MATLAB EXPO

5G+ 주파수대역 RF 송수신기 모델링과 검증

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- **1** 3GPP Release 17 Requirement
- 2 mmWave RF Down and Up Converter Design
- 3 mmWave RF Down and Up Converter Model
- 4 Hardware Performance I. and II.

3GPP Release 17 Requirement



Introduction

Release 16

3GPP TR 38.807 V16.0.0 (2019-12)



Figure 5.1-1: Use Cases for NR above 52.6GHz

Rel-16 : Technical Report

Introduction

5G NR, Release 15 and Release 16 : Supports up to 52.6 GHz designed to be optimized under 52.6 GHz.

Difficult challenges for beyond 52.6 GHz (Rel-17) :

higher phase noise (PN),

larger propagation loss due to high atmospheric absorption

lower power amplifier (PA) efficiency

strong power spectral density regulatory requirements in unlicensed bands

Benefits for beyond 52.6 GHz (Rel-17) :

very large frequency spectrum for both unlicensed and licensed bands.

various high-capacity use cases, integrated access and backhaul (IAB), ultra-high data rate mobile broadband, device-to-device communications, industrial internet-of-things (IIoT), mobile data offloading, broadband distribution networks, wireless display transfer, augmented reality (AR)/virtual reality (VR), intelligent transport systems (ITS)



Overview of 5G NR Rel 17, Frequency Band Beyond 52.6 GHz

India

Taiwan

Singapore

Australia

Global Harmonization

Max Available Bandwidth : 14 GHz Channel Bandwidth of IEEE 802.11ad/ay : 2.16 GHz

	Including Unlicensed Band		Ec	conom Scal	ies of e						
	Country Europe/CEPT Israel South Africa USA Canada		Frequency (GHz)								
			52.6-57	57-58.2	58.2-59	59-59.3	59.3-64	64-65	65-66		
				Mobile							
				Mobile							
				Mobile							
				Mobile							
	Brazil				Mo	bile					
	Mexico			Mobile							
	China					Mo	bile				
Japan				Mobile							
	Korea			Mobile							

Mobile

Mobile

Mobile

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Overview of 5G NR Rel 17, Physical Layer and Evolution Beyond 52.6GHz



I I I SICAL LATER NUMEROLOGI FOR JO NK KEL-13.									
SCS (kHz)	15	30	60	120					
Frequency band (GHz)	0.45	5-6	0.45 – 6 24 – 52.6	24 - 52.6					
Symbol duration (µs)	66.67	33.33	16.67	8.33					
Slot duration (µs)	1 000	500	250	125					
CP duration (µs)	4.69	2.34	1.17	0.60					
Max. bandwidth (MHz)	50	100	200	400					
Sampling rate (MSPS)	61.44	122.88	245.76	491.52					

PHYSICAL LAYER NUMEROLOGY FOR 5G NR REL-15.

PHYSICAL LAYER NUMEROLOGY FOR 5G NR REL-17. SCS (kHz) 120 240 480 960 52.6 - 71Frequency band (GHz) Symbol duration (µs) 8.33 4.16 2.08 1.04 Slot duration (μs) 125 62.5 31.25 15.63 CP duration (µs) 0.30 0.15 0.07 0.60 Max. bandwidth (MHz) 2 0 0 0 2 0 0 0 400 400 Sampling rate (MSPS) 491.52 983.04 1966.08 3932.16

Phase Noise and Its Modeling

Typically, characteristics of PN in frequency domain are expressed in terms of single-side-band (SSB) PN spectrum, which is defined as the noise power within 1 Hz bandwidth at a certain frequency offset, relative to the noise power at the carrier frequency.

The PN model has been investigated for mmWave frequency band based on recently published data to improve the analysis of the RF impairments in 3GPP.

It proposes a PN model to provide the analysis frequency range from 7 to 100 GHz and reflects performances of a single PLL or a set of PLLs with different frequency divider structures [1], [2], [3].

[1] R1-2003851, Enhanced phase noise modeling, Ericsson, 3GPP TSG RAN WG1 meeting #101, May. 2020.

[2] "3GPP TR 38.803 V14.2.0,"Study on new radio access technology: Radio Frequency (RF) and coexistence aspects," Tech. Spec. Group Radio Access Network, Rel. 14, Sept., 2017.

[3] R1-163984, Discussion on phase noise modeling, Samsung, 3GPP TSG RAN WG1 meeting #85, May. 2016.





mmWave RF. Down and Up Converter Design





Conceptual diagram of an ideal mixer that operates as downconverter.



Ex) Sub-Terahertz Upconverter Design







2 Table

Frequency Offset	Trace1	Trace2	Trace3
100 Hz	-53.19 dBc/Hz	-56.26 dBc/Hz	
1.00 kHz	-98.48 dBc/Hz	-97.61 dBc/Hz	
10.0 kHz	-106.74 dBc/Hz	-109.52 dBc/Hz	
100 kHz	-110.67 dBc/Hz	-110.31 dBc/Hz	
1.00 MHz	-112.69 dBc/Hz	-112.10 dBc/Hz	
			4.0
			12

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Ex) Sub-Terahertz Upconverter Design



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mmWave RF. Down and Up-Converter Model



Simulink Modeling and Simulation – Upconverter

- CCDF, PAPR and EVM measurements
- Characterize the impact of RF impairments
 - IQ imbalance, phase noise, PA nonlinearities

Modeling and Testing an NR RF Transmitter

Input signal: NR Test Model Tests: EVM, ACLR, occupied bandwidth, channel power and CCDF



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Simulink Modeling and Simulation – Upconverter







Simulink Modeling and Simulation – Downconverter

- ACLR and EVM measurements
- Explore the impact of altering the RF impairments
- LTE Interference

Modeling and Testing an NR RF Receiver with LTE Interference

Input signal: NR Test Model Interferer: LTE Test Model Tests: EVM, ACLR, occupi d bandwidth and channel power



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Simulink Modeling and Simulation – Downconverter







Ex) Sub-Terahertz Upconverter Modeling



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Ex) Sub-Terahertz Downconverter Modeling





Modeling



Down_converter

Analysis





LOX2 Characteristics

18 GHz – 40 GHz model



RF IN Characteristics

👅 RF_In

18 GHz – 40 GHz model

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파일(F) 툴(T) 보기(V) 시뮬레이션(I) 도움말(H) 😼 • 🕟 🕨 🔳 🌫 • 🔍 • 🙄 🔤 🔟 🖉 🛄 🕅 ∓▼피크 검출기 ▼설정 피크 임계값: -Inf X: -18.00 GHz X: 18.00 GHz 레이블 형식: X + Y991.495 mdBm Y: 991.495 mdBm 값▼ \checkmark 주파수 (GHz) ▽ 0.991495 \sim -18.000 \sim 0.991495 ▼ 왜곡 측정 왜곡: 고조파 고조파의 수: 고조 3 ☑ 고조파에 레이블 지정 주파수 (GHz) Power (dBm) 주파수 (GHz) Power (dBc) THD: -77.70 dBc (0.01304%) SNR 31.95 dBc SINAD 31.95 dBc 34.46 dBc

RF OUT Characteristics

18 GHz – 40 GHz model

ø X

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RF_out 파일(F) 툴(T) 보기(V) 시뮬레이션(I) 도움말(H) 🐻 • 📀 🕨 🔳 🐎 • 🔍 • 💭 🔤 🔟 🖉 🛄 🛄 📉 ∓▼피크 검출기 7 X 2 ▶설점 X: -8.02 GHz X: 8.02 GHz \sim 값 🔻 주파수 (GHz) 🗵 Y: -14.766 dBm Y: -14.766 dBm \checkmark \sim ∓▼ 커서 측정 N X ▶설정 Power (dBm) -20.000 20.000 40.000 GHz 0 dB 채널 전력: -10.854 dBm ∓▼왜곡 측정 왜곡: 고조파 고조파의 수: 고조 고조파에 레이블 지정 주파수 (GHz) Power (dBm) 주파수 (GHz) Power (dBc) 24.0625 THD: -53.54 dBc (0.2104%) 32.26 dBc SINAD: 32.23 dBc SFDR: 51.69 dBc

LOX4 Characteristics

40 GHz - 60 GHz model

– 🗗 🗙

▲ Lox4 파일(F) 툴(T) 보기(V) 시뮬레이션(I) 도움말(H)

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RF IN Characteristics

40 GHz - 60 GHz model

– 0 ×

▲ RF_In 파일(F) 둘(T) 보기(V) 시뮬레이션(I) 도움말(H)



RF OUT Characteristics

40 GHz – 60 GHz model



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LOX6 Characteristics

60 GHz – 90 GHz model

🚺 Lo x6 ð × 파일(F) 툴(T) 보기(V) 시뮬레이션(I) 도움말(H) 🐻 • 🕕 🕨 🗷 • 🔍 • 🙄 🔤 🔟 🖉 🛄 🔤 ₹▼피크 검출기 ▶설정 X: -68.00 GHz X: 68.00 GHz 값 💌 $\mathbf{\mathbf{v}}$ 주파수 (GHz) 🔽 Y: 5.990 dBm Y: 5.990 dBm \sim 5.98991 $\mathbf{\mathbf{v}}$ 5.98991 ∓▼왜곡측정 왜곡: 고조파 ☑ 고조파에 레이블 지정 주파수 (GHz) Power (dBm) 주파수 (GHz) THD: -54.44 dBc 34.18 dBc SINAD: 34.14 dBc 45.02 dBc

RBW=531.25 MHz Sample rate=544 GHz T=4.8e-08

RF IN Characteristics

60 GHz – 90 GHz model



IF Characteristics

60 GHz - 90 GHz model



RBW=117.188 MHz Sample rate=120 GHz T=5.12e-08

Benefits of Simulink Modeling and Simulation

- Simulate RF transceivers and front-ends
- RF amplifiers
 - Gain, noise, even-order, and odd-order intermodulation distortion, memory effects
- RF mixers
 - image rejection, reciprocal mixing, local oscillator phase noise, DC offset
- Custom Models
 - Data sheet specifications or measured data(S-parameters)

→ Validate design in early stage (without Hardware)

Hardware Performance



Hardware Feasibility



RF 42 GHz, 1GHz BW (400M+400M+200M)_ (256QAM) (R&S SMW200A → FSW50)

MultiView 💶 Spectr	um ×	5G NR	×					•
RefLevel 0.00 dBm Fre	q 42.0 GHz	Mode	DL, 400/400 ľ	MHz Capture T	ime 5.0 ms Viev	v1 CC1 F1		
Att 10 dB		Frame Count	: 1/1 of 1/1(:	1/1) BWP/SS	All/All Viev	v2 CC2 F1		Auto Demod Once
TRG:EXT1 YIG Bypass								
1 Capture Buffer		🖙 I/O Export	3 EVM vs Car	rier		4 Alloc ID vs S	Symbol X Carrier	
				1 View2			1 View/2	
	1 0 CC0 E1		21 01 4	2 Mi o 2 Mi o 2 0		4 1 CC1 E1		יס ב1
1.1 CC1 F1 01 Cliw	1.2 GGZ F1		3.1 U IAV	Z MI S MR 3.2		PSS SSS PBCHPT	RSORESESET D PSS SS	S PBCHPTRSORESESET [
4.320337309115	104.009043031 115					CH DMCH DCSI-RSPR	RS PDSCHot Use CH DMCH	DDSI-REPRS PDSCHot Use
		a all a car			6			
0.0 ms 5.0 ms	0.0 ms	5.0 ms	5 %	30.16 MHz 0 F	lz 380.16 Mł			
2 Result Summary				Frame Averaged	5 Power Spectr	um	6 Constellation	Diagram
						Viow2		Viow2
							6 1 CC1 E1	6 2 CC2 E1
2,1 All	All cos		Mann Value		J.I C(J I CIIW	J.Z C(J CIIW	0.1 GG1 F1	0.2 CC2 F1
Energy Describe Assessed	All CCS	001		^			221090	221090
Frame Results Averaged	ししょうしいろ	UU I	ιιz	663	-60 dBm/Hz	-60 dBm/Hz		
EVM PDSCH QPSK (%)								
					-70 dBm/Hz	-70 dBm/Hz		
EVM PDSCH 2560AM (%)	3 09	2.96	3 27	3.04				and the second s
Results for Selection	-	All. All. All	All, All, All	All, All, All	-80 dBm/Hz	-80 dBm/Hz		6
EVM All (%)	3.08	2.96	3.26	3.03				
EVM Phys Channel (%)	3.09	2.96	3.27	3.04	-90 dBm/Hz	-90 dBm/Hz		
EVM Phys Signal (%)	3.02	2.89	3.19	2.96				
Frequency Error (Hz)		4.00	14.01	21.97	-100 aBm/Hz-	-100 aBm/Hz-		
Sampling Error (ppm)	-	0.00	0.00	-0.00			**************	
I/Q Offset (dB)	-	-73.75	-78.21	-75.11	-IIO UBIN/H2-			
I/Q Gain Imbalance (dB)	-	-		-	100 100 (11-			
I/Q Quadrature Error (°)	-	-	-	_	-12U dBin/Hz	-120 dBin/Hz		
OSTP (dBm)	-	-7.08	-7.33	-9.38				
Power (dBm)	-3.04	-7.08	-7.34	-9.36 🔻	0 491.52	0 491.52		
~			Sync Foun	d		✓ Measurin	g	13.12.2021 12:24:23

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RF 52 GHz, 1GHz BW (400M+400M+200M)_ (256QAM) $(SMW200A \rightarrow 4060UC \rightarrow 4060DC \rightarrow FSW50)$

MultiView 🕶 Specti	rum 🗙	5G NR	×						•
RefLevel -10.00 dBm	reg 9.0 GHz	Mode	DL, 400/400	MHz Capture	Time	5.0 ms Vie	w1 CC1 F1		
Att 0 dB		Frame Coun	t 1/1 of 1/1(1/1) BWP/SS		All/All Vie	w2 CC2 F1		Auto Demod Once
TRG:EXT1 YIG Bypass		i i diffo oodii	- 1,10,1,1(, .,		,			Add Delling Office
1 Capture Buffer		🖙 I/Q Export	3 EVM vs Car	rier			4 Alloc ID vs S	Symbol X Carrier	
All View1 View2			All View	1 View2			All View	1 View2	
1.1 CC1 F1 01 Clrw	1.2 CC2 F1	O1 Clrw	3.1 01 AVO	2 Mi ● 3 M∉ 3.2	• 1	Av ● 2 Mi●3 I	M∉ 4.1 CC1 F1	4.2 CC	C2 F1
20 882142838 ps un an	120.905767176 ns. 0 dBm		15 %	15 9	6		PSS SSS PBCH PT CH DMCH DCSI-RSPI	RSORESESET C PSS SS RS PDSCHot Use CH DMCH	S PBCH PTRSORESESET D DESI-RSPRS PDSCHot Use
PHOMAR AND A CARACTER			5 %-	finite and the set		e eleveran la la sur el contener en el contener en el contener el contener en el contener en el contener en el			
0.0 ms 5.0 ms	0.0 ms	5.0 ms	0 Hz 38	30.16 MHZ 0 F	lZ	380.16 MF	IZ PRE PR		
2 Result Summary				e Frame Averaged	5 Pc	ower Spectr	um	6 Constellation	Diagram
All View1 View2					AI	View1	View2	All View1	View2
2.1 All					5.1	C(O1 Clrw	5.2 C(01 Clrw	6.1 CC1 F1	6.2 CC2 F1
	All CCs		Mean Value	^				221690	221690
Frame Results Averaged	CC1~CC3	CC1	CC2	CC3	-60				
EVM PDSCH QPSK (%)									
EVM PDSCH 10QAM (78)					-70				
EVM PDSCH 256QAM (%)	1.95	1.99	2.01	1.86				*********	**********
Results for Selection	-	All, All, All	All, All, All	All, All, All	-80				
EVM All (%)	1.95	1.99	2.01	1.85	-90	dBm/Hz	-90 dBm/Hz		**************
EVM Phys Channel (%)	1.95	1.99	2.01	1.86	l í m	~~~ <u>~</u> ^		***************	
EVM Phys Signal (%)	1.88	1.95	1.95	1.75	-100) dBm/Hz	-100 dBm/Hz		
Frequency Error (Hz)		1/ 01	25.00	22.02					
Sampling Error (ppm)	_	74.17	0.00	70.00	-110) dBm/Hz	-110 dBm/Hz		
I/Q Oliset (dB)	_	-/4.1/	-03.30	-/0.0/					
I/O Ouadrature Error (°)	_	_	_		-120) dBm/Hz	-120 dBm/Hz		
OSTP (dBm)		-5.82	-6.26	-7.85					
Power (dBm)	-1.79	-5.83	-6.26	-7.84 -		491.52	0 491.52		
~			Sync Foun	d			• Measurin	g	13.12.2021 15:04:17
									36

RF 56 GHz, 1GHz BW (400M+400M+200M)_ (256QAM) (SMW200A → 4060UC → 4060DC → FSW50)



RF 59 GHz, 1GHz BW (400M+400M+200M)_ (256QAM) (SMW200A → 4060UC → 4060DC → FSW50)

MultiView 💶 Spect	trum ×	5G NR	×					•
Ref Level -10.00 dBm	Freq 9.0 GHz	Mode	DL, 400/400	MHz Capture	Time 5.0 ms Vie	w1 CC1 F1		
Att OdB		Frame Coun	t 1/1 of 1/1(1/1) BWP/SS	All/All Vie	w2 CC2 F1		Auto Demod Once
TRG:EXT1 YIG Bypass								
1 Capture Buffer		🖙 I/Q Export	3 EVM vs Car	rier		4 Alloc ID vs S	ymbol X Carrier	
All View1 View2	2		All View	1 View2		All View	1 View2	
1.1 CC1 E1 0.1 Clow	1.2 CC2 E1	O1 Clrw	3.1 01 Ave	2 Mi • 3 M/ 3.2	01 A\02 Mi031	₩ 4.1 CC1 F1	4.2 CC	2 F1
20 zestastzelne 0 den -	120.969417594 ns 0 dBm 	dia.a.t arat i	15 %	15 9	6	PSS SSS PBCH PT CH DMCH DCSI-R\$PF	RSORESESET I PSS SS IS PDSCH <mark>ot Use CH DMCH</mark>	S PBCH PTRSORESESET D DESI-RSPRS PDSCHot Use
0.0 ms 5.0 ms	0.0 ms	5.0 ms	5 % 0 Hz 38	5 % 000000000000000000000000000000000000	land 1 a constant Iz 380,16 MH			
2 Result Summary			Selected Fram	e Frame Averaged	5 Power Spectr	um	6 Constellation	Diagram
All View1 View2	2				All View1	View2	All View1	View2
2.1 All					5.1 C(01 Clrw	5.2 C(01 Clrw	6.1 CC1 F1	6.2 CC2 F1
	All CCs		Mean Value				221690	221690
Frame Results Averaged	CC1~CC3	CC1	CC2	CC3	60 dBm/lila	60 dBm /112		
EVM PDSCH QPSK (%) EVM PDSCH 16QAM (%)					-70 dBm/Hz	-70 dBm/Hz		
		2.30	2.20	2.14				
Results for Selection					-80 dBm/Hz	-80 dBm/Hz		
EV/M All (%)	2.23	2.29	2.27	2.13				
EVM Phys Channel (%)	2.24	2.30	2.28	2.14	-90 dBm/Hz	-90 dBm/Hz		
EVM Phys Signal (%)	2.10	2.15	2.17	1.97				
Erequency Error (Hz)	_	13.73	24 53	32.86	-100 aBm/Hz-	1 - 100 aBm/Hz-1		
Sampling Error (ppm)	-	0.00	0.00	0.00	-110 dBm/Uz	-110 dBm/Uz	<u> </u>	********
I/Q Offset (dB)	-	-73.37	-76.81	-73.52	1.10 00 00 00			
I/Q Gain Imbalance (dB)	-	-		-	-120 dBm/Hz-	-120 dBm/Hz		
I/Q Quadrature Error (°)	-	-	-	-	110 0000/112			
DSTP (dBm)	- 4.25	-8.1/	-8.39	-11.05	<u>الاحديادة بحال</u>			
	-4.25	-0.18	-6.59	-11.04 •	0 491.52	0 491.52		
~			Sync Found	t		✓ Measurin	g	13.12.2021 15:09:59



Hardware Performance









MATLAB EXPO

Thank you



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