SKYWORKS

New Rx Performance Metrics for 5G Massive MIMO Systems

Eid Alsabbagh and Darcy Poulin

VIRTUAL WORKSHOP:

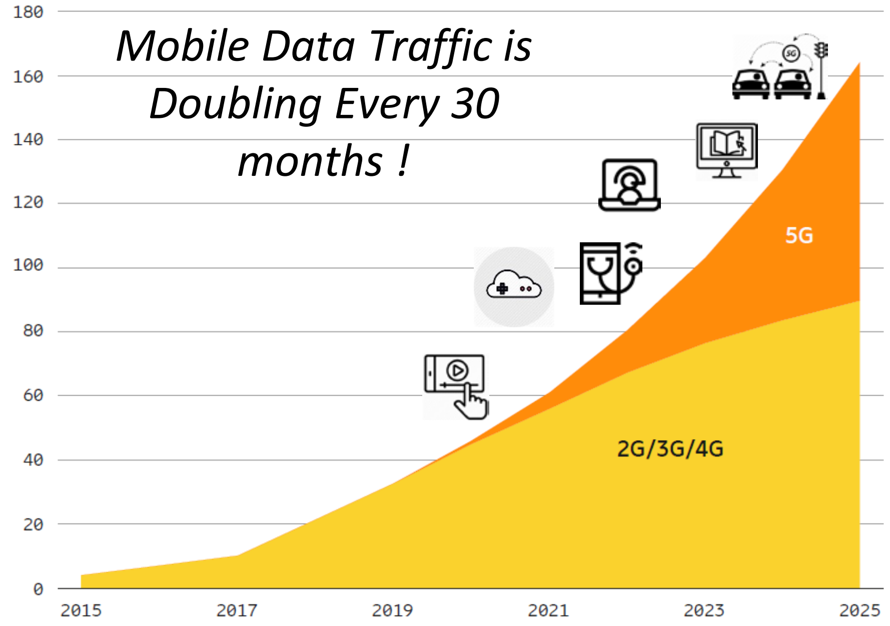
RF Front-End Evolution for 5G and Future Cellular Network Infrastructure, July 2021

IWPC The International Wireless Industry Consortium™

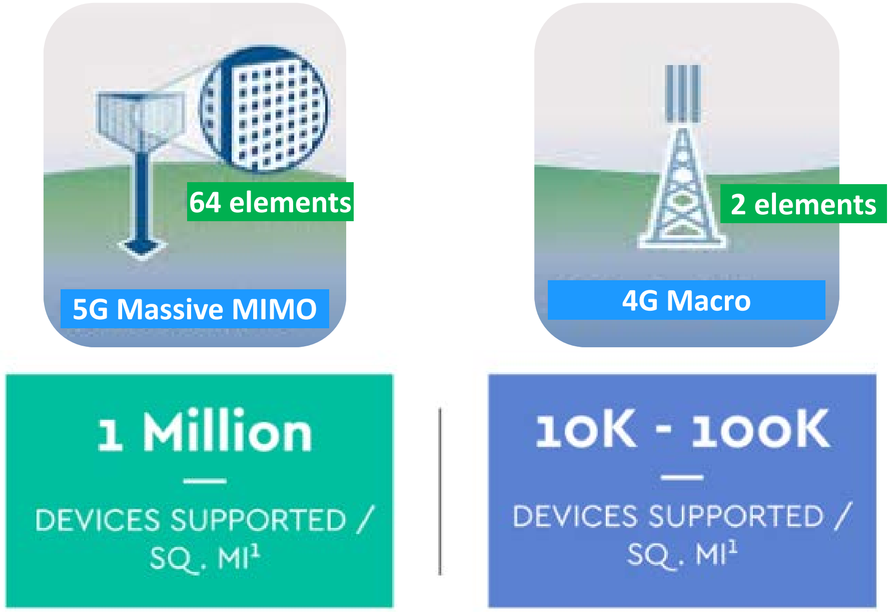
Source: NOKIA

Massive MIMO Basestation Expands 5G Network Capacity

Figure 18: Global mobile data traffic (EB per month)



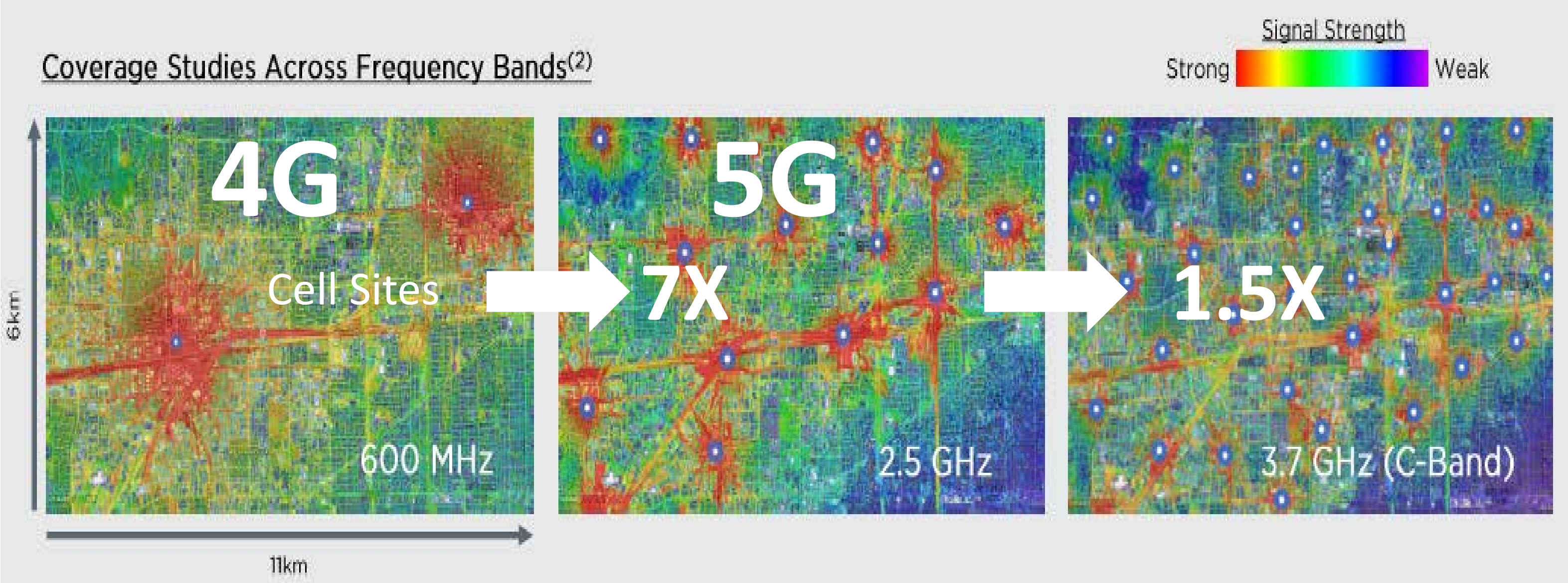
Source: Ericsson



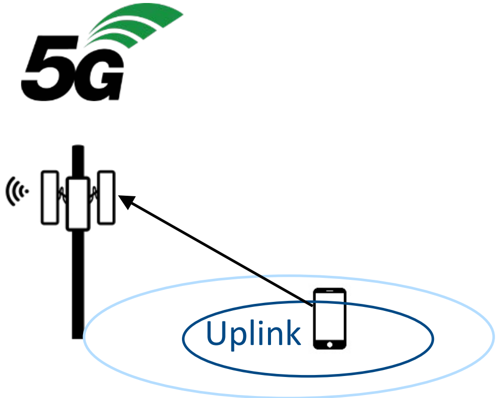
- The Macro base station by itself cannot support the capacity required
- Massive MIMO technology is uniquely designed for high density networks
- The larger number of elements in Massive MIMO significantly increases complexity of the base station
- RF T/R complexity is changing the way we think about system costs, power consumption, interferers, thermals

5G Massive MIMO Systems are Changing the 5G Ecosystem

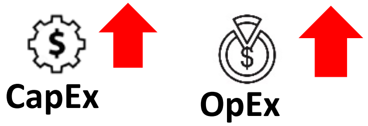
5G Frequencies Drive Higher Network Densification



Source: Crown Castle Tower Company



Uplink is the Weak Link in 5G Cell Edge Performance Limiting Coverage for a Target Capacity



Redefine Rx Requirements Based on Use Cases to Improve Uplink Coverage and Reduce Expenditure

3GPP Rx Requirements

- **Rx sensitivity (i.e., minimum detectable signal)**
  - Minimum detectable QPSK signal is ~-100 dBm and implies a system-level noise figure of ~6dB
- **Rx performance with blockers (linearity)**
  - Desired signals are specified to be QPSK only, with blockers applied at -43dBm
  - The blocker will degrade the EVM of the LNA
  - This means a receiver can pass the 3GPP test, but may be unable to receive a 256QAM signal
- **On the UE side, 3GPP defines blocker tests with 256QAM, so the issue is only present on the gNB**

Sensitivity

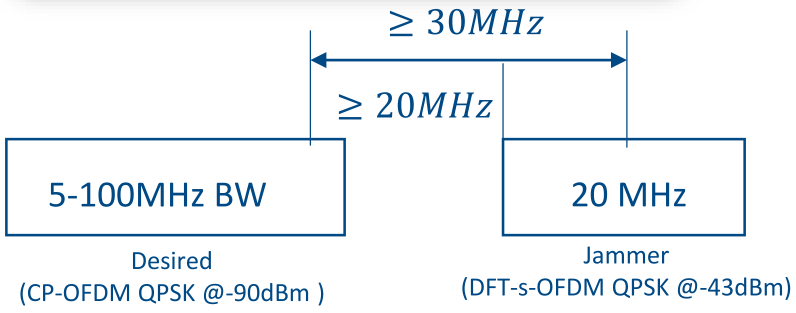
3GPP TS 38.104 version 16.8.0 Release 16

Table 7.2.2-1: NR Wide Area BS reference sensitivity levels

BS channel bandwidth (MHz)	Sub-carrier spacing (kHz)	Reference measurement channel	Reference sensitivity power level, $P_{REFSENS}$ (dBm)
5, 10, 15	15	G-FR1-A1-1 (Note 1)	-101.7
		G-FR1-A1-10 (Note 3)	-101.7 (Note 2)
10, 15	30	G-FR1-A1-2 (Note 1)	-101.8
10, 15	60	G-FR1-A1-3 (Note 1)	-98.9
20, 25, 30, 40, 50	15	G-FR1-A1-4 (Note 1)	-95.3
		G-FR1-A1-11 (Note 4)	-95.3 (Note 2)
20, 25, 30, 40, 50, 60, 70, 80, 90, 100	30	G-FR1-A1-5 (Note 1)	-95.6
20, 25, 30, 40, 50, 60, 70, 80, 90, 100	60	G-FR1-A1-6 (Note 1)	-95.7

NOTE 1: $P_{REFSENS}$ is the power level of a single instance of the reference measurement channel. This requirement shall be met for each consecutive application of a single instance of the reference measurement channel mapped to disjoint frequency ranges with a width corresponding to the number of resource blocks of the reference measurement channel each, except for one instance that might overlap one other instance to cover the full *BS channel bandwidth*.

In-Band



In-Band Blockers

Table 7.4.2.2-1: Base station general blocking requirement

BS channel bandwidth of the *lowest/highest carrier* received (MHz)	Wanted signal mean power (dBm) (Note 2)	Interfering signal mean power (dBm)	Interfering signal centre frequency minimum offset from the lower/upper *Base Station RF Bandwidth edge* or *sub-block* edge inside a *sub-block gap* (MHz)	Type of interfering signal
5, 10, 15, 20	$P_{REFSENS}$ + x dB	Wide Area BS: -43 Medium Range BS: -38 Local Area BS: -35	±7.5	5 MHz DFT-s-OFDM NR signal 15 kHz SCS, 25 RBs
25, 30, 40, 50, 60, 70, 80, 90, 100	$P_{REFSENS}$ + x dB	Wide Area BS: -43 Medium Range BS: -38 Local Area BS: -35	±30	20 MHz DFT-s-OFDM NR signal 15 kHz SCS, 100 RBs

There are no specifications for Rx EVM in 3GPP standards

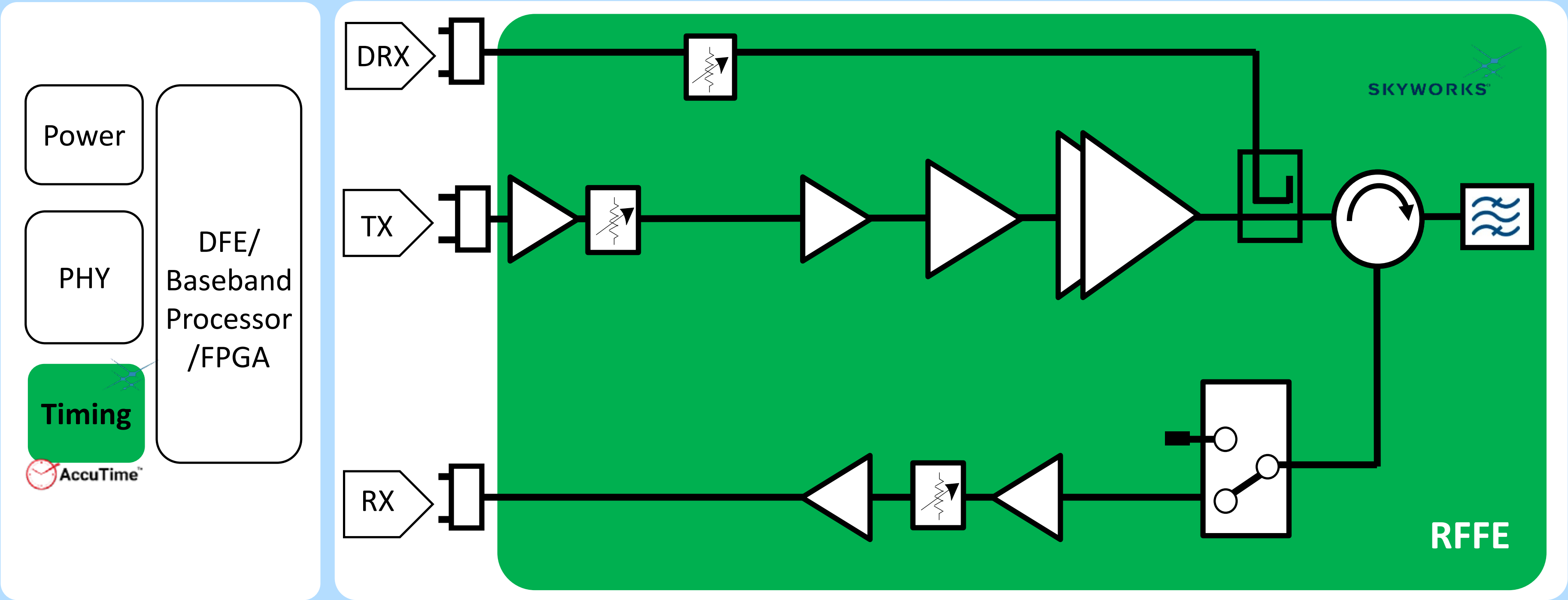
Translating 3GPP to Receive Front End Specifications

- Primary RF Specification are Gain, Noise Figure and 3rd Order Intermodulation (IP3)
- Gain and Noise Figure directly relate to Rx Sensitivity
- IIP3 is used to address Throughput and Capacity for a target Coverage
  - IIP3 is easy to simulate/test, since it only requires 2 RF tones

RF Front End Specifications Directly Impact Key Performances for the Base Station

Source: ERICSSON

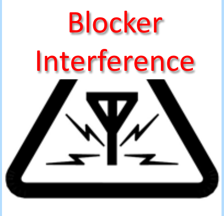
5G Massive MIMO AAS RF Front End



UL Range
- Noise Figure
- Gain

UL Capacity/ Throughput
- IIP3

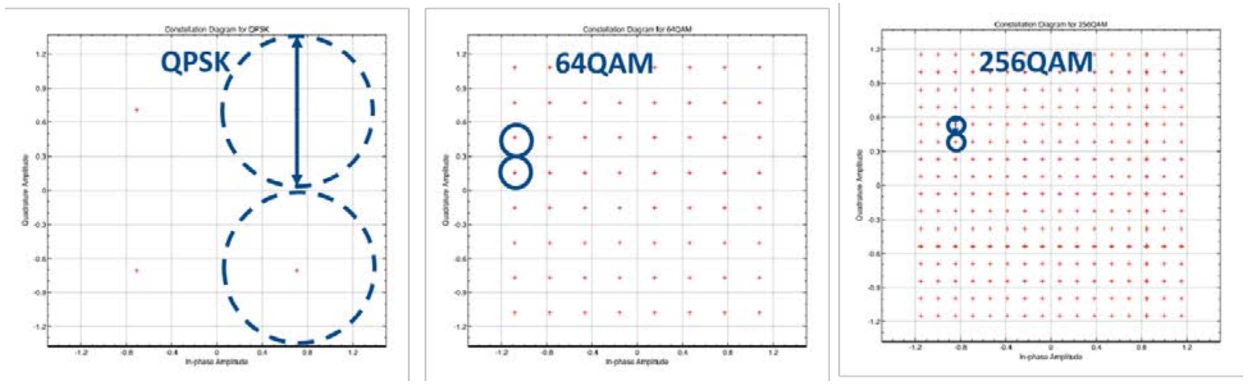
X-Factor!

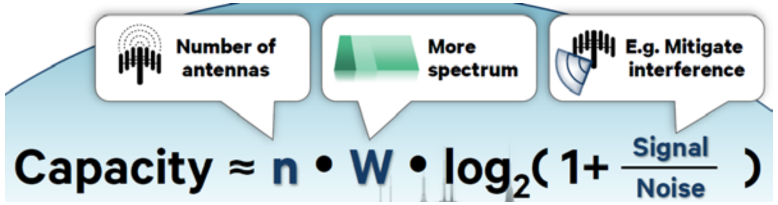


Improving Receiver Sensitivity Against Different Interferer Environments in The Basestation is Critical to Extending Coverage and Capacity/Throughput at the Cell Edge

Receiver Design Considerations

- 5G capacity needs drive UL requirements to 256QAM
- Higher order modulations require much more precise resolution of magnitude and phase to avoid bit errors
- This means the receiver linearity requirements become much tougher to meet
- The traditional method to spec Rx performance relied heavily on specifying more stringent IIP3
- Cons:
  - IIP3 is correlated to both EVM and blocker performance, but the relationship is difficult to derive
  - IIP3 changes as the tone spacing between the tones is changed, making it difficult to use
  - IIP3 changes dramatically based on the amplifier’s architecture, and may not necessarily result in improved performance in the presence of blockers





Mobile Data Traffic is Doubling in Size Every 30 months !

IIP3 alone is not enough metric for specifying Rx linearity in Future Designs

EVM vs Modulation

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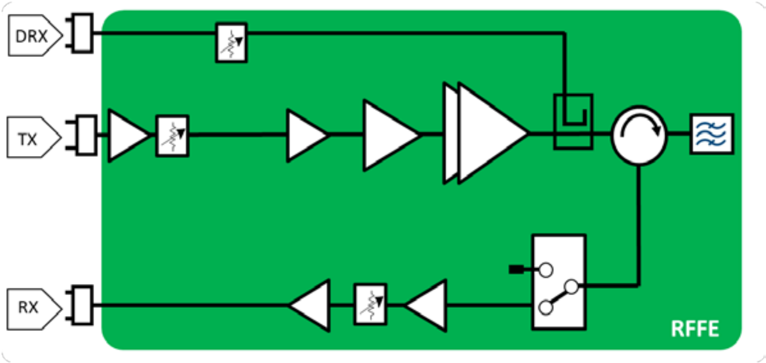
- Table shows derived Rx EVM for each modulation based on SNR from Shannon capacity
- Assumes that the Rx EVM is 10dB better than the required system level SNR
- Required Rx EVM is increased by 33dB moving from QPSK to 256QAM



Number of antennas

Shannon ideality factor (CP, signaling).

More spectrum

Signal to Noise ratio (noise figure, linearity)

$$Capacity \cdot coding = N \cdot \alpha \cdot BW \cdot \log_2(1 + SNR)$$

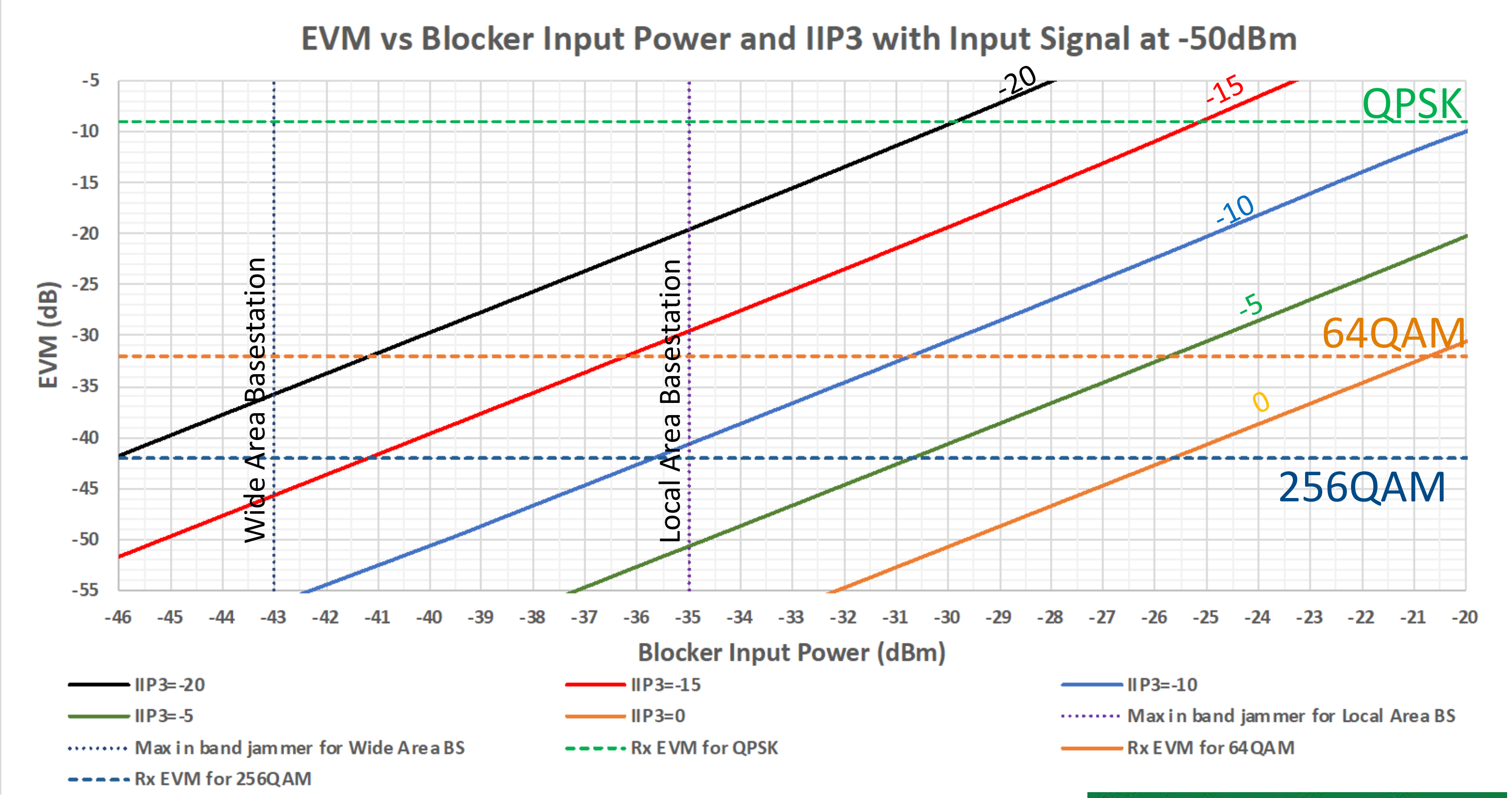
Coding gain (FEC)

Modulation / Coding	System Level SNR	Rx EVM Required (dB)	Rx EVM Required (%)
1024QAM-0.926	40	-50	0.32
256QAM-0.926	32	-42	0.81
64QAM-0.853	22	-32	2.52
16QAM-0.479	8	-18	13.30
QPSK-0.301	-1	-9	35.08

EVM is now a critical metric for Rx performance Especially for Wider Bandwidths and Higher QAM

Rx EVM vs Blocker Input Power

- **Plots are based on simplified cubic model**
  - When moving to multistage LNA EVM curves will no longer be linear with power and IIP3
- **3GPP only consider QPSK signals**
  - IIP3 requirements increase by ~10dB to demodulate 256QAM compared to QPSK
  - QPSK design will not demodulate 256QAM in the presence of blocker
- **This means EVM at a given maximum blocker level is very critical design parameter**
- **Using only IIP3 may lead to over- or under-designed receiver**



Simulated EVM vs IIP3 for LNA with Jammers

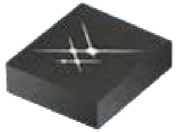
The tendency to increase IIP3 to give additional margin to blocker specs can lead to overdesign of the LNA, with larger size, higher current and cost

Conclusions

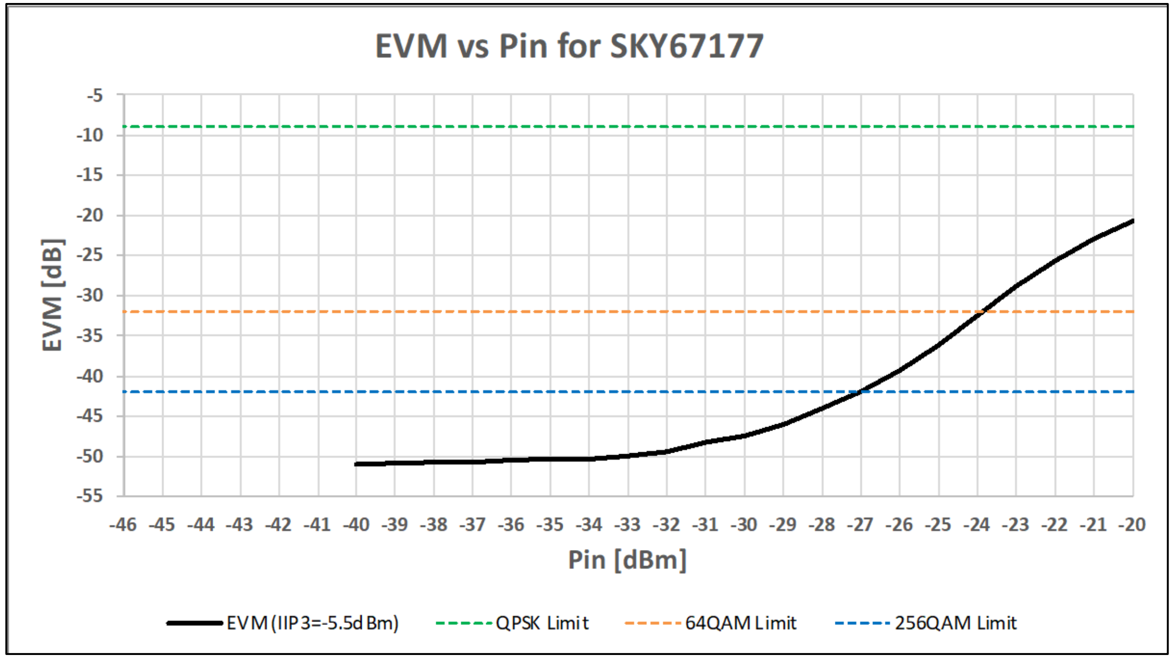
- As we move to expand Basestation Capacity and Throughout all the way to the cell edge, we need to change the way that Rx linearity is addressed in the RF front end

- Future designs will need to critically and adequately incorporate blocker scenarios and EVM requirements

- Designing for the target EVM and key blocker scenarios ensure the base station RF solutions are optimized for power consumption, size and cost



SKY67177 LNA Receive Module



Thank You