Horizon 2020 Grant Agreement no: 814523

Tera**h**ertz end-to-end wireless systems supp**o**rting ultra-high data **R**ate applications

ThoR

Deliverable D3.6

Testing report of 70/80 GHz TRX module

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Start date of project: 01-Jul-2018

Date of issue: 11-DEC-2020
Due date: 31-Oct-2020
ThoR Ref:
ThoR_SIKLU_201122_B_WP3

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Project co-funded by the European Commission within the Horizon 2020 programme and the National Institute of Information and Communications Technology in Japan (NICT)		
Dissemination level		
PU	**Public**	**X**
PP	**Restricted to other programme participants (including the Commission Services)**	
RE	**Restricted to a group specified by the consortium (including the Commission Services)**	
CO	**Confidential, only for members of the consortium (including the Commission Services)**	

Contents

Change register

Version	Date	Author	Organisation	Changes
A	30-Sep-2020	Yigal Leiba Ran Timar	Siklu Communication Siklu Communication	First full draft
B	22-Nov-2020	Yigal Leiba Ran Timar	Siklu Communication Siklu Communication	Fixed after review

Reviewed by Eisaku Sasaki NEC CORPORATION Version A, 09-Nov-2020

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1. Statement of independence

The work described in this document is genuinely a result of efforts pertaining to the ThoR project. Any external source is properly referenced.

Confirmation by Authors: Yigal Leiba Siklu Communication
Ran Timar Siklu Communication

2. Abbreviations

AGC	Automatic Gain Control
BB	Baseband
BER	Bit Error Rate
BW	Bandwidth
C/I	Carrier to Interference Power Ratio
CS	Channel Separation
DUT	Device Under Test
FDD	Frequency Division Duplex
IF	Intermediate Frequency
NF	Noise Figure
P1dB	1dB compression Point
P2P	Point to Point
PC	Personal Computer
PSAT	Saturation Power
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RX	Receive[r]
TX	Transmit[ter]
WG	Wave Guide
WP	Work Package

3. Executive summary

The system specification ([1]) defined in WP2 defines the requirements from a carrier class point-to-point (P2P) wireless link operating at the terahertz band around 300 GHz. One of the implementations for this P2P wireless link is based on operating in Frequency Division Duplex (FDD) mode using an IF frequency around 70/80 GHz ([2], [3]).

This document contains the testing results for the 70/80 GHz transceiver that is tuned to serve as the IF section for the 300 GHz link. The measurements are done on the individual transceiver level but focus on performance attributes that are essential for transceiver parallelization and for the frequency band up/down conversion process. Such parameters include transmitter spectral mask performance, receiver adjacent channel rejection, phase noise characteristics and overall link sensitivity and bit error rate thresholds. The measurements include a range of modem modulations from high to low, as the effect of the up/down conversion process and potential signal degradations by the 300 GHz RF front end are yet unknown. The individual transceiver performance in terms of throughput is measured in the various modulations at the digital network interface, providing net usable throughput figures per each modulation.

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4. Introduction

This deliverable reports the testing and performance of the intermediate frequency (IF) and base-band (BB) section of the ThoR Terahertz ultra-high data rate point-to-point (P2P) wireless link. This deliverable focuses on the modems with the IF frequency in the E-band (70/80 GHz).

The testing reported refers to the 70/80 GHz module specification ([2]) and design ([3]) documents. The related technical specifications document for the overall system ([1]) was defined in WP2 and defines a system that could be easy for commercialized and deliver multi Gigabit per second transmission throughput for applications such as cellular fronthaul and backhaul for carrier-class customers.

The tests reported in this document are split in two main sections, one testing performance aspects of the 70/80 GHz radio alone, and the other testing the combined performance of the radio frequency (RF) and modem.

The overall system operating conditions assume,

- 2 x 2 GHz of operation bandwidth (BW) per modem in FDD mode (overall 2 x 8 GHz with 4 modems working in parallel)
- Operation up to 128 QAM modulation (but possibly only a lower modulation can be used with operation at the 290 – 310 GHz band
- Targeted for operation throughput close to 40 Gbps per direction with using 4 modems in parallel

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5. Radio testing

5.1. TX test setup

The TX test setup is targeted at allowing the measurement of the link TX output power and output power control. The test setup is depicted in Figure 1 below.

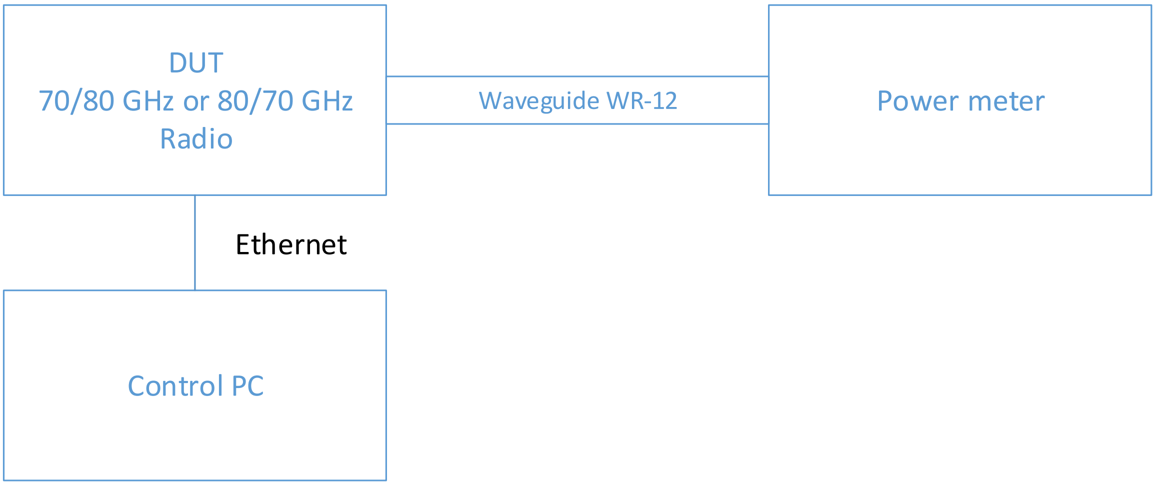

Figure 1: Radio TX testing setup

5.2. TX output power

The TX output power test is done with the operating frequency as parameter. Both the saturation power (PSAT) and the P1dB power are measured. The excitation signal is generated inside the device under test (DUT) by the modem block and is a single tone at nominal BB level. Figure 2 shows the measurement result for the 70 GHz band and Figure 3 shows the measurement result for the 80 GHz band.

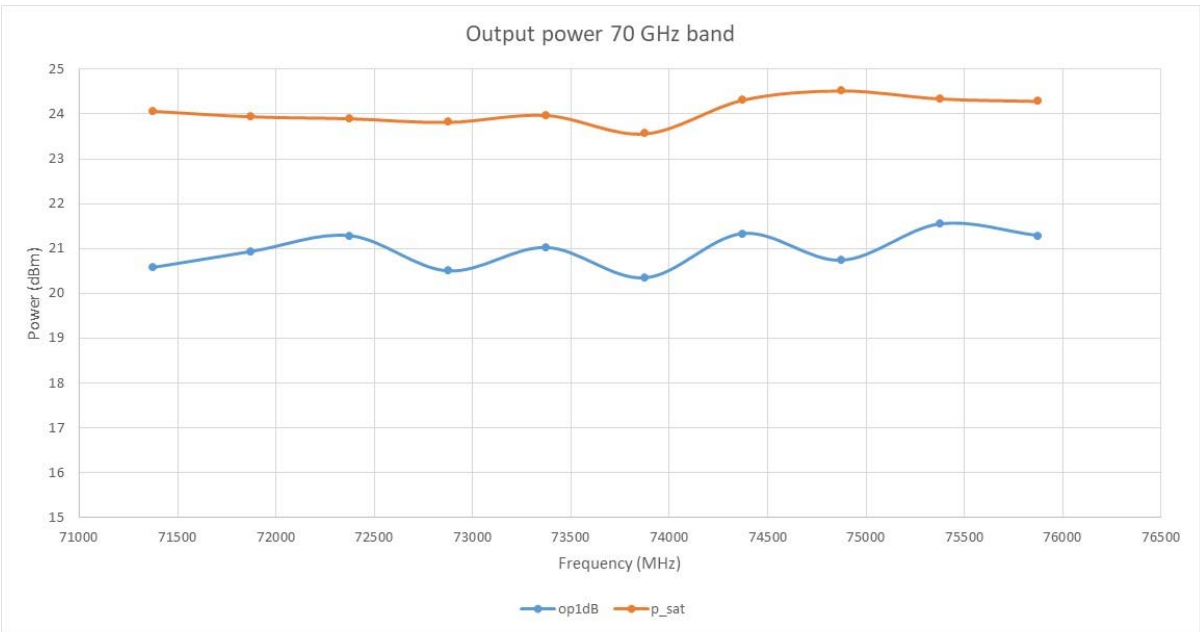

Figure 2: PSAT and P1dB for the 70 GHz TX radio

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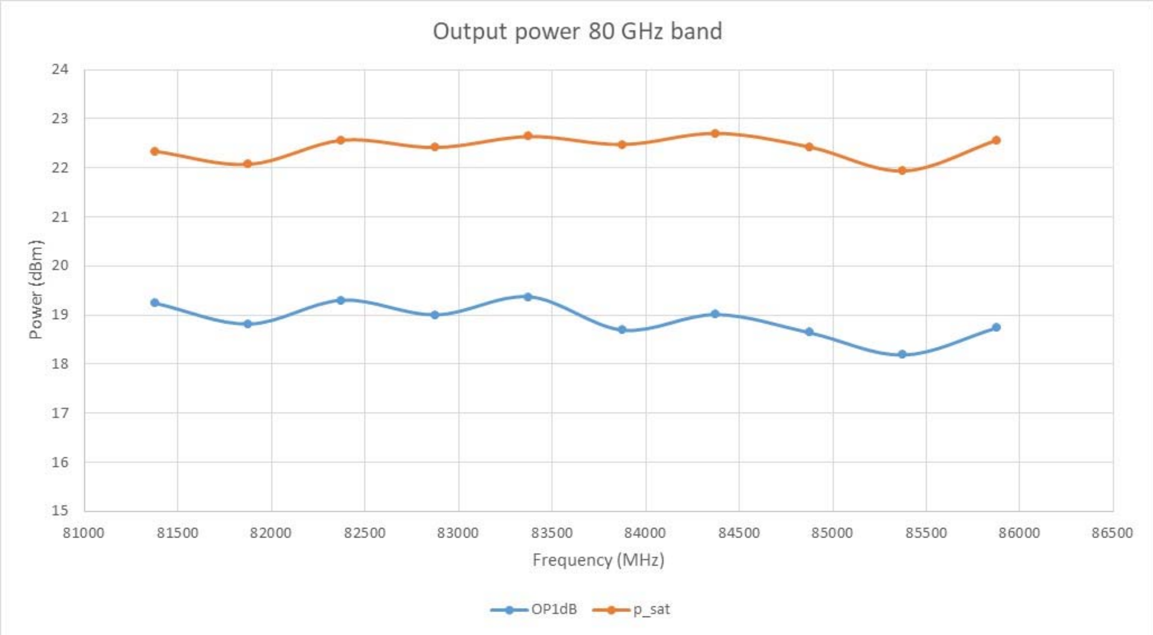

Figure 3: PSAT and P1dB for the 80 GHz TX radio

5.3. Output power control

The output power control enables placing the radio at the desired operation point in terms of backoff from saturation, as required for a specific modulation level. The excitation signal is generated inside the DUT by the modem block and is a single tone at nominal BB level. Figure 2 shows the measurement result for the 70 GHz band and Figure 3 shows the measurement result for the 80 GHz band. As can be observed by the garphs, the power is not linear in proportion to the control value, so the control value will be used gain control functions must be adequately calibrated.

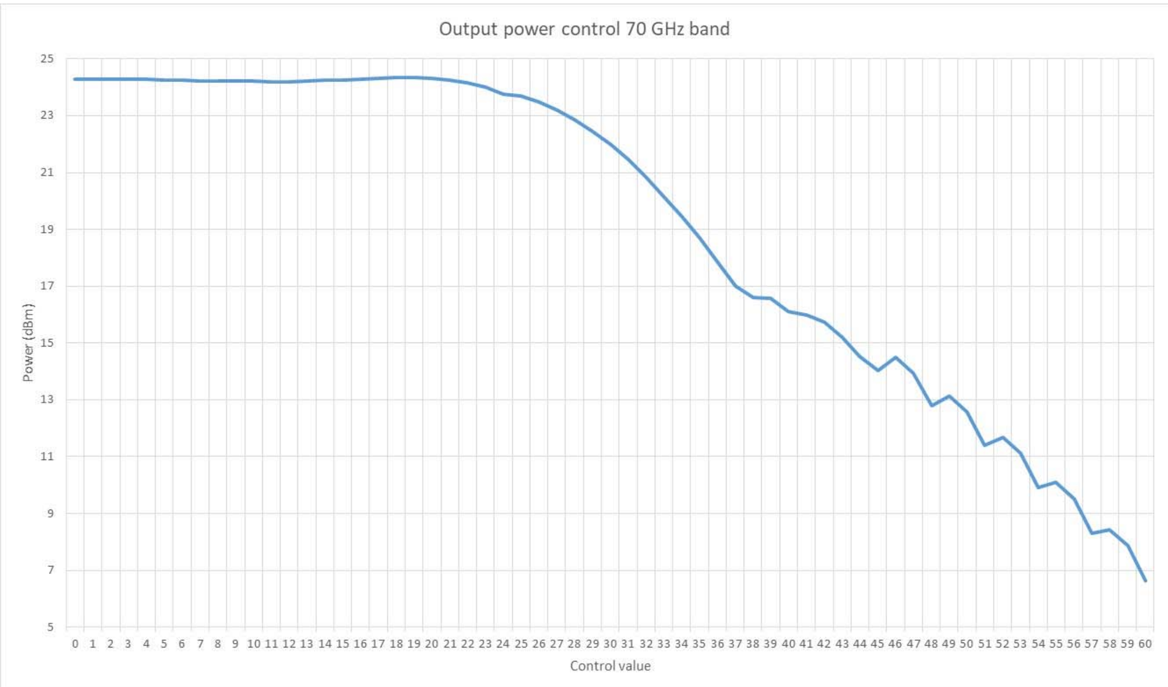

Figure 4: Power control performance for the 70 GHz radio

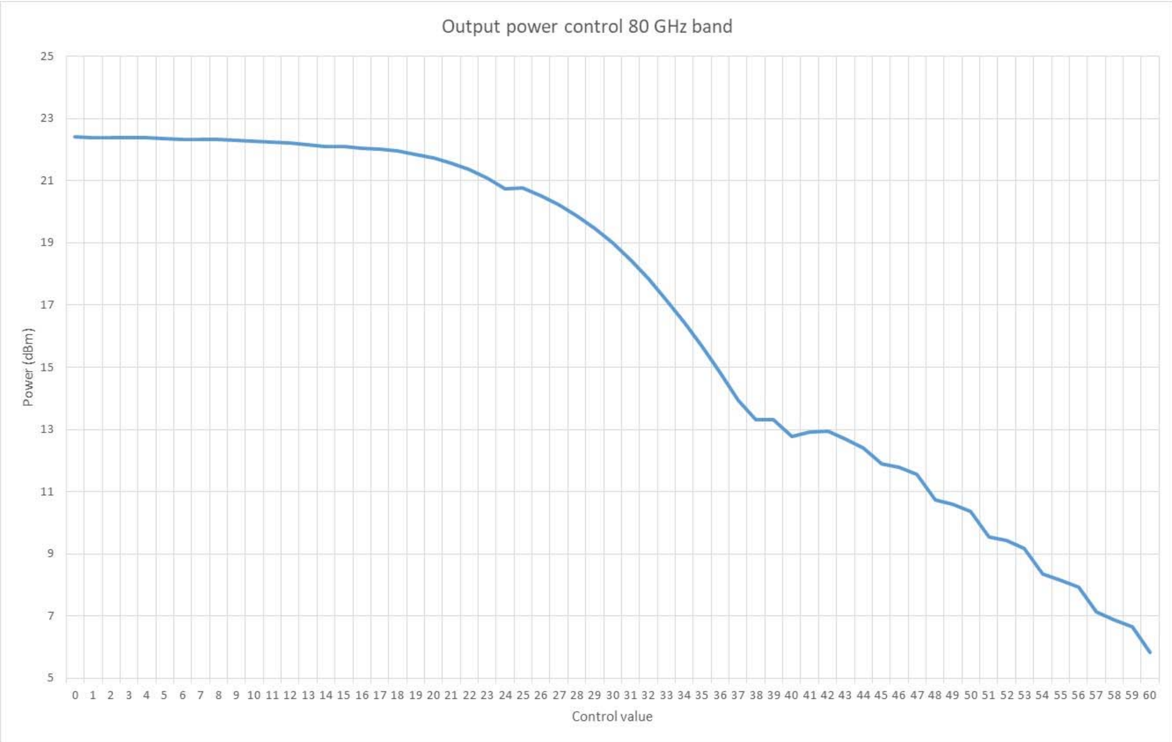

Figure 5: Power control performance for the 80GHz band

5.4. RX test setup

The RX test setup is targeted at allowing the measurement of the link RX gain, RX noise figure, RX filter performance and phase noise. The test setup is depicted in Figure 6 below.

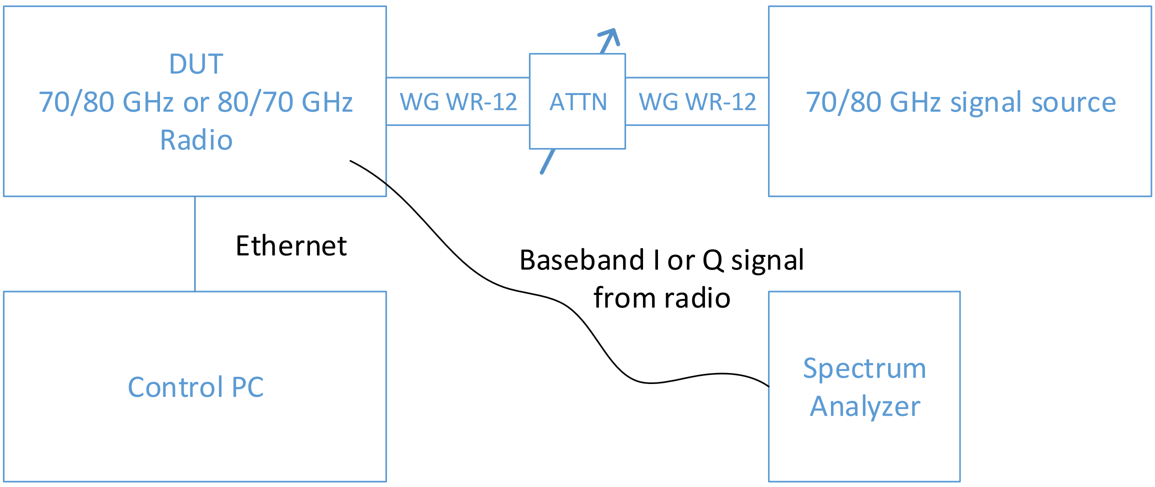

Figure 6: Radio RX testing setup

5.5. RX gain

The RX gain test is done with the operating frequency as parameter. During normal operation there is an automatic gain control (AGC) loop operating to keep the output signal level constant, this control loop is disabled for this test and the gain setting is not changed between frequencies. The excitation

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signal, which is a single tone, is generated by the 70/80 GHz signal source and the BB signal is measured inside the DUT at the modem block input. Figure 7 shows the measurement result for the 70 GHz band and Figure 8 shows the measurement result for the 80 GHz band.

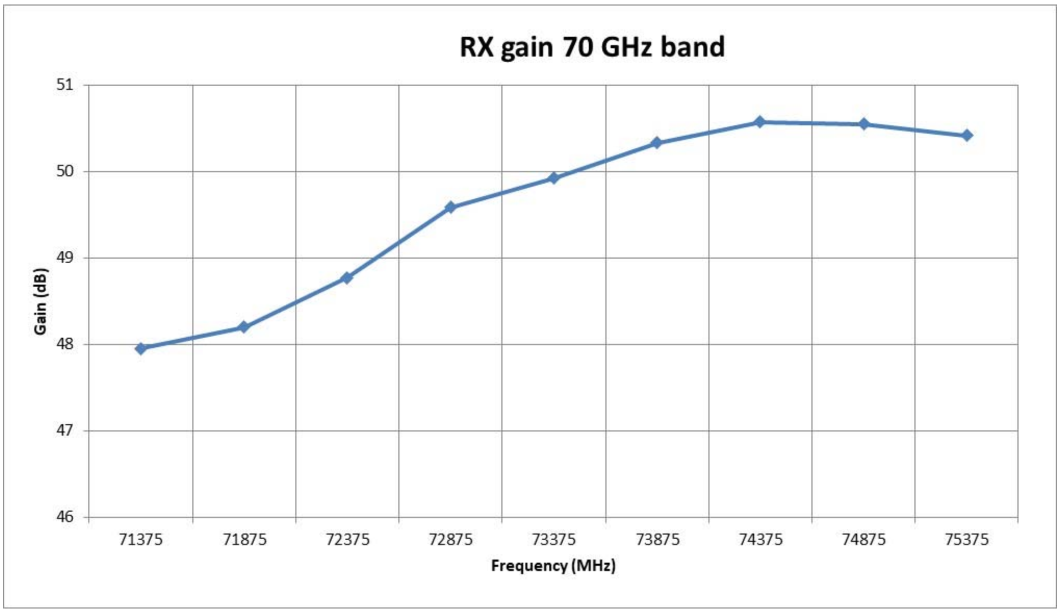

Figure 7: RX gain for the 70 GHz RX radio

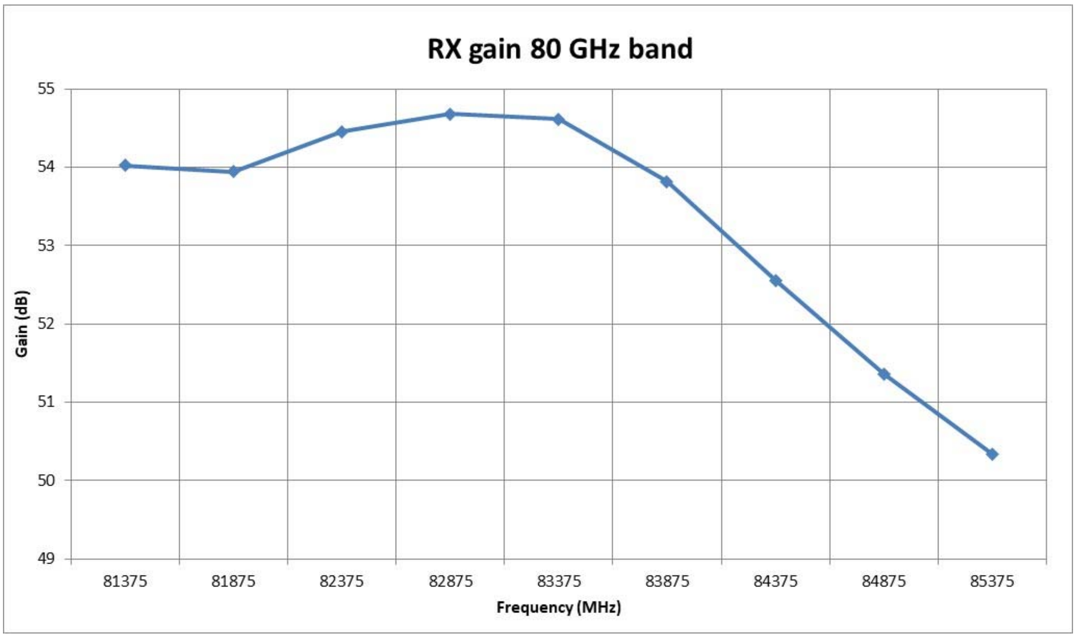

Figure 8: RX gain for the 80 GHz RX radio

5.6. RX Noise Figure

The RX noise figure (NF) test is done with the operating frequency as parameter. The test procedure is based on measuring the noise power within the operating BW while compensating for the radio chain gain. A single tone excitation signal generated by the 70/80 GHz signal source is used to calibrate the gain and the BB signal is measured inside the DUT at the modem block input. Figure 9 shows the measurement result for the 70 GHz band and Figure 10 shows the measurement result for the 80 GHz band.

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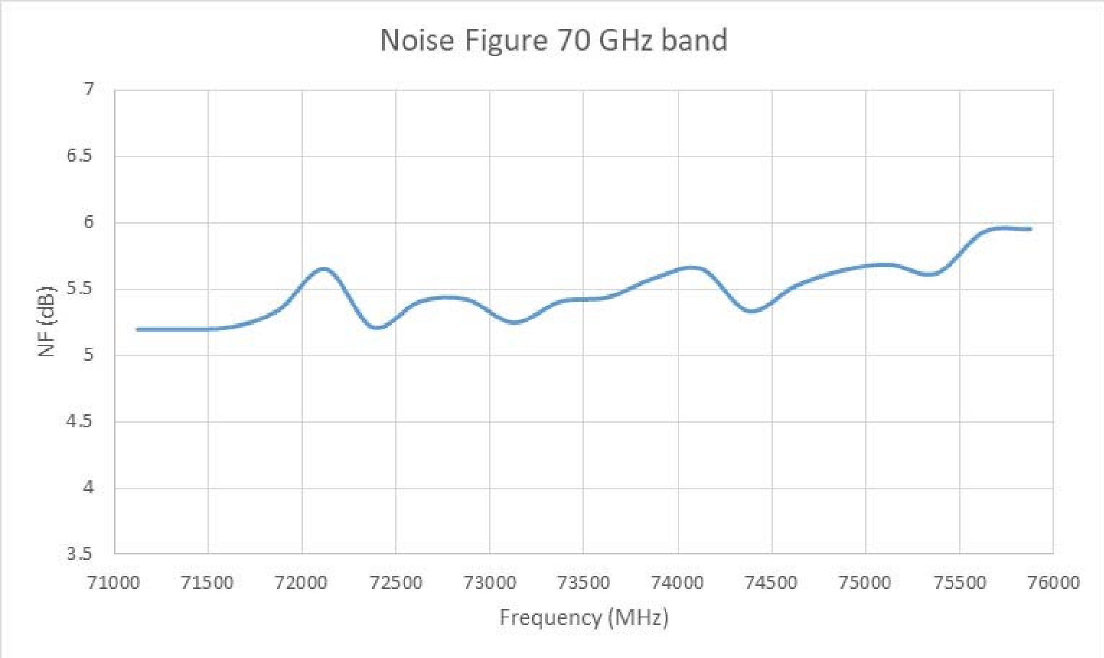

Figure 9: RX NF for the 70 GHz RX radio

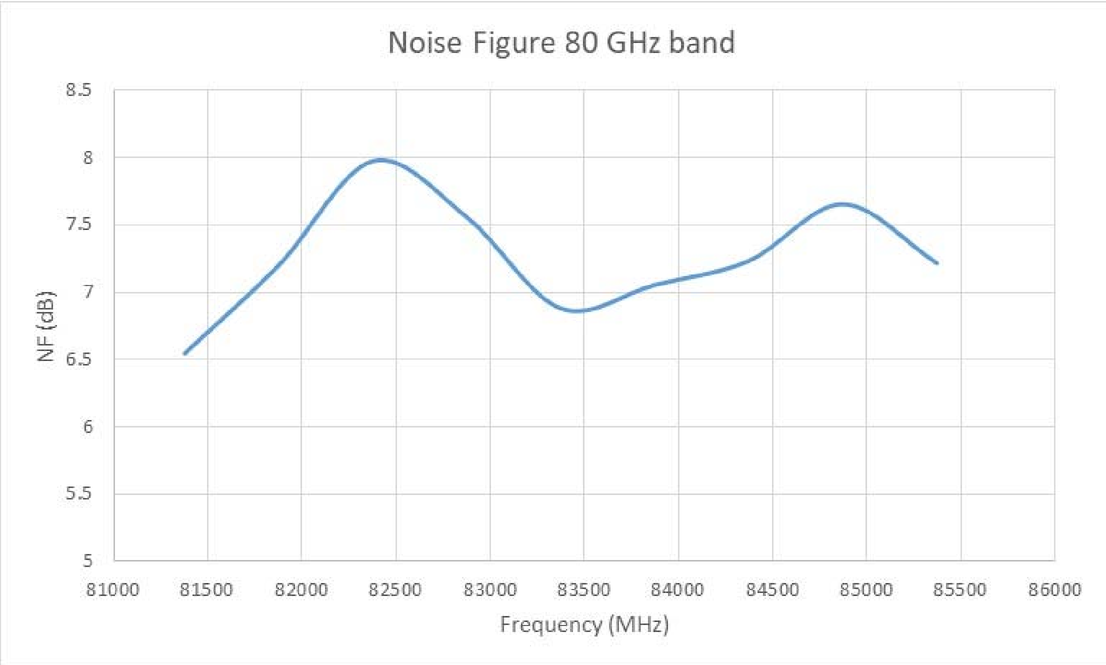

Figure 10: RX NF for the 80 GHz RX radio

5.7. RX filters

The RX filter test is done with injecting a test tone within the filter BW and measuring the relative signal power after transition through the filter. The single tone excitation signal is generated by the 70/80 GHz signal source and the BB signal is measured inside the DUT at the modem block input. For input signals wider than the signal BW, it is possible to bypass this filter. Since both the 70 GHz and the 80 GHz radio use the same filter, it may be measured only once and the result is shown in Figure 11.

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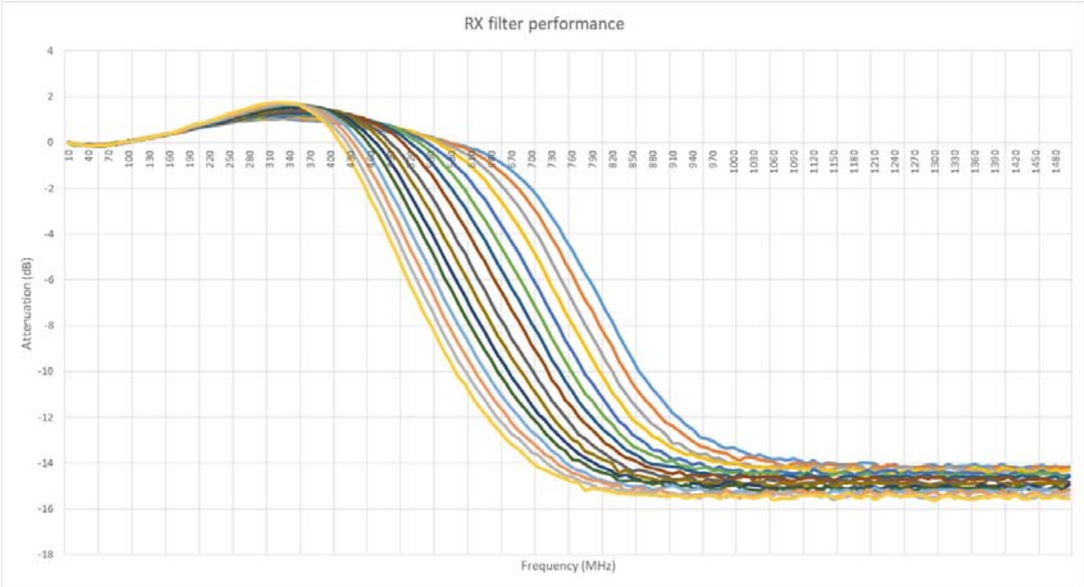

Figure 11: RX filter performance – Various bandwidth settings

5.8. Phase noise

The phase noise test attempts to tune the radio to the best phase noise with a control parameter controlling internal bias. The test is done at frequencies at the extremes of the operation band. The test is done with a single tone excitation signal generated by the 70/80 GHz transmitter and is measured by the receiver at the modem block input, therefore it tests combined TX+RX phase noise. Figure 12 shows the measurement result for the 70 GHz band and Figure 13 shows the measurement result for the 80 GHz band.

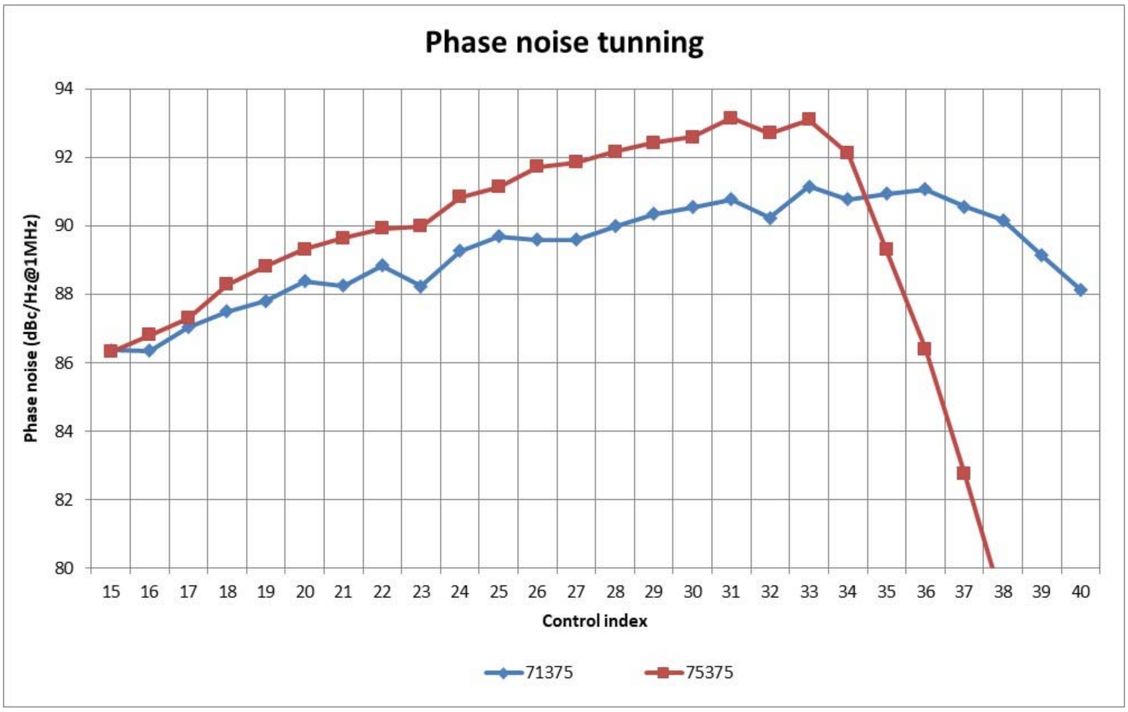

Figure 12: Phase noise for the 70 GHz TX+RX radio

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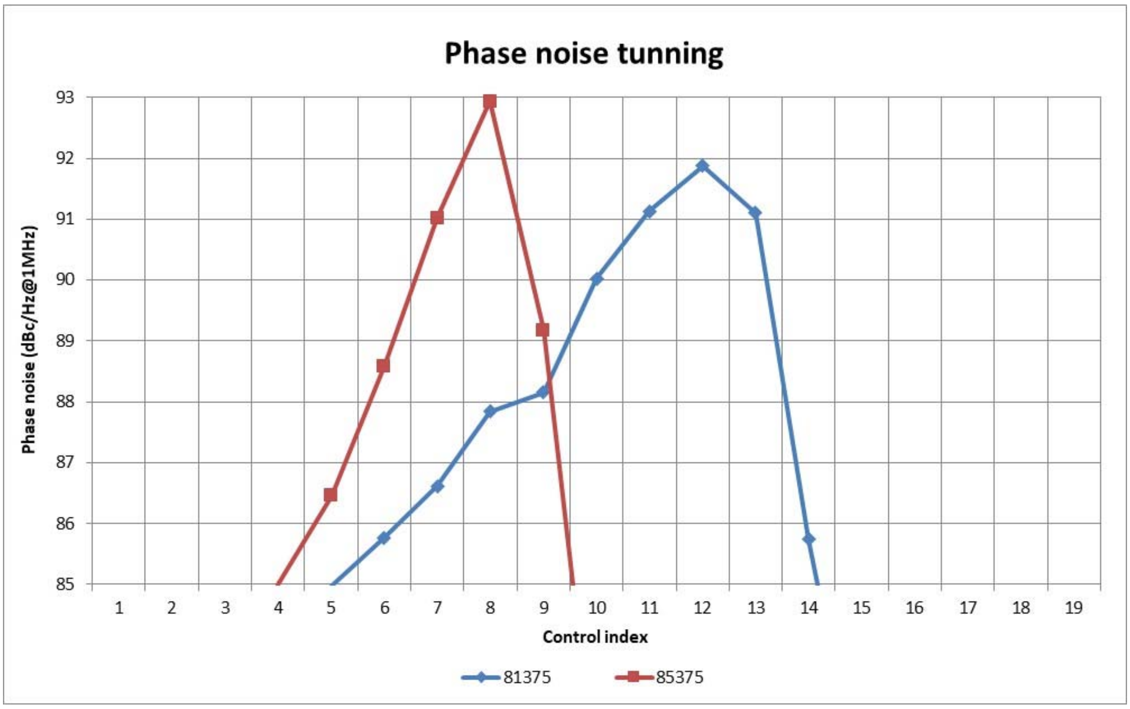

Figure 13: Phase noise for the 80 GHz TX+RX radio

It is worth to note the phase noise performance of the radio does determine the overall phase noise performance of the system, as the modem has some capability to handle phase noise. For a single carrier modem, this capability is achieved by use of pilot symbols that serve as a phase reference. A typical pilot symbol overhead will typically not exceed 10% of the modem symbol rate, which implies that the modem has phase noise cancelation which is equal to the same proportion of its bandwidth, divided by the desired processing gain. A typical value in case of 10% pilot overhead would be 2% of the bandwidth, so for the modem used in this TRX module, phase noise improvement ability would extend to about 40MHz, and would roughly behave as a 1^{st} order filter.

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6. Combined radio/modem testing

6.1. Radio/modem testing setup

The radio/modem test setup is targeted at allowing the measurement of the modem related performance attributes. The test setup is depicted in Figure 14 below.

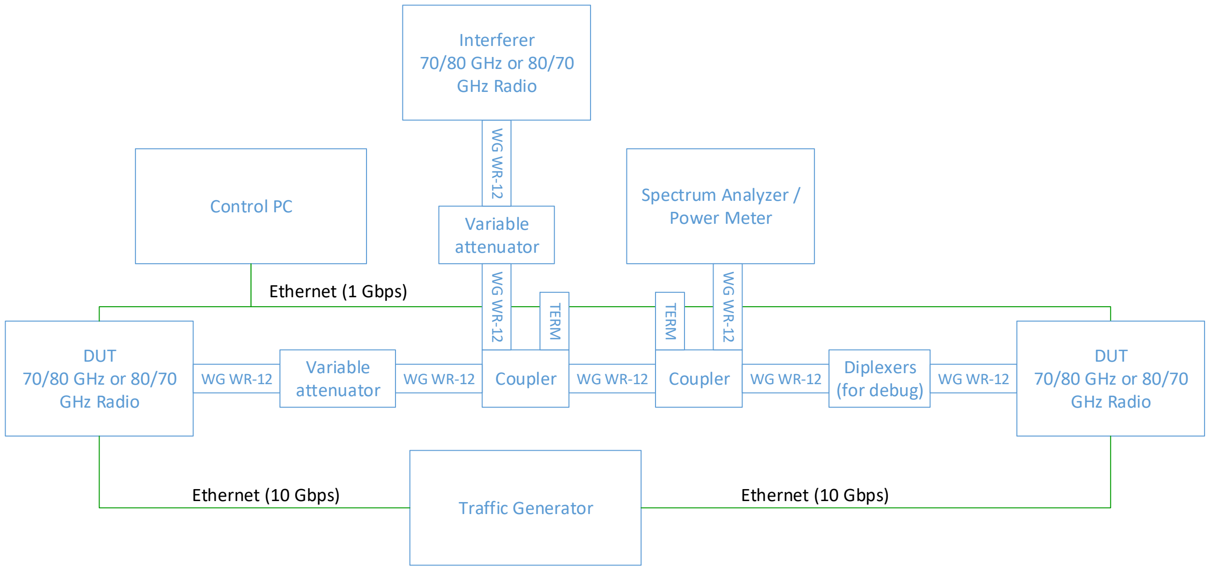

Figure 14: Radio/modem testing setup block diagram

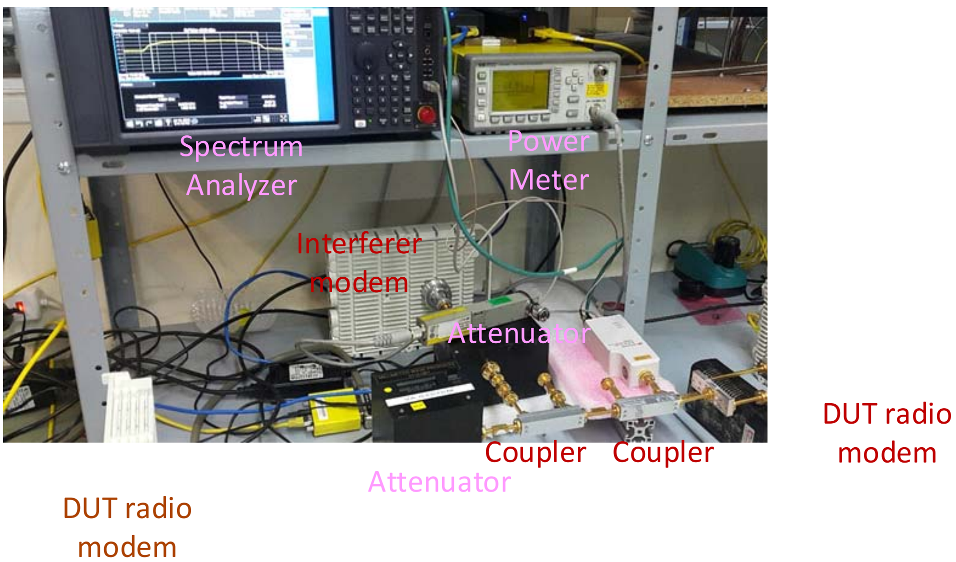

Figure 15: Radio/modem testing setup picture

6.2. TX spectral masks

The TX spectral mask test observes the modulated signal BW to demonstrate that adjacent channels can be grouped side by side with reasonable self-inflicted interference. The test is done at several frequency channels. The signal is generated inside the DUT by the modem block with a specific over-the-air modulation. Figure 16 through Figure 19 shows the measurement result for the 70 GHz band and 80 GHz band channels. Note that TX masks at the carrier frequency is impacted by LO

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leakage/cancellation, and this is not used by the modem. The slight unflattens to the TX mask is due to the large bandwidth and is handled by the modem on the receive side.

Figure 16: Emission BW with 2GHz channel centered on 72.125 GHz, 128QAM modulation

Figure 17: Emission BW with 2GHz channel centered on 74.625 GHz, 128QAM modulation

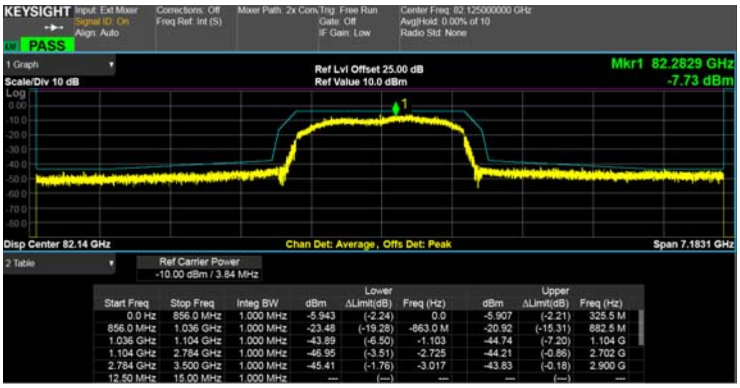

Figure 18: Emission BW with 2GHz channel centered on 82.125 GHz, 128QAM modulation

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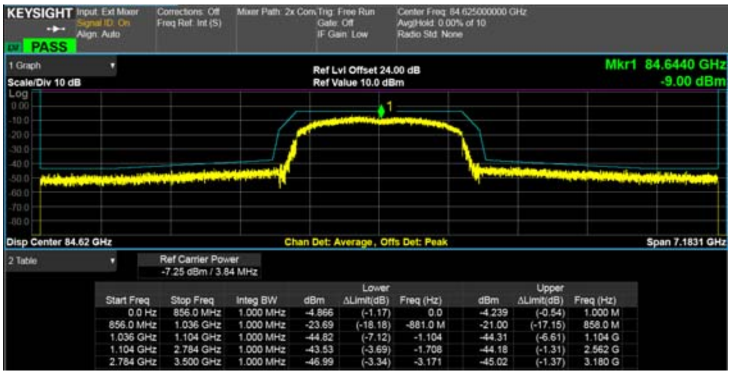

Figure 19: Emission BW with 2GHz channel centered on 84.625 GHz, 128QAM modulation

6.3. Receiver selectivity

The receiver selectivity test observes injects a broadband interfering signal from an independent transmitter into the desired receive signal. The signal is injected either at the same channel (co-channel interfere scenario) or at an adjacent channel (adjacent channel interfere scenario). The test measures the level of attenuation required on the interfering signal such that a predefined level of sensitivity degradation is caused to the receiver. The sensitivity degradation is defined by placing the desired signal level a certain X dB (specifically, 1dB and 3dB in this measurement) above the sensitivity threshold (as defined by the BER performance) and observing the interference level that will degrade the receiver to the threshold. The results measured are shown in Table 1.

Data rate (Mbps)	Channel Separation (MHz)	C/I for BER threshold 10e-6 (dB)			
		Co-Channel Interference		Adjacent Channel Interference	
		1dB	3dB	1dB	3dB
8180	2000	32	28	-5	-8.5

Table 1: Receiver selectivity

6.4. Sensitivity performance and system gain

The sensitivity performance test verifies the system gain as calculated based on the transmit power minus the receiver sensitivity at a threshold BER. The system gain is the most useful parameter when determining the distance over which the radio/modem is useful. The test is conducted in several modulations by setting the variable attenuator to a level that brings the BER performance to the threshold and measuring the receiver power at that point. The data rate performance as well as the BER are measured by the traffic generator using traffic injection via the DUT 10 Gbps optical Ethernet interface (SFP+). The results measured are shown in Table 2.

CS (MHz)	Modulation	FEC Rate	Pout (dBm)	Receiver Threshold (dBm @ BER=10^{-6})	Data rate (Mbps)	CINR at threshold (dB)	System Gain (dB)
2000	128QAM	0.87	14	-50	9550	23.6	64
2000	64QAM	0.87	14	-53	8180	20.3	67
2000	32QAM	0.87	15	-56	6820	17.3	71
2000	16QAM	0.87	16	-59	5460	14.3	75
2000	8PSK	0.87	17	-62	4090	11.3	81
2000	QPSK	0.87	18	-66	2730	7.3	84

Table 2: Sensitivity performance and system gain

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7. Conclusion

The document reviews the measurement and testing of the 70/80 GHz radios and modems used as the IF and BB stages of the 300 GHz P2P link. The testing relates to the 70/80 GHz TRX module specifications ([2]) and design ([3]), which address an architecture including multiple IF module parallelization and a radio/modem architecture to enable operation with high spectral efficiency.

The various measurements results described in this document are done for the radio and the combined modem/radio as a stand-alone component. However, the measurement address specifically performance attributes that will impact module role as an IF stage in the integrated system. The measurement results demonstrate meeting and even exceeding the performance targeted in [2] in terms of sensitivity, output power, throughput and other parameters. The most critical parameter to the integration with the Thor RF stage is the up/down conversion phase noise, which should be kept within the bounds specified in [2] to ensure the modem can reach its maximum performance

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8. References

[1] P. Jurcik, Y. Leiba and R.-P. Braun, “Deliverable 2.1 Requirements for fronthaul/backhaul wireless links in 5G and B5G networks,” 2018.

[2] Y. Leiba and R. Timar, “Deliverable 3.2 Specifications for the 70-80 GHz TRX modules,” 2018.

[3] Y. Leiba and R. Timar, “Deliverable 3.4 Design of the 70-80 GHz TRX modules,” 2019.

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