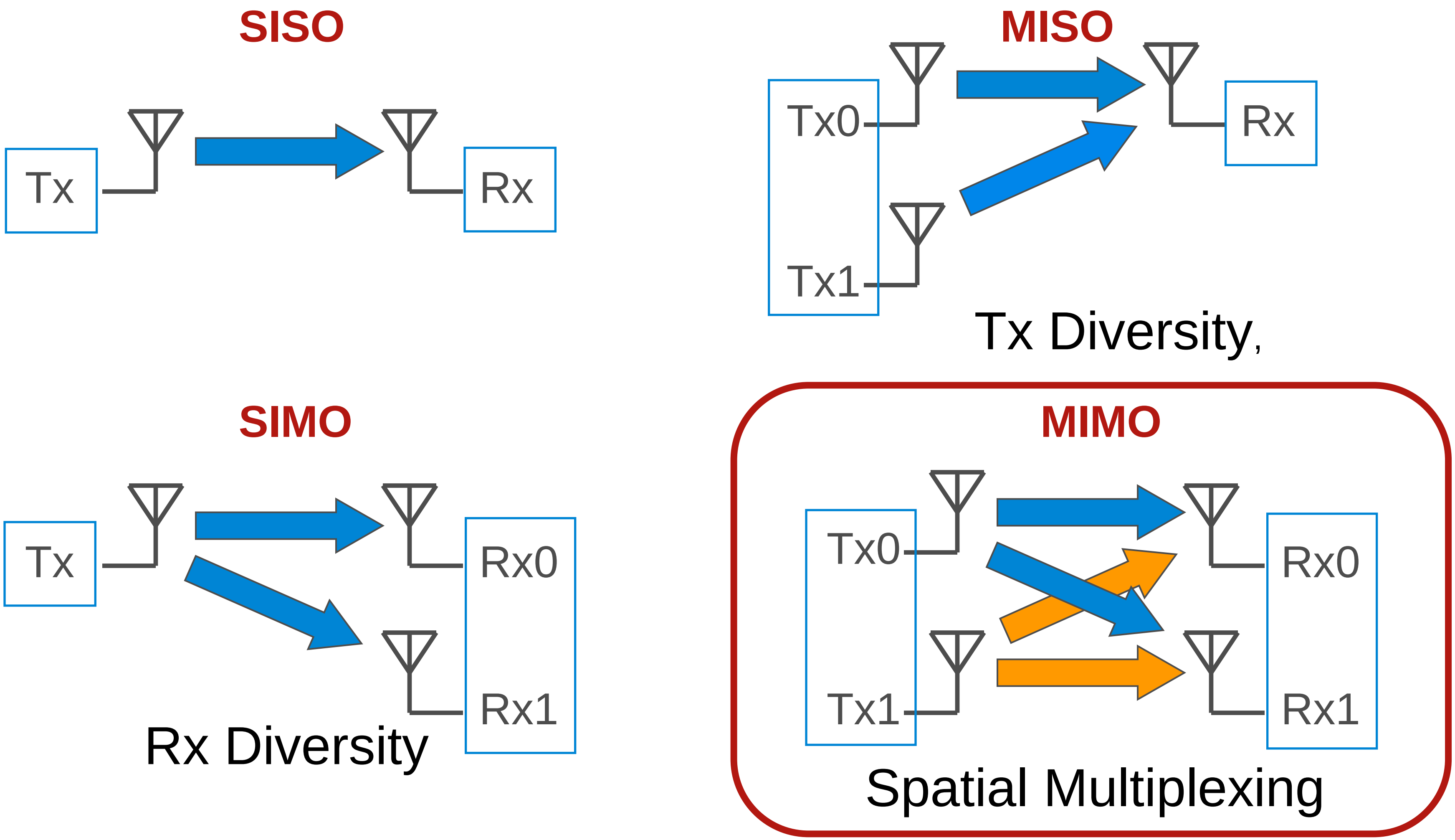
- **Path diversity**
- **Beamsteering**
- **Spatial multiplexing**



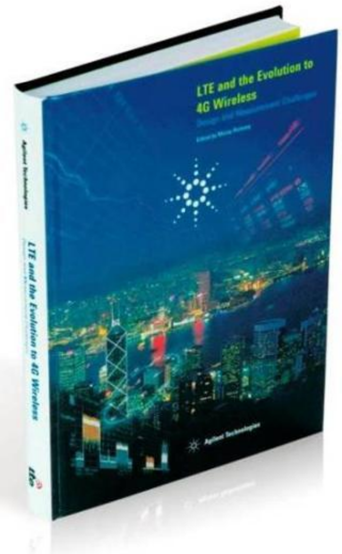
Beamforming: Feedback of channel conditions is used to pre-code the signal

System & Antenna Configurations, Terms

"Input" and "Output" Refer to the Channel



Agilent Tools to Help You



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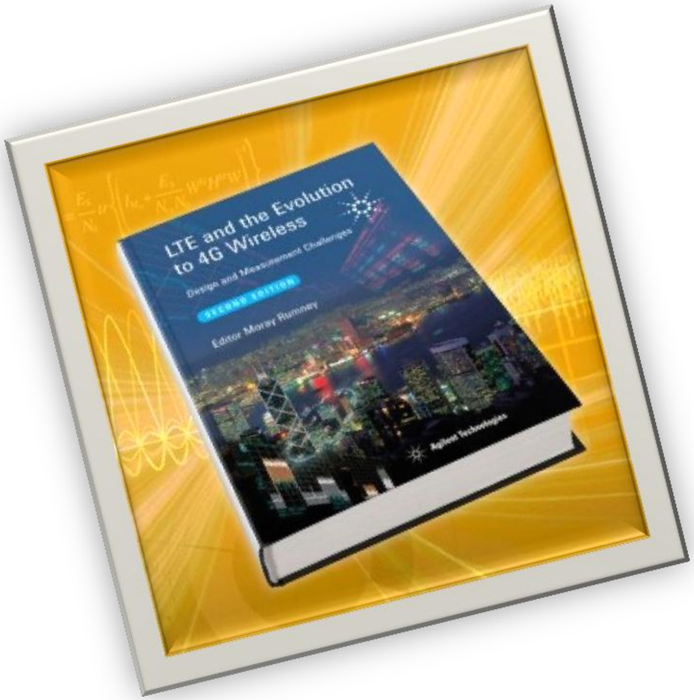

Thank You!

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