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Abstract: This paper provides a simulation based study on the impact of inter symbol and co-channel interference for THz intra-device communication systems in the presence of multiple links. The simulations are carried out using ray tracing simulations in a realistic board-to-board scenario. Error vector magnitude based figures of merit are used to evaluate the scenarios. The analysis reveals that the operation of a single THz link is generally feasible even at a low antenna directivity of 6dBi at each end. When multiple links are required to operate at the same time a moderate increase of directivity to 12dBi will be necessary.

Purpose: Information of the IG THz

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Interference Study for THz Intra-Device Communication Systems

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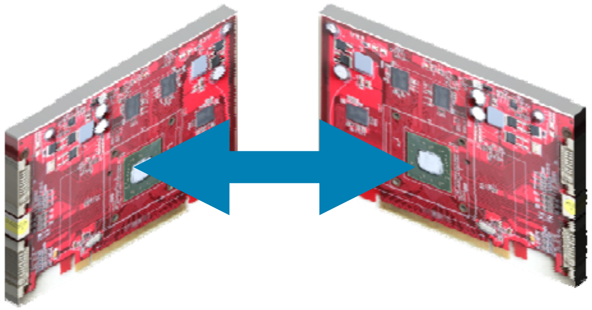
This contribution is based on [1]

Outline

- Motivation
- Scenario Definitions
- Evaluation Methodology
- Simulation Results
- Conclusions

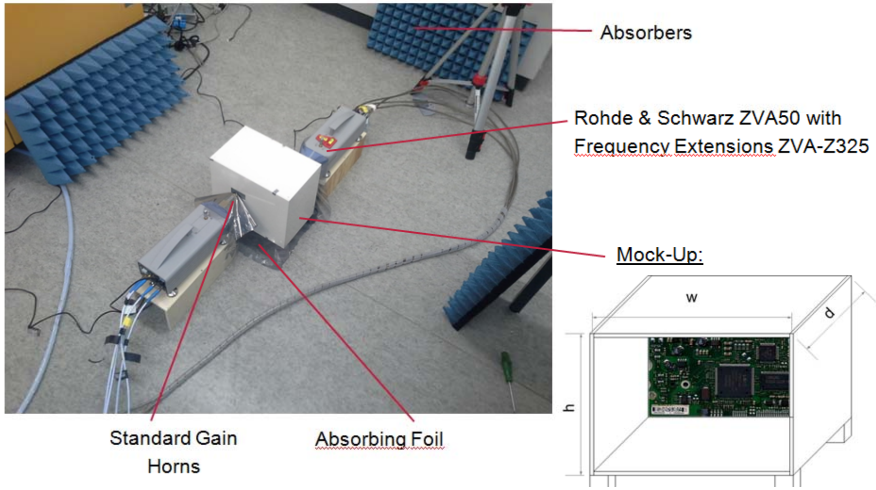
Motivation

- Ever increasing demand for higher wireless data rates, 100 Gbit/s estimated for 2020, enforced e. g. by upcoming UHD content
- Data Links capable of providing these data rates are also needed in the “back-end” inside of systems or devices

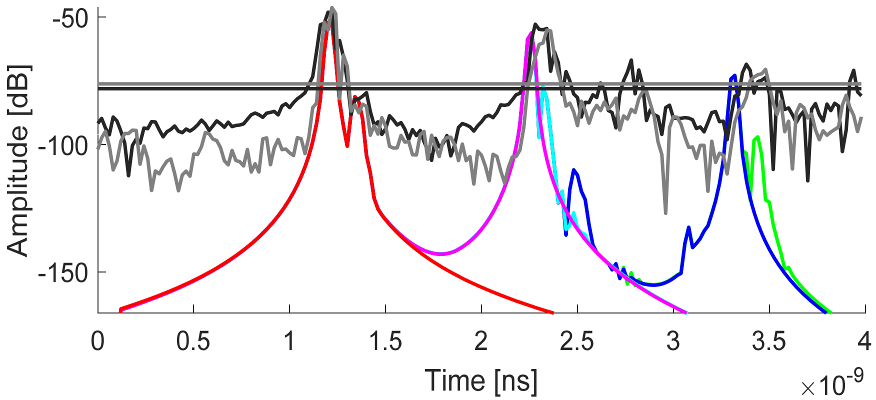


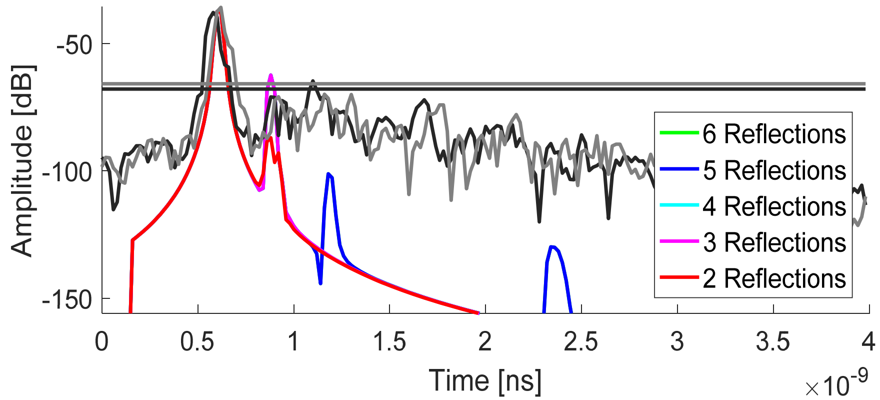
- Spectrum above 300 GHz (“THz Communications”) can provide these data rates at very low transceiver complexity.
- Short wave lengths of several millimeters and less enable data transmission from chip to chip with integrated antennas.
- October 2017: Std. IEEE 802.15.3d-2017 has been published as the first standard for fixed point-to-point links at 300 GHz
- How about interference situation for multiple links inside the same device?

Approach: Simulation using a validated Ray Tracing Model

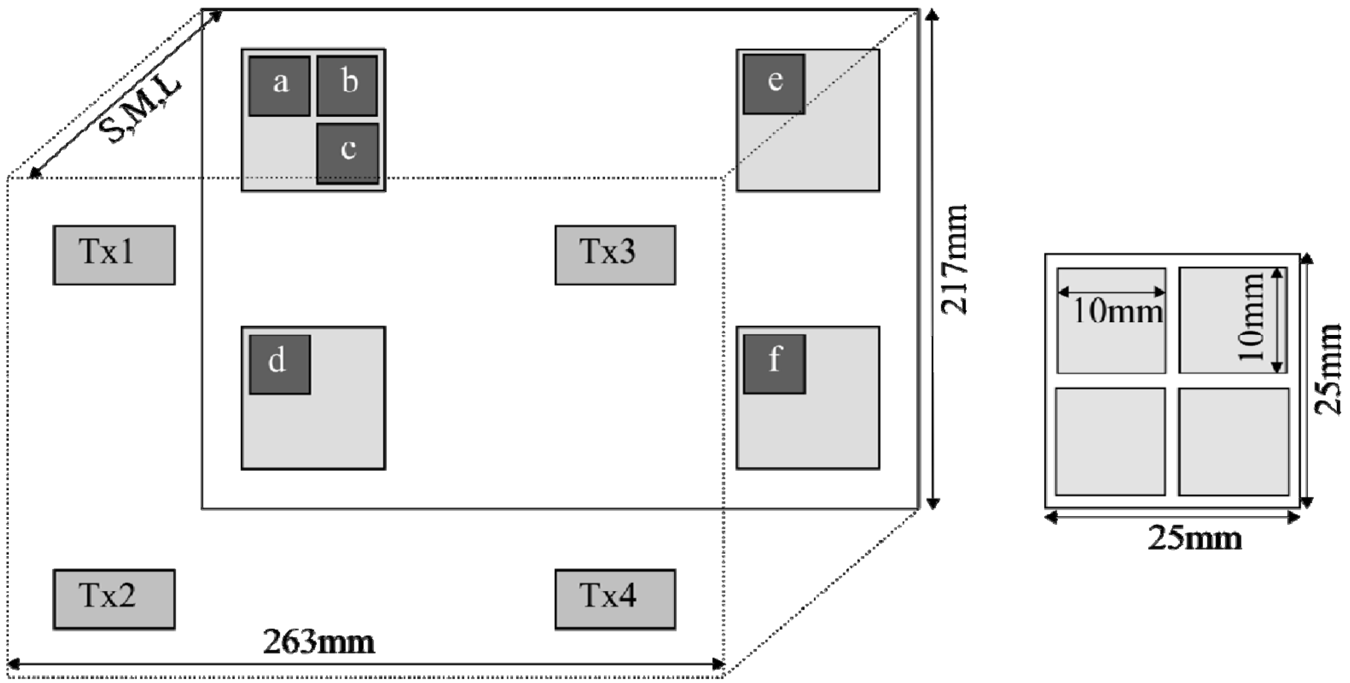


[2], [3]



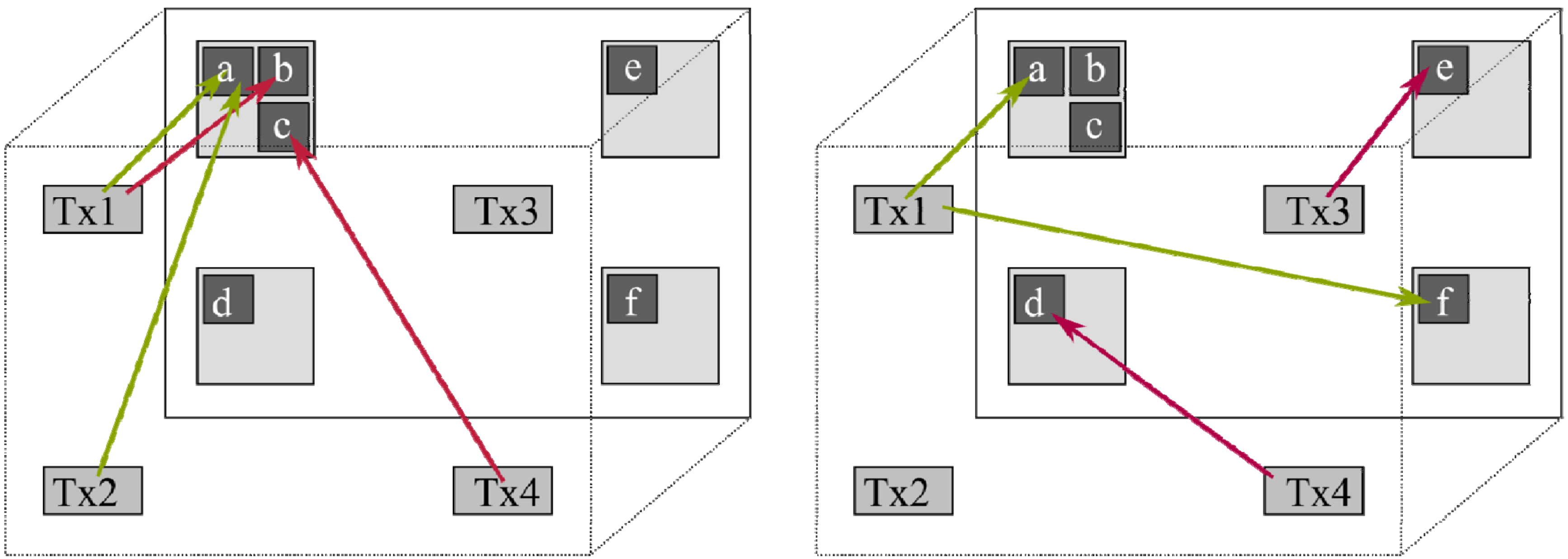


Geometry of the investigated Board-to-Board Communication Scenario



Box with four chips on PCB boards
(receiver positions are denoted with a to f;
S=50 mm, M=110mm; L=160mm)

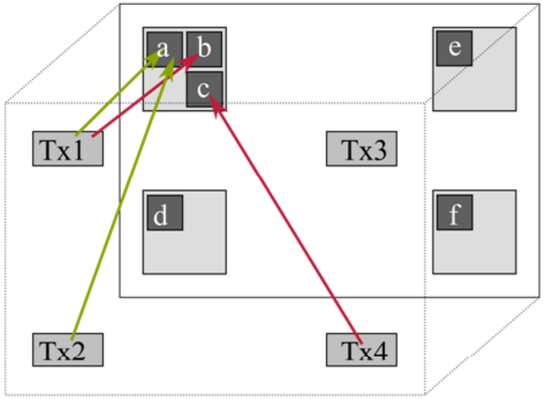
Conjunct and disjunct Communication Links



Conjunct Links

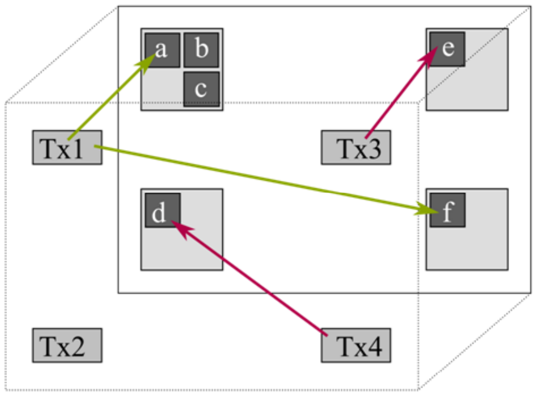
Disjunct Links

Investigated Tx/Rx configurations



Conjunct Links

Payload link	Possible interfering links			
Tx1-a	Tx1-b	Tx1-c	Tx2-b	Tx2-c
	Tx3-b	Tx3-c	Tx4-b	Tx4-c
Tx2-a	Tx1-b	Tx1-c	Tx2-b	Tx2-c
	Tx3-b	Tx3-c	Tx4-b	Tx4-c
Tx3-a	Tx1-b	Tx1-c	Tx2-b	Tx2-c
	Tx3-b	Tx3-c	Tx4-b	Tx4-c
Tx4-a	Tx1-b	Tx1-c	Tx2-b	Tx2-c
	Tx3-b	Tx3-c	Tx4-b	Tx4-c



Disjunct Links

Payload link	Possible interfering links					
Tx1-a				Tx2-d	Tx2-e	Tx2-f
	Tx3-d	Tx3-e	Tx3-f	Tx4-d	Tx4-e	Tx4-f
Tx1-d				Tx2-a	Tx2-e	Tx2-f
	Tx3-a	Tx3-e	Tx3-f	Tx4-a	Tx4-e	Tx4-f
Tx1-e				Tx2-a	Tx2-d	Tx2-f
	Tx3-a	Tx3-d	Tx3-f	Tx4-a	Tx4-d	Tx4-f
Tx1-f				Tx2-a	Tx2-d	Tx2-e
	Tx3-a	Tx3-d	Tx3-e	Tx4-a	Tx4-d	Tx4-e

Evaluation Methodology (1/3)

- For an assessment of the capabilities figures of merit defining link quality and interference level need to be defined based on the concepts of

  - Received power levels
  - Intersymbol Interference (ISI)
  - Co-channel Interference (CCI)

- Here, the received power level is defined as the peak signal strength of the CIR:

$$P_{peak} = 20 \cdot log_{10}(max(|CIR|))$$

- The analysis of both ISI and CCI is based on the Error Vector Magnitude (EVM) generated by the corresponding CIR when fed with random sequences

Evaluation Methodology (2/3)

– Two methods have been applied to calculate the EVM for ISI:

- Method 1: EVM depending on the modulation scheme

$$EVM_{ISI,mod} = \sqrt{\left| \sum_{\substack{i=1,\ldots,N \\ i \neq i_{peak}}} S_i \cdot CIR_i \right|}$$

- Method 2: EVM independent of the modulation scheme

$$EVM_{ISI,geo} = \sqrt{\sum_{\substack{i=1,\ldots,N \\ i \neq i_{peak}}} \left| CIR_i \right|^2}$$

– In both caes the level of ISI relative to the received signal power is then

$$L_{ISI} = 20 \cdot log_{10} \left(EVM_{ISI}^{payload} \right) - 20 \cdot log_{10} \left(P_{peak}^{payload} \right)$$

Evaluation Methodology (3/3)

– Two methods have been applied to calculate the EVM for CCI:

- Method 1: EVM depending on the modulation scheme

$$EVM_{CCI,mod} = \sqrt{\left| \sum_{i=1,\ldots,N} S_i \cdot CIR_i \right|}$$

- Method 2: EVM independent of the modulation scheme

$$EVM_{CCI,geo} = \sqrt{\sum_{i=1,\ldots,N} |CIR_i|^2}$$

– In both cases the level of CCI relative to the received signal power is then

$$L_{CCI} = 20 \cdot log_{10}\left(EVM_{CCI}^{interferer}\right) - 20 \cdot log_{10}\left(P_{peak}^{payload}\right)$$

Some Basic Data

- Observed mean peak symbol powers (in dBm) for the various link types, antenna gains and box sizes:

Link type		Conjunct Links			Disjunct links		
Box size		L	M	S	L	M	S
Antenna gains	6dBi	-55,88	-54,09	-49,82	-55,88	-54,09	-49,82
	12dbi	-44,03	-42,12	-37,81	-44,03	-42,12	-37,82
	18dBi	-32,28	-30,12	-25,78	-32,29	-30,12	-25,78
	24dBi	-20,37	-18,11	-13,76	-20,37	-18,11	-13,76

- Required SINR depending on the coding scheme [4,5]

	Hamming	RS	$LDPC_{11/15}$	$LDPC_{14/15}$
OOK	-15,25	-11,09	-5,95	-9,51
BPSK	-11,91	-8,13	-3,1	-6,42
QPSK	-12,81	-11,16	-6,07	-9,48
8PSK	-20,27	-16,28	-10,98	-14,46
QAM16	-22,01	-21,23	-13	-16,43
QAM64	-28,27	-24,41	-18,11	-22,37

Results: Average observed Degree of L_{ISI}

		Conjunct links			Disjunct links		
		L	M	S	L	M	S
OOK	6dBi	-9,32	-11,68	-14,66	-9,31	-11,5	-14,68
	12dBi	-11,85	-15,61	-17,94	-12,09	-15,68	-17,54
	18dBi	-17,85	-22,47	-25,24	-17,84	-22,47	-25,23
	24dBi	-28,06	-33,75	-42,47	-28,06	-33,75	-42,47
BPSK	6dBi	-8,65	-9,41	-13,25	-8,53	-9,41	-12,97
	12dbi	-11,19	-13,83	-16,3	-11,51	-13,81	-15,75
	18dBi	-16,53	-20,43	-22,87	-16,53	-20,43	-22,84
	24dBi	-26,08	-30,73	-39,45	-26,08	-30,73	-39,45
QPSK	6dBi	-8,34	-9,17	-13,3	-8,29	-9,23	-12,89
	12dbi	-10,83	-13,75	-16,28	-11,19	-13,73	-15,68
	18dBi	-16,19	-20,44	-23,2	-16,19	-20,44	-23,16
	24dBi	-25,55	-30,73	-39,45	-25,55	-30,73	-39,45

L_{ISI} < $SINR_{required}$ for RS (255,239)

L_{ISI} < $SINR_{required}$ for LDPC (1440,1344)

		Conjunct links			Disjunct links		
		L	M	S	L	M	S
8PSK	6dBi	-8,34	-9,19	-13,32	-8,29	-9,27	-12,93
	12dBi	-10,82	-13,8	-16,34	-11,18	-13,79	-15,74
	18dBi	-16,22	-20,47	-23,15	-16,22	-20,47	-23,11
	24dBi	-25,57	-30,73	-39,45	-25,57	-30,73	-39,45
16QAM	6dBi	-8,43	-9,27	-13,43	-8,38	-9,33	-13,04
	12dbi	-10,92	-13,9	-16,51	-11,3	-13,9	-15,91
	18dBi	-16,36	-20,72	-23,47	-16,36	-20,72	-23,43
	24dBi	-25,79	-31,2	-39,92	-25,79	-31,2	-39,92
64QAM	6dBi	-8,45	-9,28	-13,46	-8,42	-9,34	-13,07
	12dbi	-10,95	-13,93	-16,56	-11,32	-13,93	-15,97
	18dBi	-16,39	-20,77	-23,53	-16,39	-20,77	-23,49
	24dBi	-25,84	-31,3	-40,02	-25,84	-31,3	-40,02
Geom.	6dBi	-7,54	-8,39	-12,63	-7,49	-8,43	-12,24
	12dbi	-10,05	-13,07	-15,76	-10,42	-13,07	-15,18
	18dBi	-15,53	-20,02	-22,85	-15,53	-20,02	-22,8
	24dBi	-25,06	-30,73	-39,45	-25,06	-30,73	-39,45

Results: Average observed Degree of L_{CCI}

		Conjunct Links			Disjunct Links		
		L	M	S	L	M	S
OOK	6dBi	-1,4	-0,01	2,01	-8,15	-10,18	-12,31
	12dBi	-1,98	-0,9	-0,18	-22,9	-26,22	-32,94
	18dBi	-2,87	-2,71	-5,16	-42,66	-46,93	-51,2
	24dBi	-5,07	-6,44	-9,03	-62,08	-63,27	-62,07
BPSK	6dBi	1,1	1,63	3,74	-6,49	-8,32	-10,58
	12dBi	0,66	1,01	1,83	-20,98	-24,22	-31,3
	18dBi	-0,15	-0,3	-2,62	-40,67	-44,62	-52,14
	24dBi	-2,16	-3,68	-6,02	-59,47	-60,62	-63,63
QPSK	6dBi	1,25	1,64	3,73	-6,37	-8,34	-10,59
	12dBi	0,8	1,03	1,82	-21	-24,24	-31,36
	18dBi	-0,07	-0,29	-2,63	-40,82	-44,7	-52,42
	24dBi	-2,13	-3,67	-6,03	-59,56	-60,82	-63,76

$L_{ISI} < SINR_{required}$ for RS (255,239)

$L_{ISI} < SINR_{required}$ for LDPC (1440,1344)

		Conjunct Links			Disjunct Links		
		L	M	S	L	M	S
8PSK	6dBi	1,26	1,63	3,74	-6,37	-8,34	-10,59
	12dBi	0,82	1,03	1,82	-21	-24,25	-31,36
	18dBi	-0,07	-0,29	-2,63	-40,82	-44,69	-52,42
	24dBi	-2,13	-3,67	-6,03	-59,57	-60,83	-63,76
16QAM	6dBi	0,97	1,3	3,31	-6,62	-8,66	-11,01
	12dBi	0,47	0,61	1,39	-21,29	-24,62	-31,73
	18dBi	0,5	-0,74	3,08	-41,15	-45,05	-52,49
	24dBi	-2,58	-4,13	-6,49	-59,97	-61,18	-63,82
64QAM	6dBi	0,93	1,25	3,23	-6,65	-8,7	-11,07
	12dBi	0,41	0,57	1,29	-21,33	-24,68	-31,78
	18dBi	-0,57	-0,84	-3,19	-41,19	-45,11	-52,5
	24dBi	-2,68	-4,24	-6,59	-60,03	-61,22	-63,82
Geom.	6dBi	1,67	1,95	3,84	-5,89	-8	-10,46
	12dbi	1,1	1,17	1,89	-20,61	-24,03	-31,13
	18dBi	0,04	-0,25	-2,61	-40,49	-44,43	-51,56
	24dBi	-2,09	-3,66	-6,02	-59,41	-60,54	-62,85

Conclusion

- Deployment aspects for intra-device links at 300 GHz have been investigated
- Analysis of intersymbol interference (ISI) and co-channel interference (CCI) based on EVM derived from simulated CIR
- Calcuation of EVM based on geometric addtion yields a reasonable upper bound for the interference
- DIsjunct links are rather ISI limited. For robust modulation schemes (BPSK, QPSK) even a 6dBi antenna may work
- Conjunct links are rather CCI limited. For multiple (disjunct) links at least 12 dBi antennas are required to mitigate CCI.
- In case of conjunct links appropriate muliple access schemes are required.

References

[1] A. Fricke, T. Kürner, “Interference Study for THz Intra-Device Communication Systems with Multiple Links”, Proc. European Conference on Antennas and Propagation, EuCAP 2018, London

[2] A. Fricke, T. Kürner, M. Achir and P. Le Bars, "A model for the *reflection of terahertz signals from printed circuit board surfaces,"* 2017 11th European Conference on Antennas and Propagation (EUCAP)*, Paris,* 2017, pp. 711-715

[3] Fricke A, Achir M, Le Bars P, Kürner T. A model for the reflection of terahertz signals from printed circuit board surfaces. International Journal of Microwaveand Wireless Technologies https://doi.org/ 10.1017/S1759078718000119

[4] T. Kürner, “Summary of Results from TG3d Link Level Simulations”, DCN: 15-17-0039-04-003d, January, https://mentor.ieee.org/802.15/documents

[5] A. Fricke, T. Kürner, “Preliminary Performance of FEC Schemes in TG3d Channels”, DCN: 15-16-0746-07-003d, January 2017, https://mentor.ieee.org/802.15/documents