Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: Digital Data Transmission at 300 GHz
Date Submitted: 8 July, 2010
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Re: doc.: IEEE 802.15-15-09-0496-00-0thzr1-channel-measurements

Abstract: After first detailed ultra broadband propagation measurements have been performed (cf. doc.: IEEE 802.15-15-09-0496-00-0thzr1-channel-measurements), the next logical step is a feasibility study of digital data transmission at 300 GHz. While data transmission employing an optical signal source has already been shown, this presentation is first to demonstrate digital data transmission using electrical components. DVB-T and DVB-S2 test signals are transmitted over distances up to 52 m and analyzed considering BER, C/N and EVM.

Purpose: Proof of concept of digital data transmission at THz frequencies using electrical components

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Digital Data Transmission at 300 GHz

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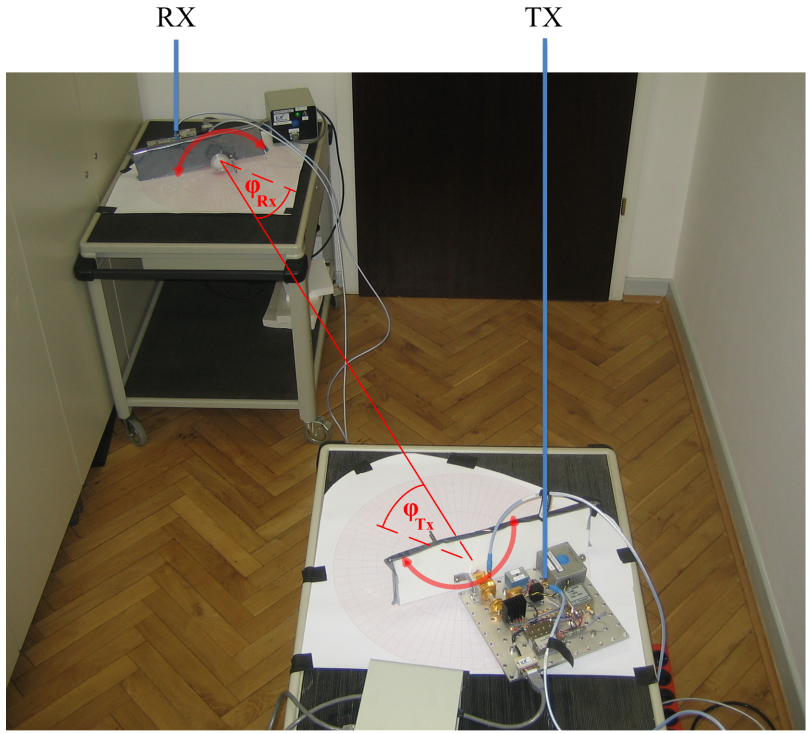
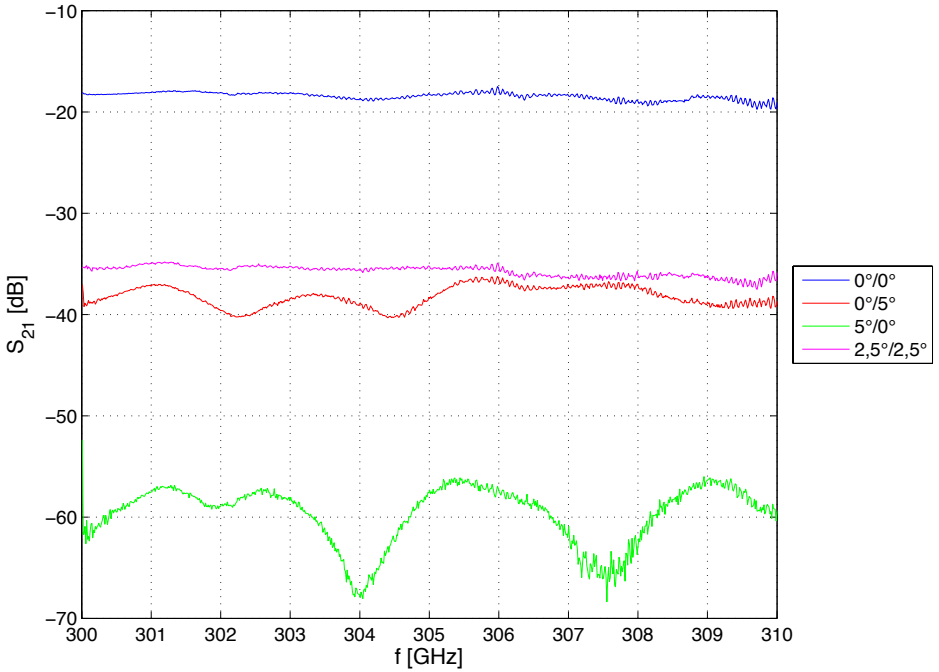
Outline

1. **Introduction**
2. The Measurement Setup
3. Measurement Results
4. Summary/Outlook

Introduction (1)

- First ultra broadband short range indoor channel measurements





doc.: IEEE 802.15-15-09-0756-00-0thz

→ Input for 300 GHz channel modeling activities

→ But: data transmission?

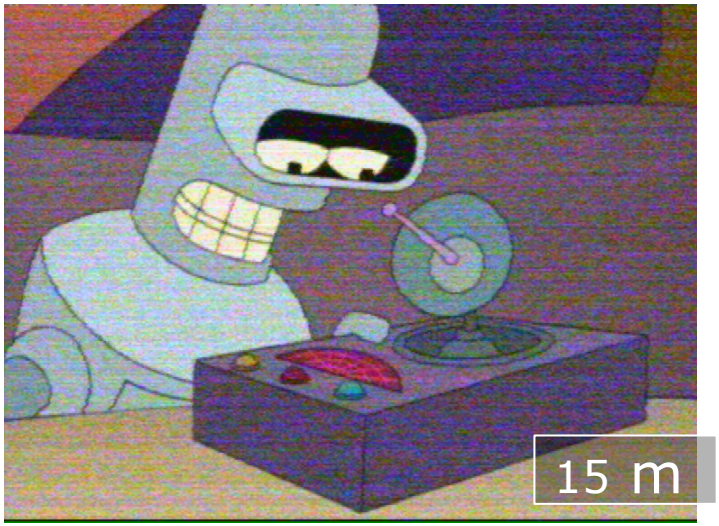
Introduction (2)

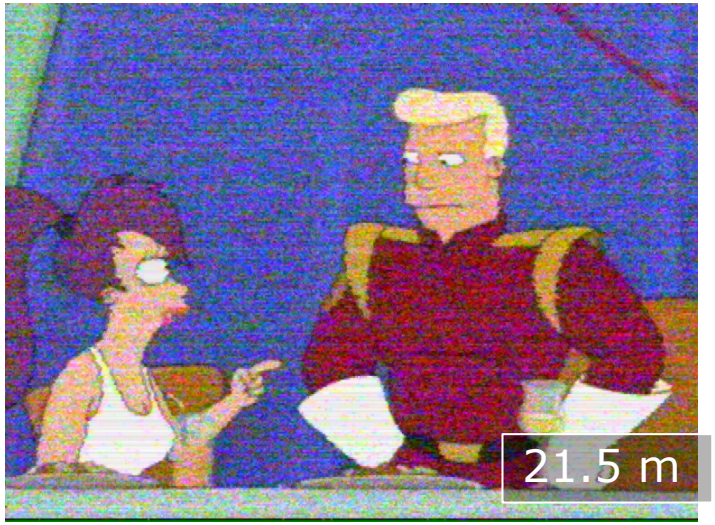
- Demonstration of an analog video transmission at 300 GHz

cf.: C. Jastrow, K. Munter, R. Piesiewicz, T. Kürner, M. Koch, T. Kleine-Ostmann: 300 GHz Transmission System, Electronics Letters, Volume 44, Issue 3, Pages 213-214, January 2008

→ Analag transmission feasible

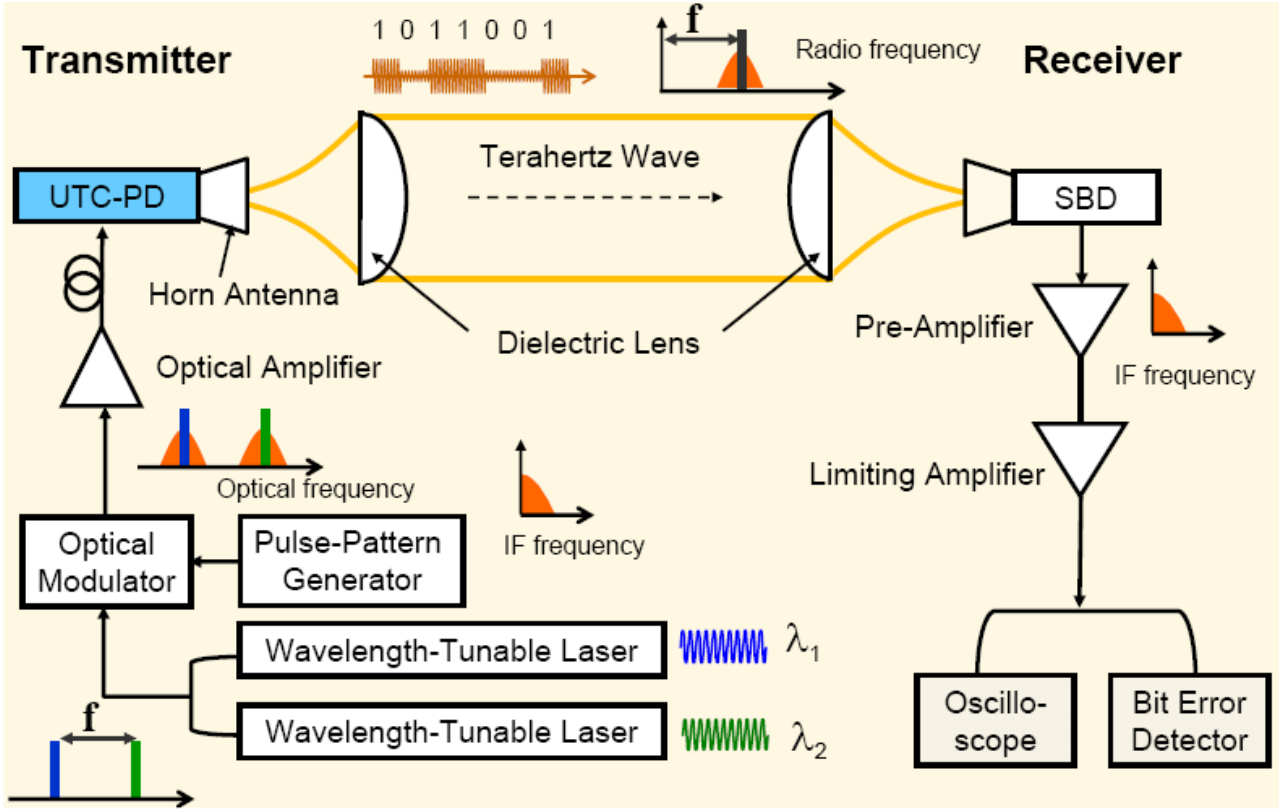
Introduction (3)





Introduction (4)

- Transmission of pulse patterns at 300 – 400 GHz based on photonic components (by NTT)



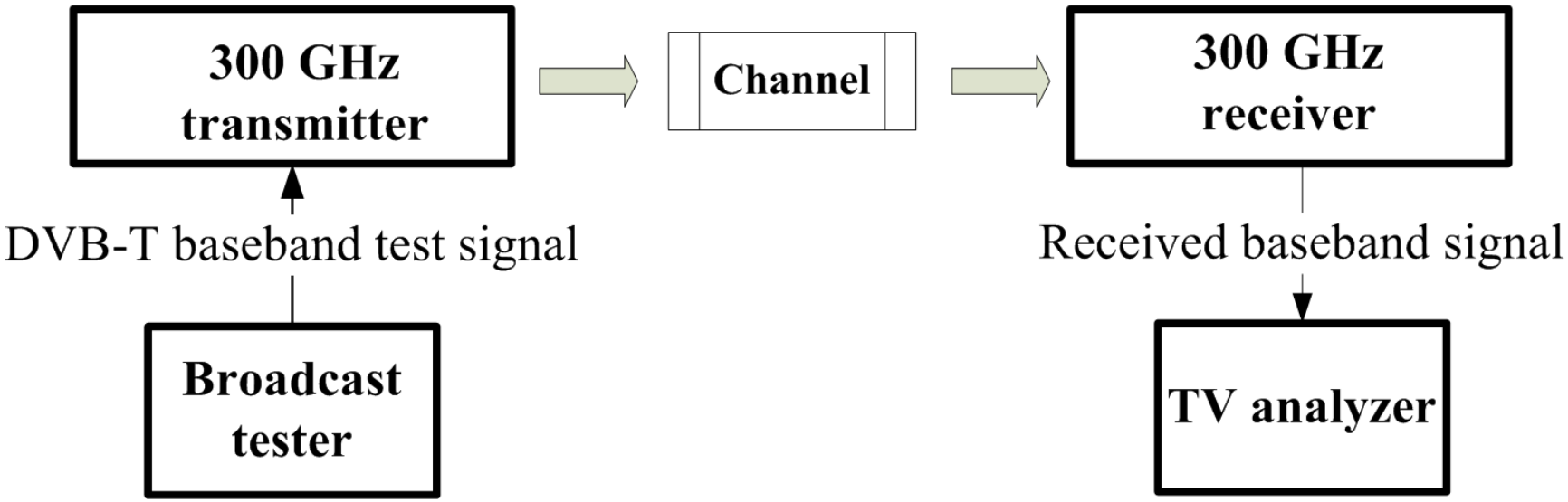
doc.: IEEE 802.15-15-10- 0149-01-0thz

→ Next step: Digital data transmission using electrical components

Outline

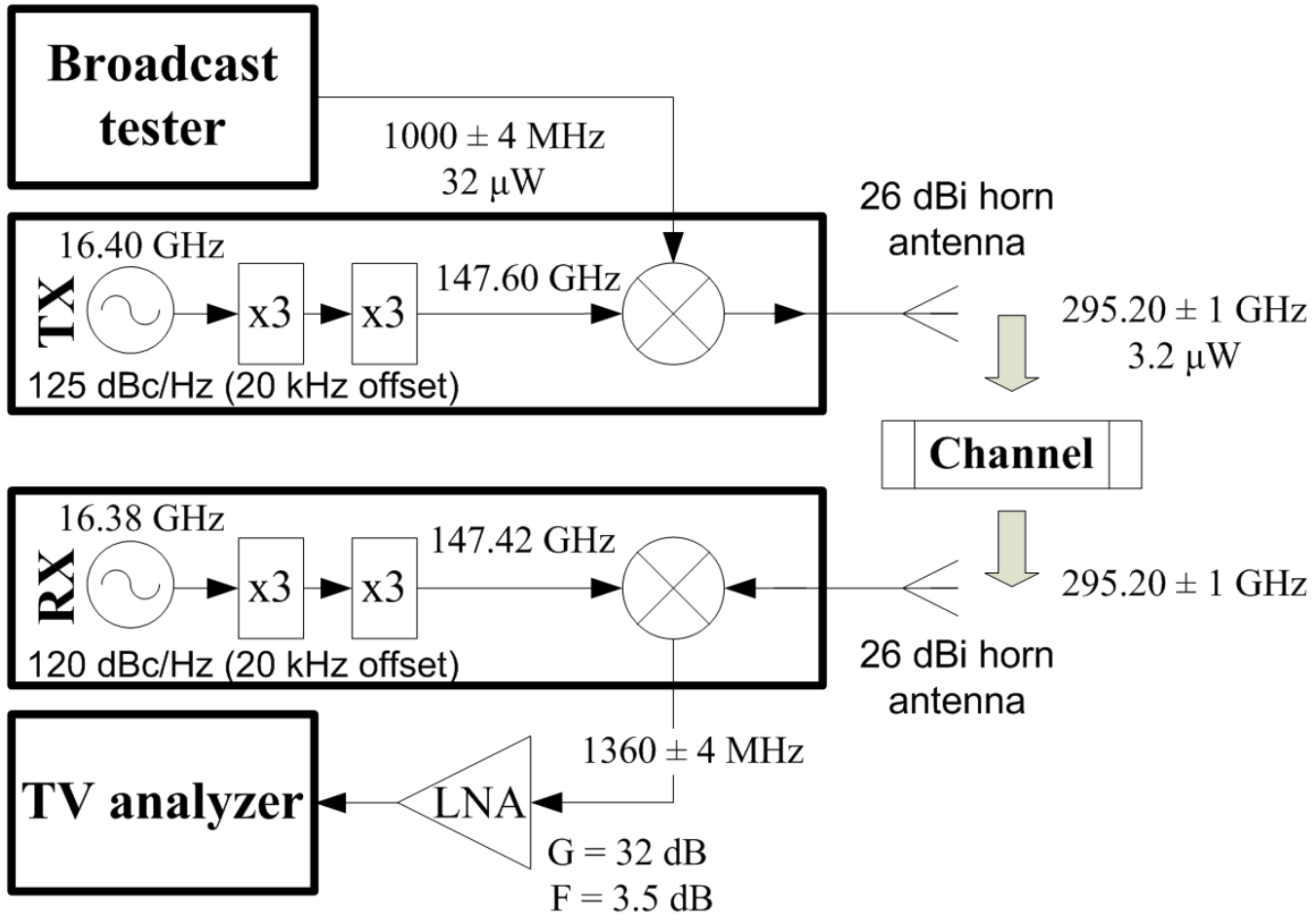
1. Introduction
2. **The Measurement Setup**
   - **DVB-T Test Signal Transmission**
   - **DVB-S2 Feasibility Demonstration**
3. Measurement Results
4. Summary/Outlook

DVB-T Test Signal Transmission (1)



→ DVB-T test signal used to analyze channel quality at 300 GHz

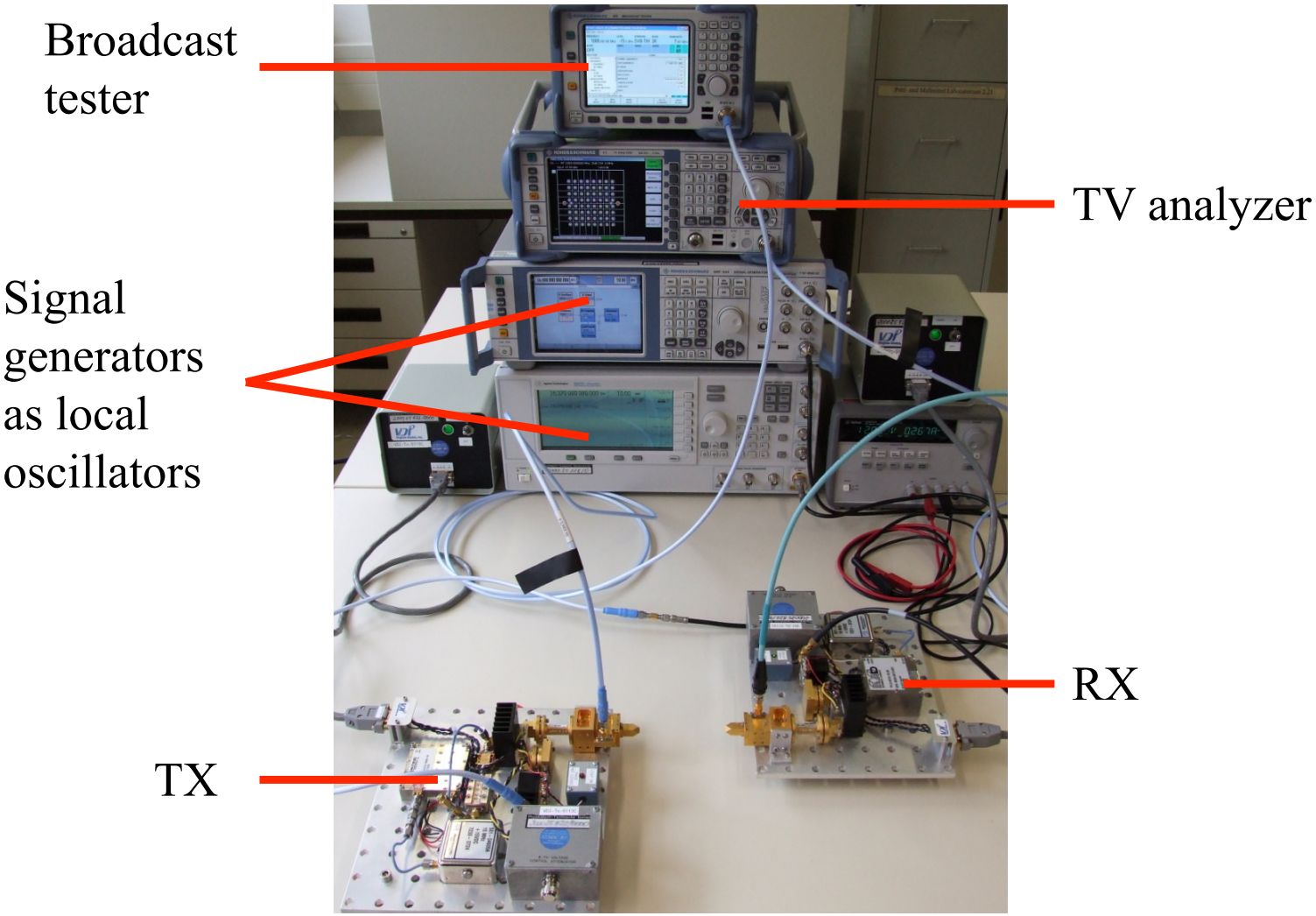
DVB-T Test Signal Transmission (2)



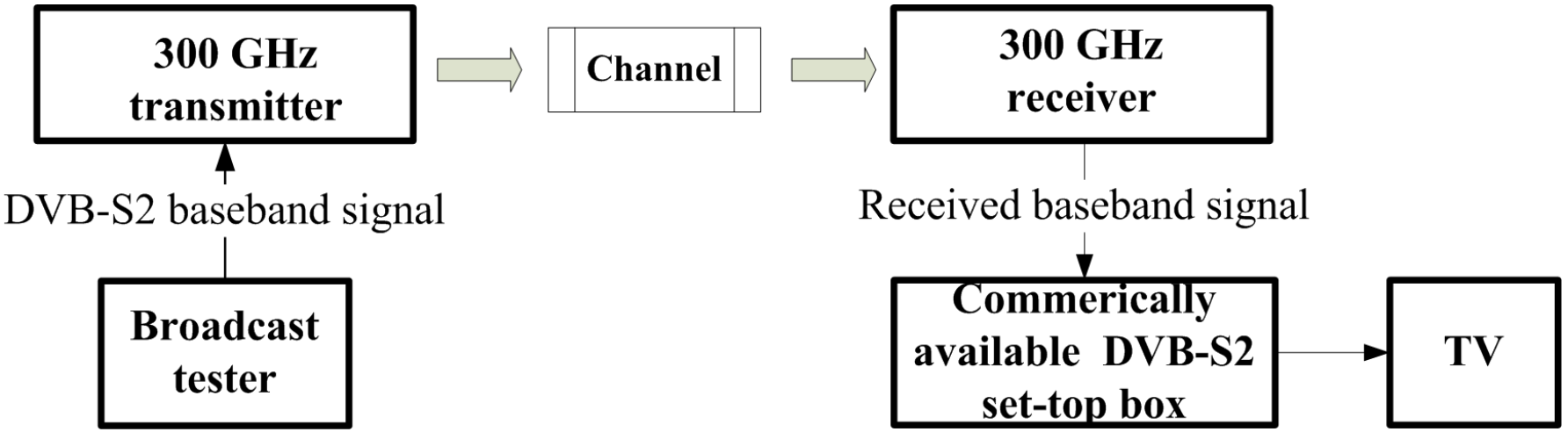
cf.: C. Jastrow, S. Priebe, B. Spitschan, J. Hartmann, M. Jacob, T. Kürner, T. Schrader and T. Kleine-Ostmann: *Wireless Digital Data Transmission at 300 GHz*, Electronics Letters - 29 April 2010 - Volume 46, Issue 9, p.661–66

→ Extremely limited output power

DVB-T Test Signal Transmission (3)



DVB-S2 Feasibility Demonstration



→ DVB-S2 video signal transmitted over 300 GHz channel

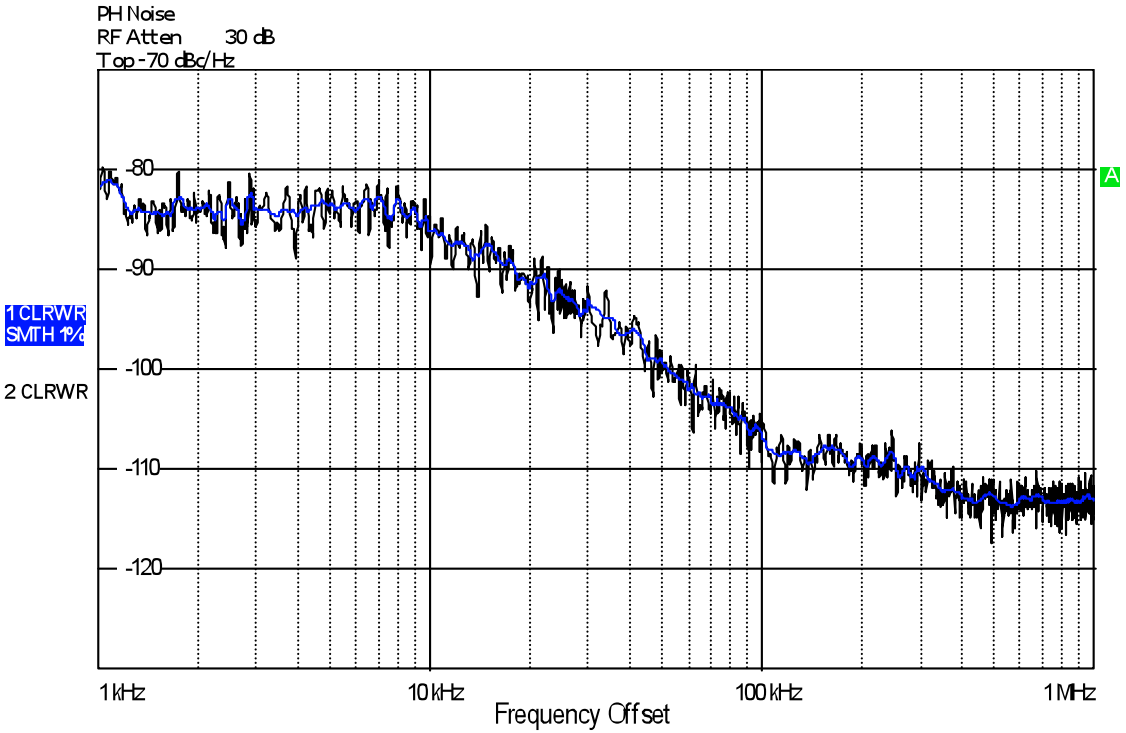
Outline

1. Introduction
2. The Measurement Setup
3. **Measurement Results**
   - **Phase Noise Measurements**
   - **DVB-T Test Signal Transmission**
   - **DVB-S2 Over 52 Meters**
4. Summary/Outlook

Phase Noise Measurements (1)

- Dielectric resonator oscillator (MITEQ) with f = 16.38 GHz:

PHASE NOISE					
Settings		Residual Noise		Spot Noise [T1]	
Signal Freq:	16.380020 GHz	Evaluation from	1 kHz to 1 MHz	1 kHz	-81.73 dBc/Hz
Signal Level:	13.55 dBm	Residual PM	0.672 °	10 kHz	-86.21 dBc/Hz
Signal Freq ? :Δ	-20.16 Hz	Residual FM	1.891 kHz	100 kHz	-106.87 dBc/Hz
Signal Level ? :Δ	0.05 dBm	RMS Jitter	0.1140 ps	1 MHz	-113.06 dBc/Hz

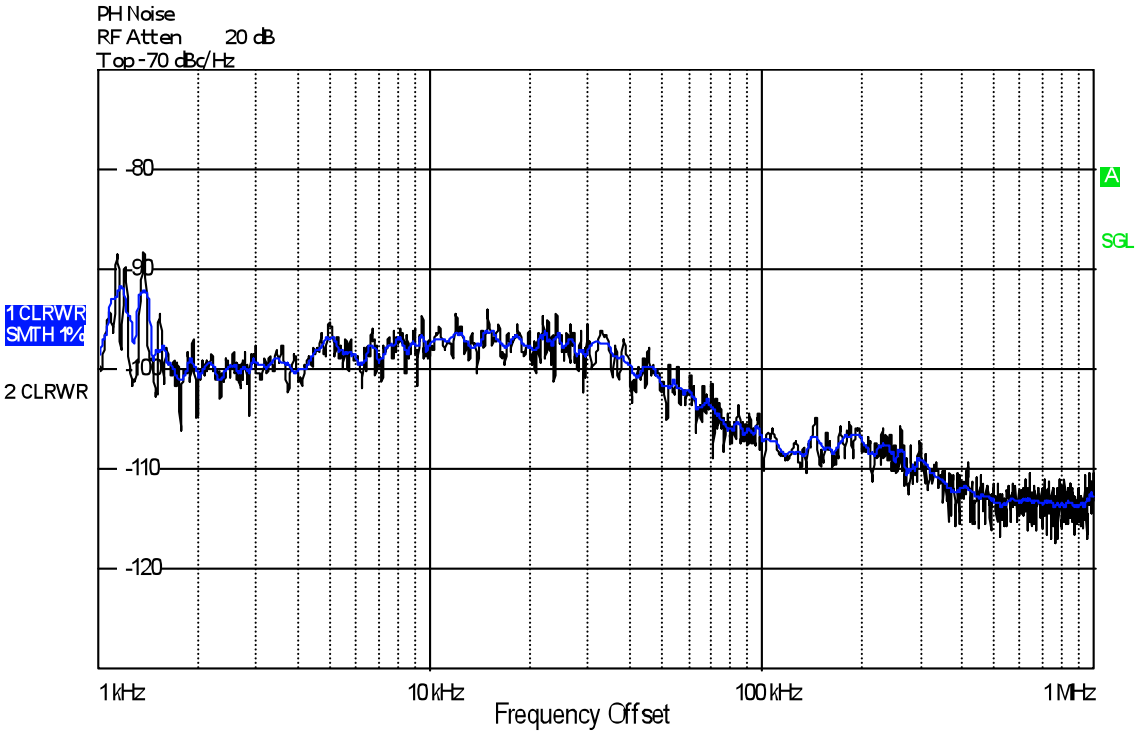


→ High phase noise

Phase Noise Measurements (2)

- Low phase noise signal generator (R&S) with f = 16.38 GHz:

PHASE NOISE					
Settings		Residual Noise		Spot Noise [T1]	
Signal Freq:	16.380017 GHz	Evaluation from	1 kHz to 1 MHz	1 kHz	-98.93 dBc/Hz
Signal Level:	6.43 dBm	Residual PM	0.327 °	10 kHz	-97.72 dBc/Hz
Signal Freq ? :Δ	-4.9 Hz	Residual FM	1.857 kHz	100 kHz	-107.19 dBc/Hz
Signal Level ? :Δ	-0.02 dBm	RMS Jitter	0.0555 ps	1 MHz	-112.79 dBc/Hz

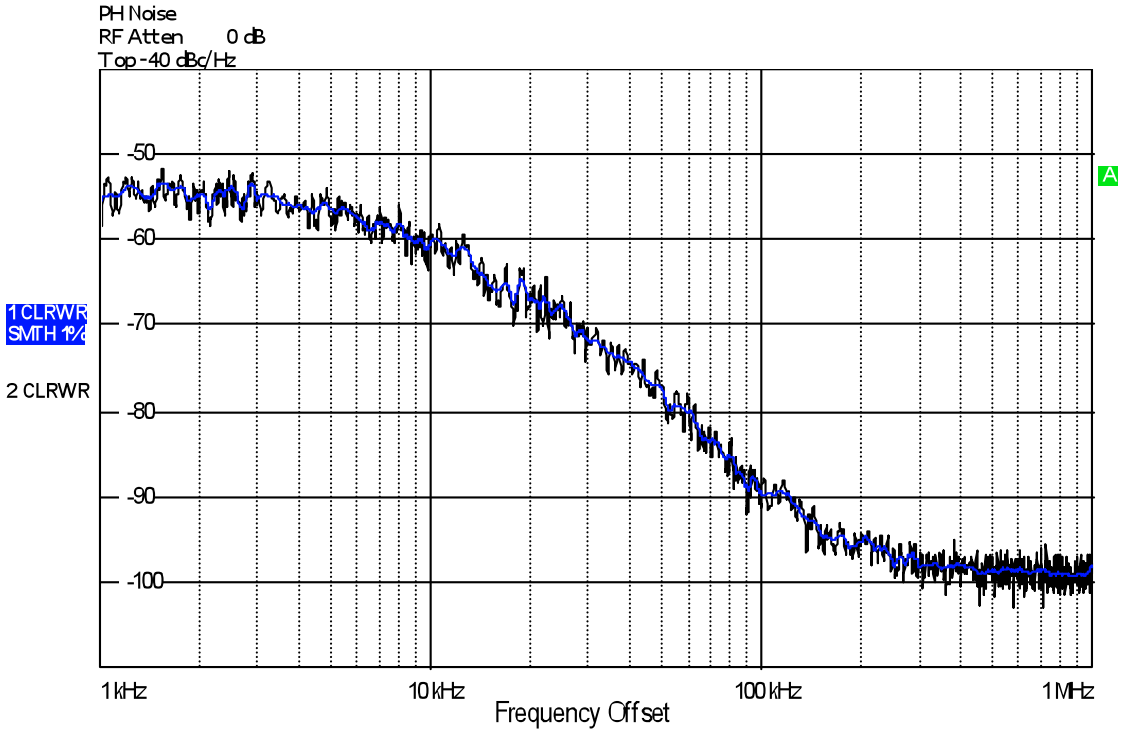


→ Far better performance for lower offsets

Phase Noise Measurements (3)

- Combined phase noise at RX using DROs:

PHASE NOISE					
Settings		Residual Noise		Spot Noise [T1]	
Signal Freq:	6.039997 GHz	Evaluation from	1 kHz to 1 MHz	1 kHz	-55.63 dBc/Hz
Signal Level:	-47.62 dBm	Residual PM	13.191 °	10 kHz	-60.62 dBc/Hz
Signal Freq ? :Δ	35.31 Hz	Residual FM	9.904 kHz	100 kHz	-89.86 dBc/Hz
Signal Level ? :Δ	-0.28 dBm	RMS Jitter	6.0666 ps	1 MHz	-98.26 dBc/Hz

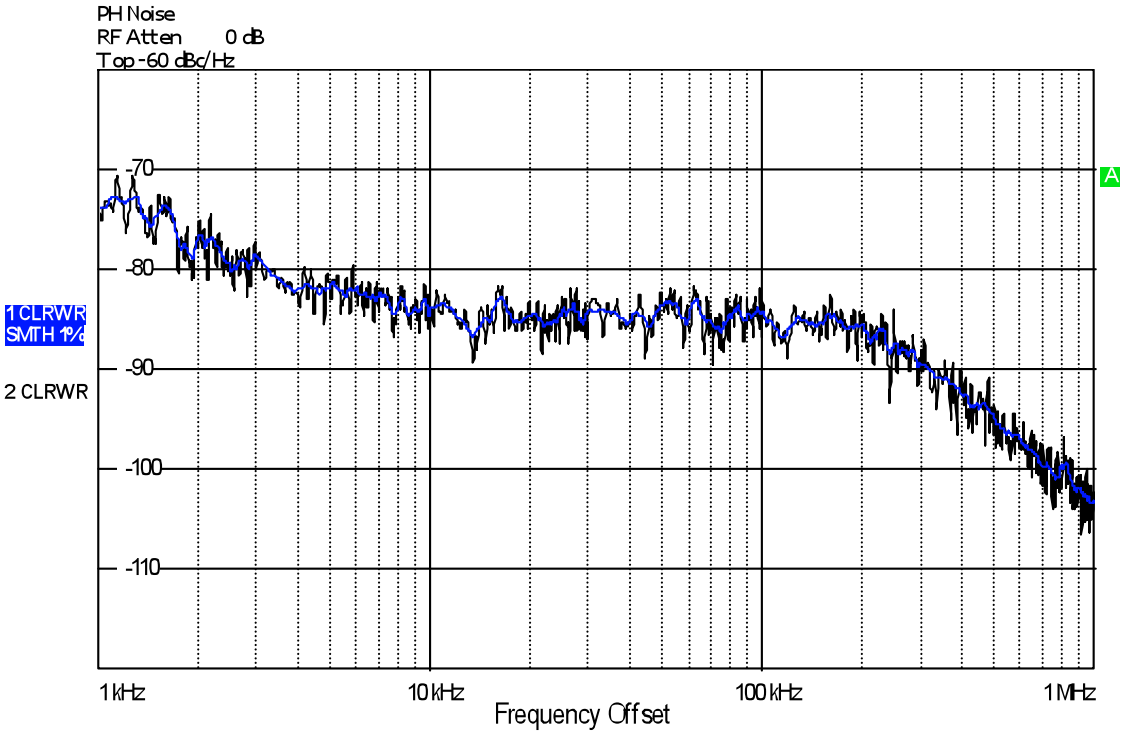


→ Unacceptable performance

Phase Noise Measurements (4)

- Combined phase noise at RX using signal generators:

PHASE NOISE					
Settings		Residual Noise		Spot Noise [T1]	
Signal Freq:	1.359945 GHz	Evaluation from	1 kHz to 1 MHz	1 kHz	-74.03 dBc/Hz
Signal Level:	-45.65 dBm	Residual PM	2.542 °	10 kHz	-83.94 dBc/Hz
Signal Freq ? :Δ	19.58 Hz	Residual FM	11.532 kHz	100 kHz	-84.41 dBc/Hz
Signal Level ? :Δ	-0.05 dBm	RMS Jitter	5.1925 ps	1 MHz	-103.32 dBc/Hz



→ At least 20 dBc/Hz better than with two DROs

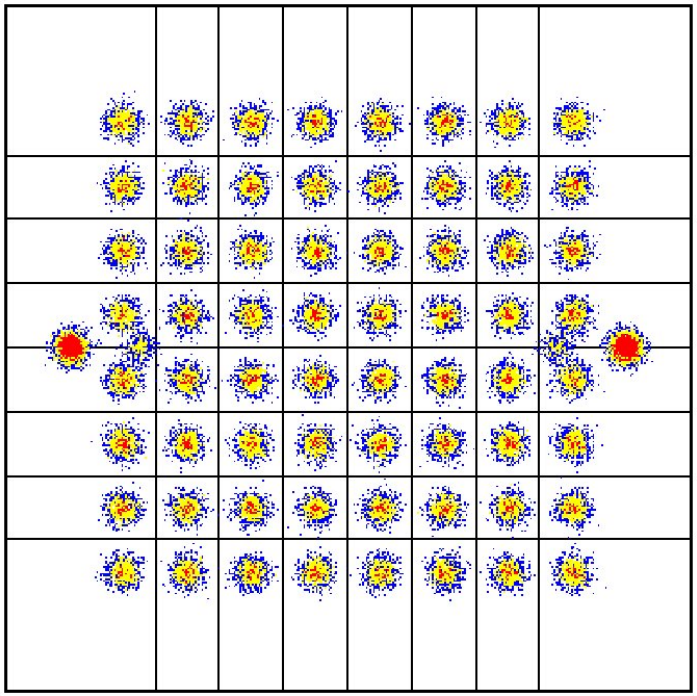
Phase Noise Measurements (5)

- High phase noise considerably influences system performance of communication systems
- Phase noise is seriously increased if frequency multiplying components are employed
- The measured DROs provide insufficient phase noise qualities

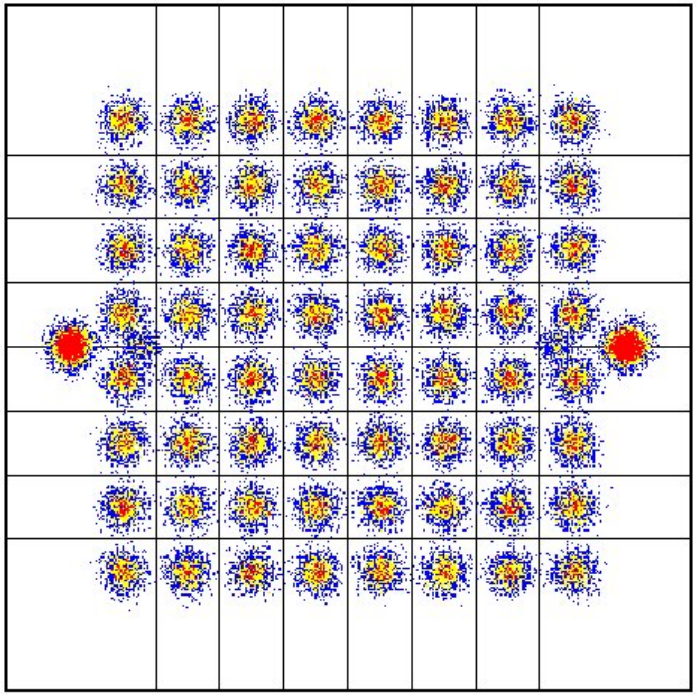
→ Low phase noise oscillators will be a critical component in Terahertz communication systems based on electrical components

DVB-T Test Signal Transmission (1)

- Constellation diagrams for a DVB-T test signal
  - 2k subcarriers, code rate r_c = 7/8, channel bandwidth B = 8 MHz, P_{signal} = -15 dBm, guard interval 1/32×T_S, modulation scheme: 64 QAM
    → 31.668 Mbit/s



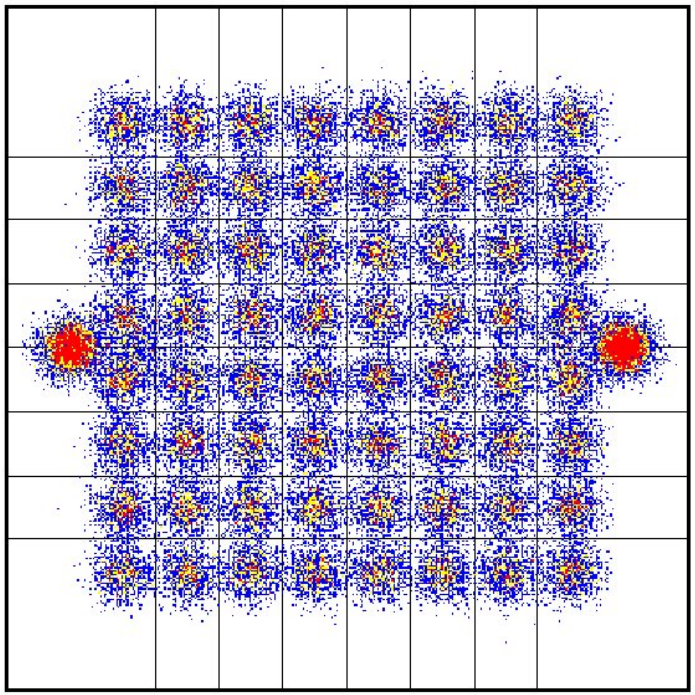
d = 10 cm, $BER_{before\ RS} < 10^{-9}$



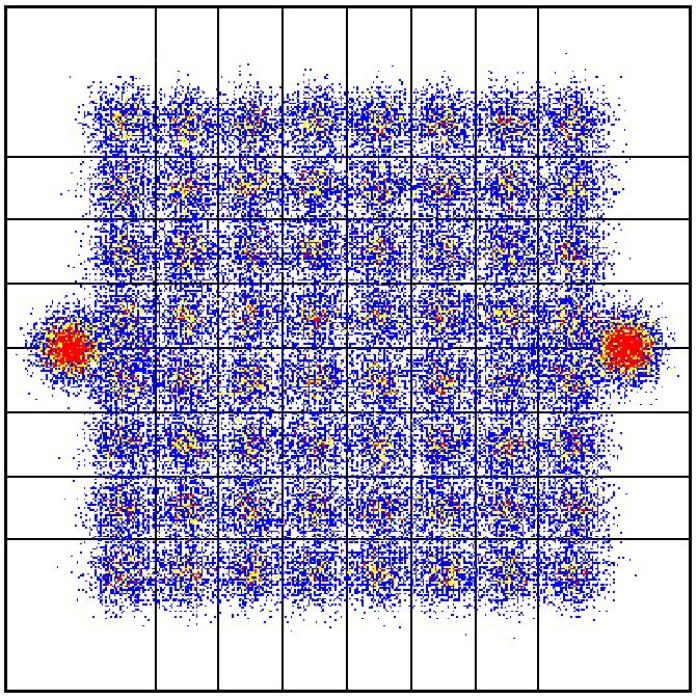
d = 30 cm, $BER_{before\ RS} = 2.6 \times 10^{-8}$

cf.: C. Jastrow, S. Priebe, B. Spitschan, J. Hartmann, M. Jacob, T. Kürner, T. Schrader and T. Kleine-Ostmann: Wireless Digital Data Transmission at 300 GHz, Electronics Letters - 29 April 2010 - Volume 46, Issue 9, p.661–66

DVB-T Test Signal Transmission (2)



d = 50 cm, $BER_{before\ RS} = 1.2 \times 10^{-4}$



d = 70 cm, $BER_{before\ RS} = 3.4 \times 10^{-3}$

DVB-T Test Signal Transmission (3)

Transmission distance	Free space loss	Signal power at the analyser input	C/N	BER before Reed Solomon	EVM (rms)
10 cm	62.0 dB	-36.4 dBm	35.4 dB	$< 10^{-9}$	3.41 %
30 cm	71.5 dB	-45.4 dBm	26.9 dB	2.6×10^{-8}	4.40 %
50 cm	76.0 dB	-50.4 dBm	21.5 dB	1.2×10^{-4}	6.15 %
70 cm	78.9 dB	-52.0 dBm	20.4 dB	3.4×10^{-3}	6.89 %

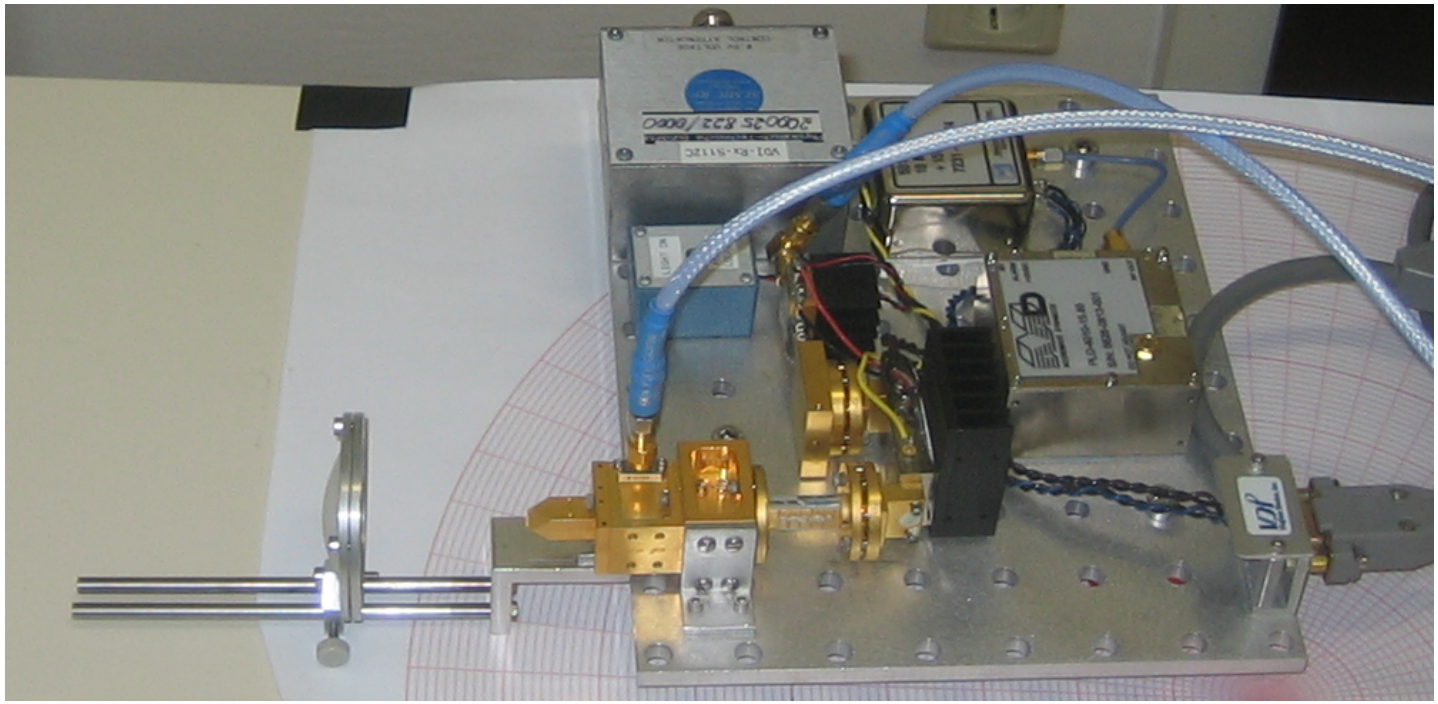
- C/N > 20.2 dB required for quasi error-free decoding under AWGN-conditions

→ Fulfilled for a module distance up to d = 70 cm

→ High gain antennas help to compensate for the high free space losses

DVB-T Test Signal Transmission (4)

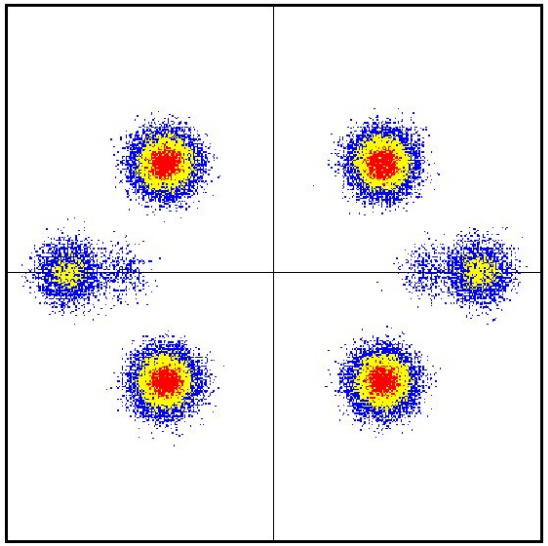
- Polyethylene lenses mounted in front of the horn antennas (14 dBi gain each)



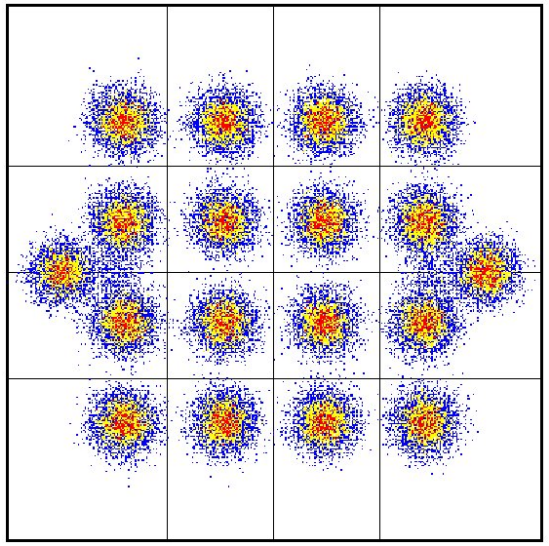
→ Larger transmission distances achievable

DVB-T Test Signal Transmission (5)

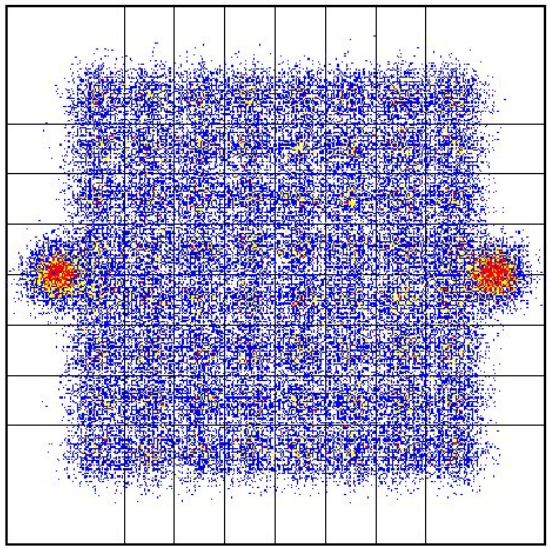
- Transmission distance of 52 m with lenses
  - P_{RX} = -52.9 dBm



QPSK: $BER_{before\ RS} < 10^{-9}$



16 QAM: $BER_{before\ RS} < 10^{-8}$



64 QAM: $BER_{before\ RS} = 2.8 \times 10^{-4}$

→ Usage of simple modulation schemes allows better performance

→ Tradeoff: Robustness vs. Spectral efficieny

DVB-T Test Signal Transmission (6)

- Coding scheme performance:

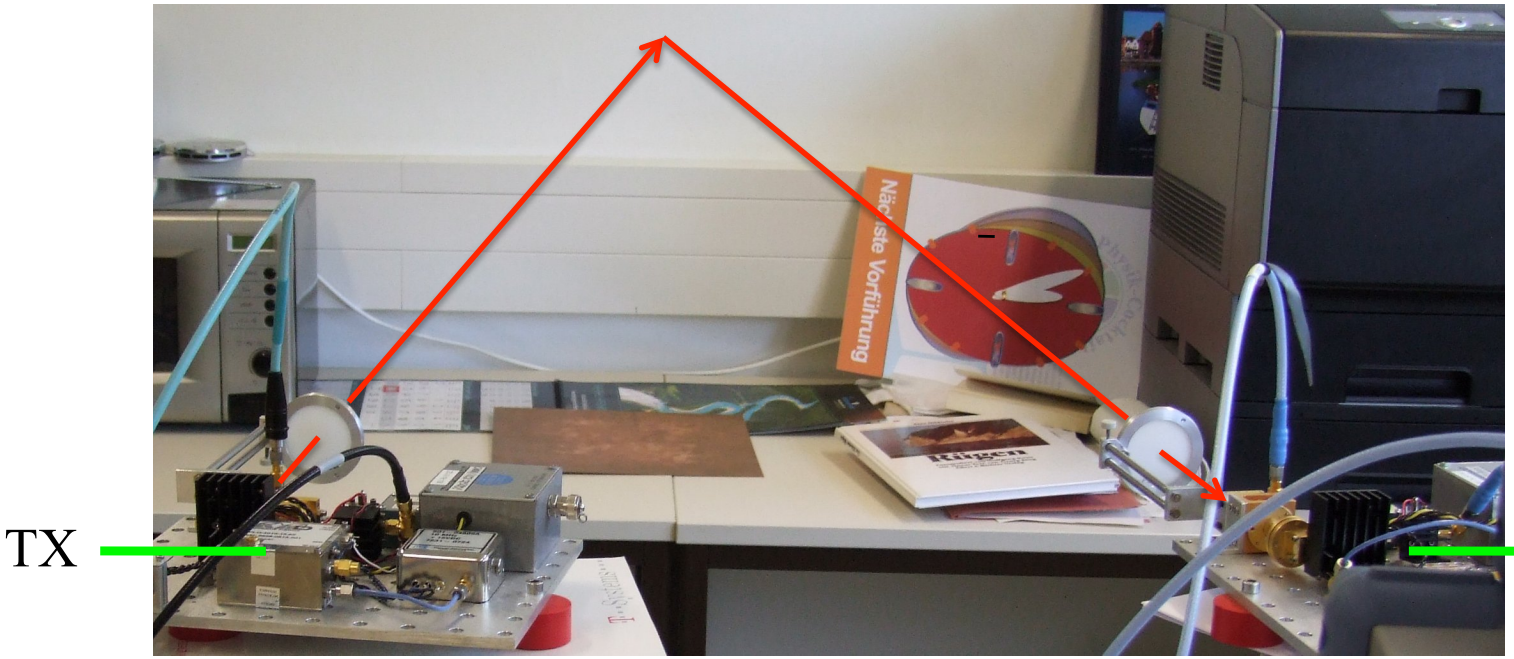
Transmission distance	BER before Viterbi	BER before Reed Solomon	BER after Reed Solomon	Packet error ratio	Packet errors per second
10 cm	7.5×10^{-6}	$< 10^{-9}$	$< 10^{-9}$	$< 10^{-9}$	0
30 cm	3.6×10^{-4}	2.6×10^{-8}	$< 10^{-9}$	$< 10^{-8}$	0
50 cm	7.3×10^{-3}	1.2×10^{-4}	$< 10^{-9}$	$< 10^{-7}$	0
70 cm	1.6×10^{-2}	3.4×10^{-3}	6.6×10^{-7}	1.1×10^{-4}	4
52 m QPSK	$< 10^{-7}$	$< 10^{-9}$	$< 10^{-9}$	$< 10^{-9}$	0
52 m 16 QAM	2.2×10^{-4}	$< 10^{-8}$	$< 10^{-8}$	$< 10^{-8}$	0
52 m 64 QAM	2.7×10^{-2}	2.8×10^{-4}	$< 10^{-7}$	$< 10^{-6}$	0

→ Coding schemes provide suffient performance under given conditions

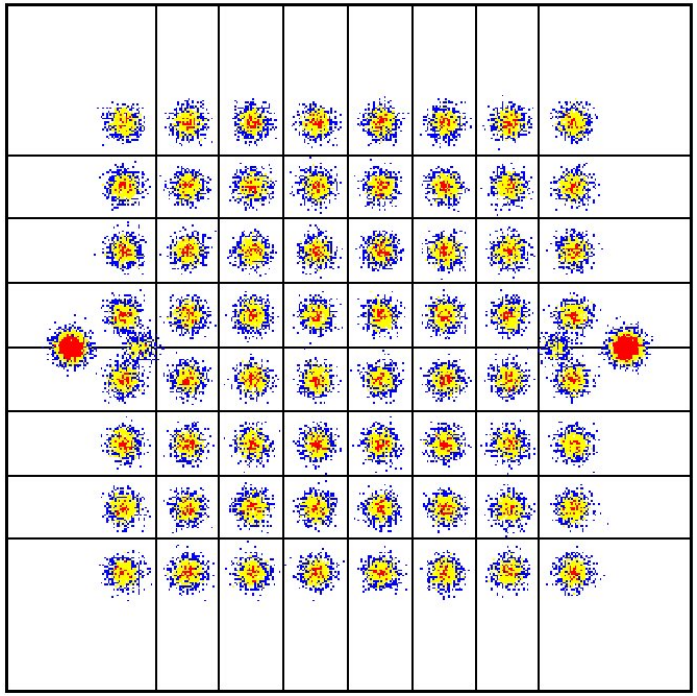
→ Open question: Behaviour during shadowing event

DVB-T Test Signal Transmission (7)

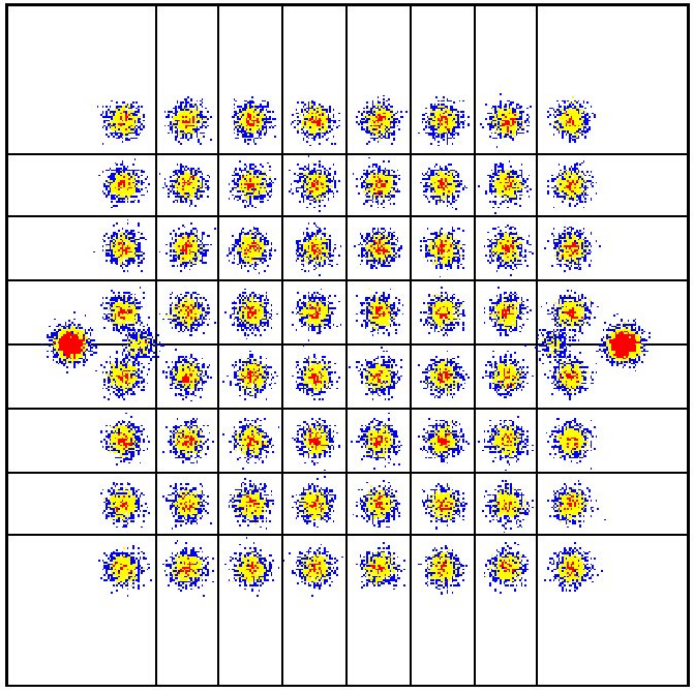
- Analysis of reflected paths:
  - d_{wall} = 200 cm, φ_{in} = 8°/φ_{in} = 18.5°



DVB-T Test Signal Transmission (8)



φ_{in} = 8°, C/N = 37.6 dB,
$BER_{before\ RS} < 10^{-8}$

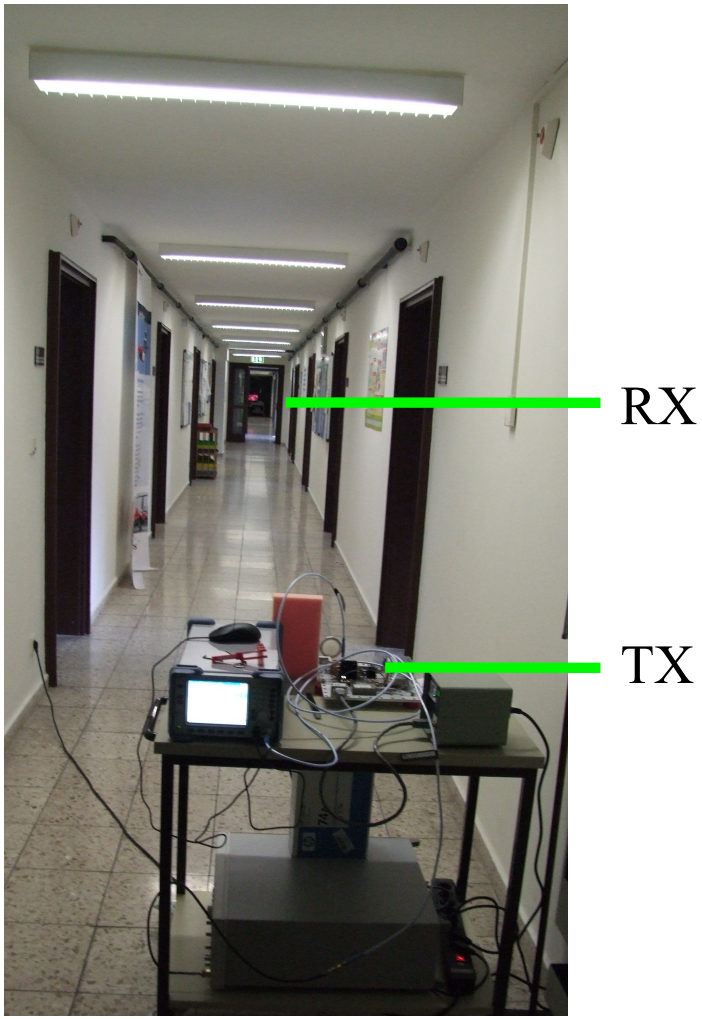


φ_{in} = 18.5°, C/N = 34.2 dB,
$BER_{before\ RS} < 10^{-8}$

→ Directed NLOS-path can be utilized for data transmission

DVB-S2 Over 52 Meters

- Feasibility demonstration with commerically available DVB-S2 receiver
  - No high-end components like in measurement receiver used before
- 1080p video signal:
  B = 36.8 MHz, r_c = 9/10, 8 PSK
  → net bit rate 85.78 Mbit/s



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Summary/Outlook

- The feasibility of digital data transmission at 300 GHz using electrical components has been demonstrated
  - A transmission system based on frequency multipliers and subharmonic mixers has been used
  - Low phase noise oscillators are crucial for sysems employing electric components
  - Rather simple modulation schemes are to be prefered as channels at 300 GHz provide huge available bandwiths at low output powers of components (by now)

Outlook:

- Detailed channel and propagation measurements will be performed to derive an appropriate 300 GHz channel model
- The channel model can then be used to design ultra broadband transmission systems

Thank you for paying attention.

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