High-Speed Radio Communication over a Plastic Fiber

WICON project

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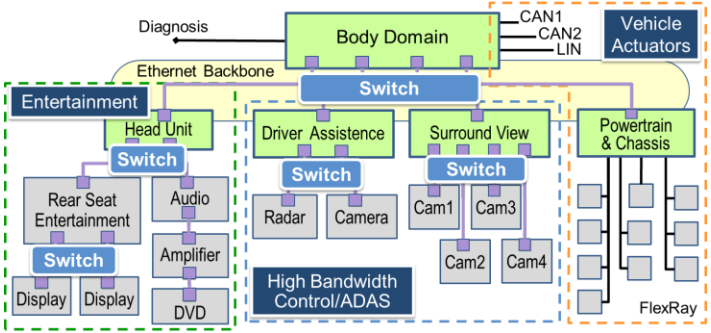
SECURE CONNECTIONS FOR A SMARTER WORLD

Future, ultra-high data-rate applications for In-Vehicle Networking

- “Cockpit Computer” driving all displays from central processing unit → video link for ultra high resolution displays*
- Autonomous car - “Central Computing Unit” consisting of two connected units (hemispheres) for redundancy reasons*
- Domain cluster architecture → backbone between domain controller(s)**

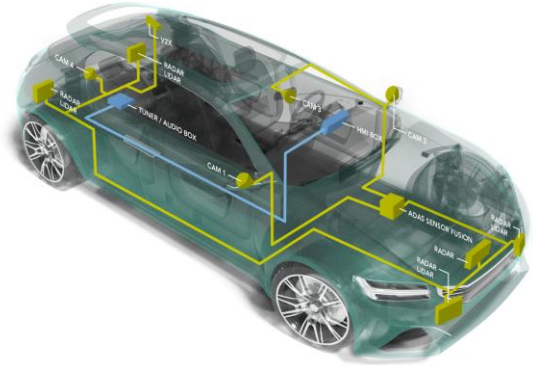


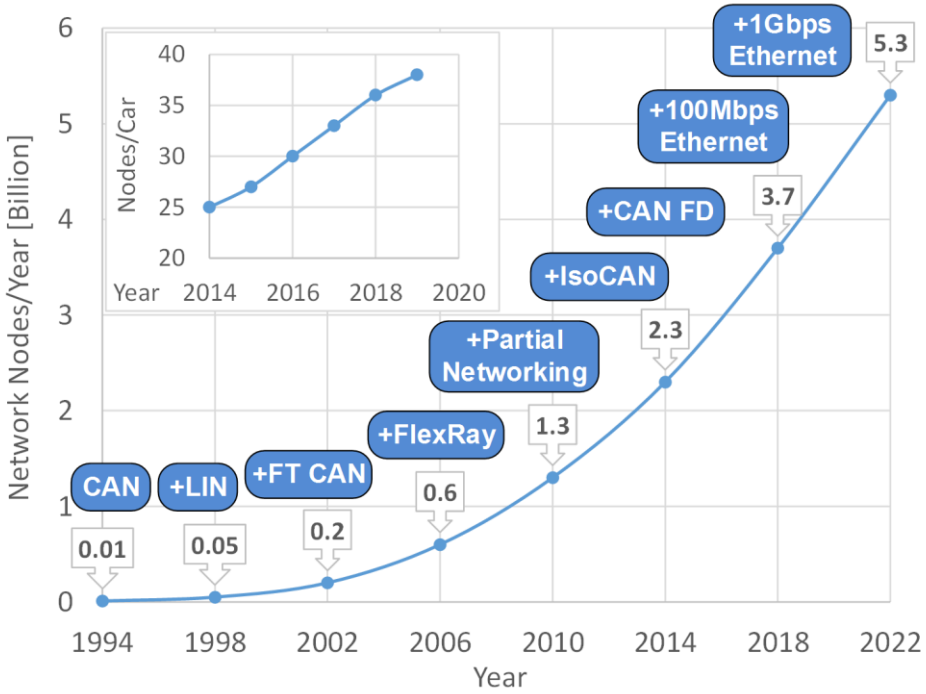
* http://www.all-electronics.de/die-automobilindustrie-im-radikalen-umbruch/

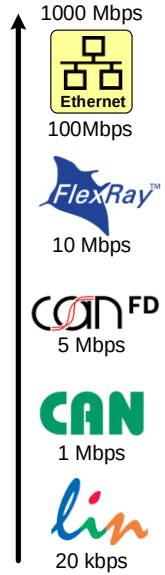
** L. Reger, “The Road Ahead for Securely Connected Cars”, proc. ISSCC2016

Next generation in-vehicle networking

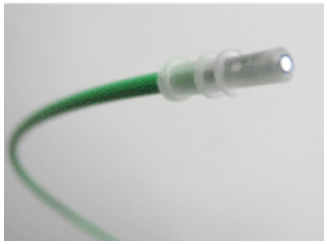
more connections - more bandwidth







Limitations of conventional cabling



	Unshielded Twisted Single Pair	Plastic Optical Fiber	Polymer Microwave Fiber
Data rate	• Limited bandwidth • EMI issue at high data rate ☹	• High bandwidth • No EMI issues ☺	• High bandwidth • Coherent detection possible • No EMI issue ☺
Cost	• Simple cable construction • Simple assembly ☺	• Accurate fiber alignment, clean mechanical interfaces required • CMOS incompatible, III-V required for light generation ☹	• 100% CMOS • Relaxed fiber alignment, easy assembly ☺

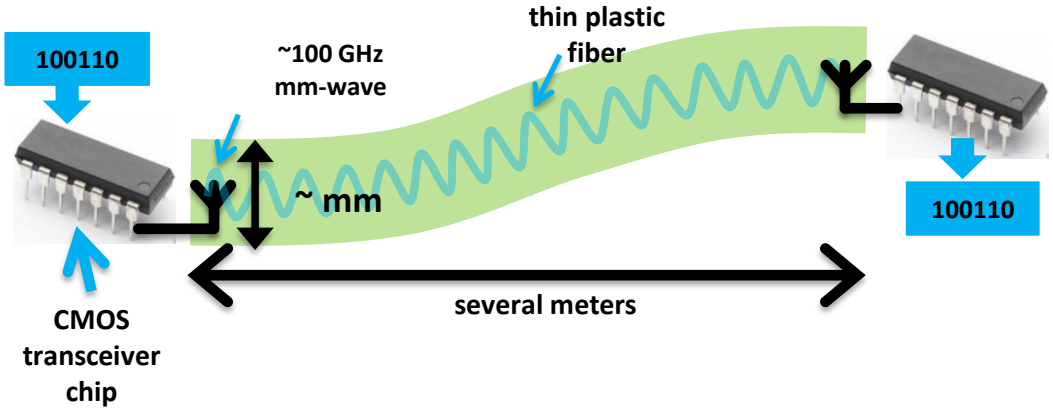
The Big Idea

Three key elements come together:

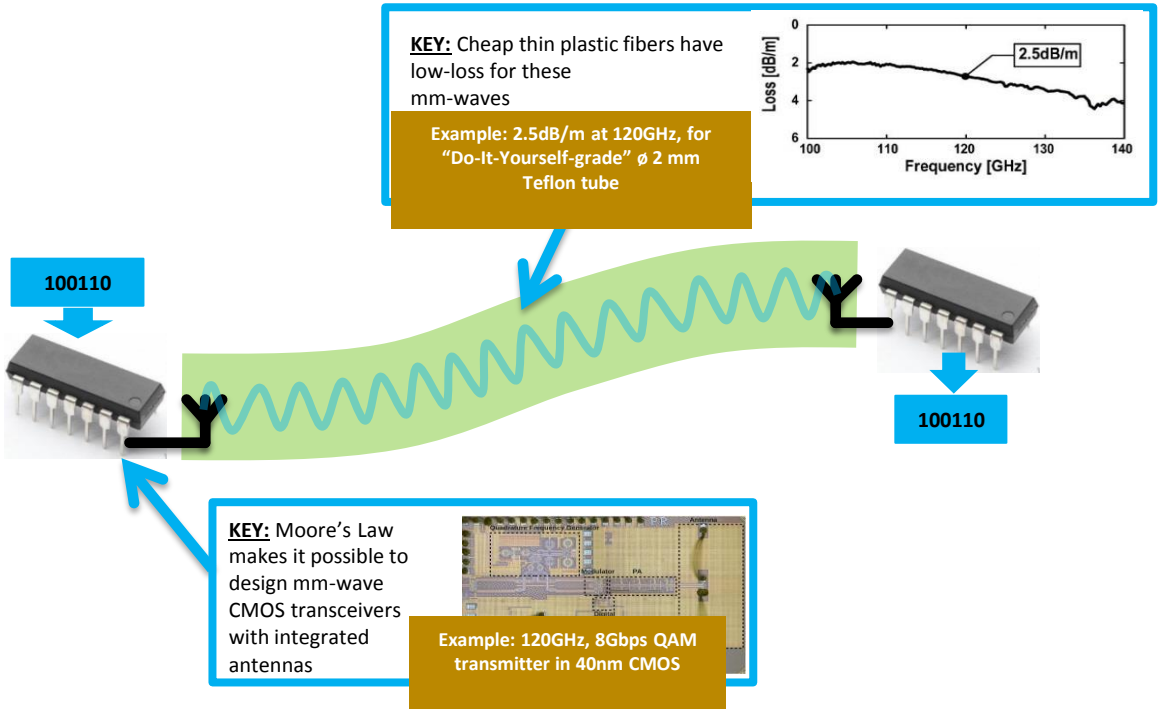
1 - cheap CMOS mm-wave radios

2 - cheap PCB antennas, on-chip antennas

3 - cheap thin plastic fibers



It is possible!



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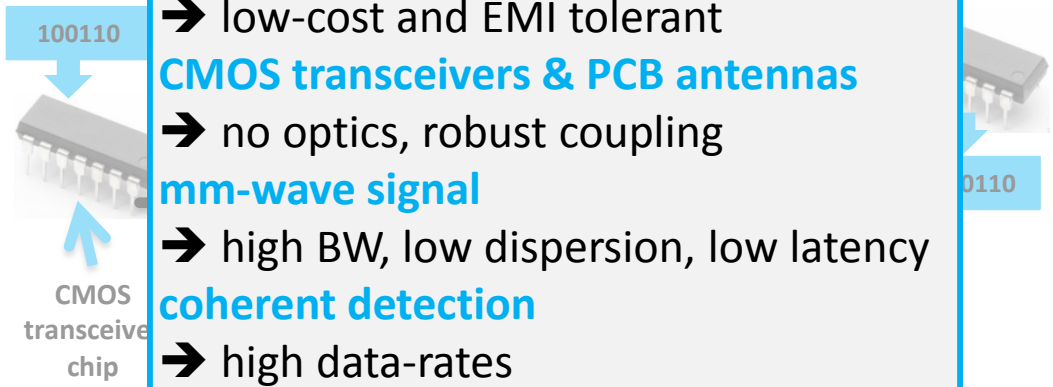
*Prof. Patrick Reynaert (KUL) received the 2014 Bell Labs Prize for this concept
http://www.polymermicrowavefiber.com/

The Big Idea:

Three key elements come together:

1 - cheap CMOS mm-wave radios

2 - small on-chip antennas



Unique benefits:

cheap plastics

➔ low-cost and EMI tolerant

CMOS transceivers & PCB antennas

➔ no optics, robust coupling

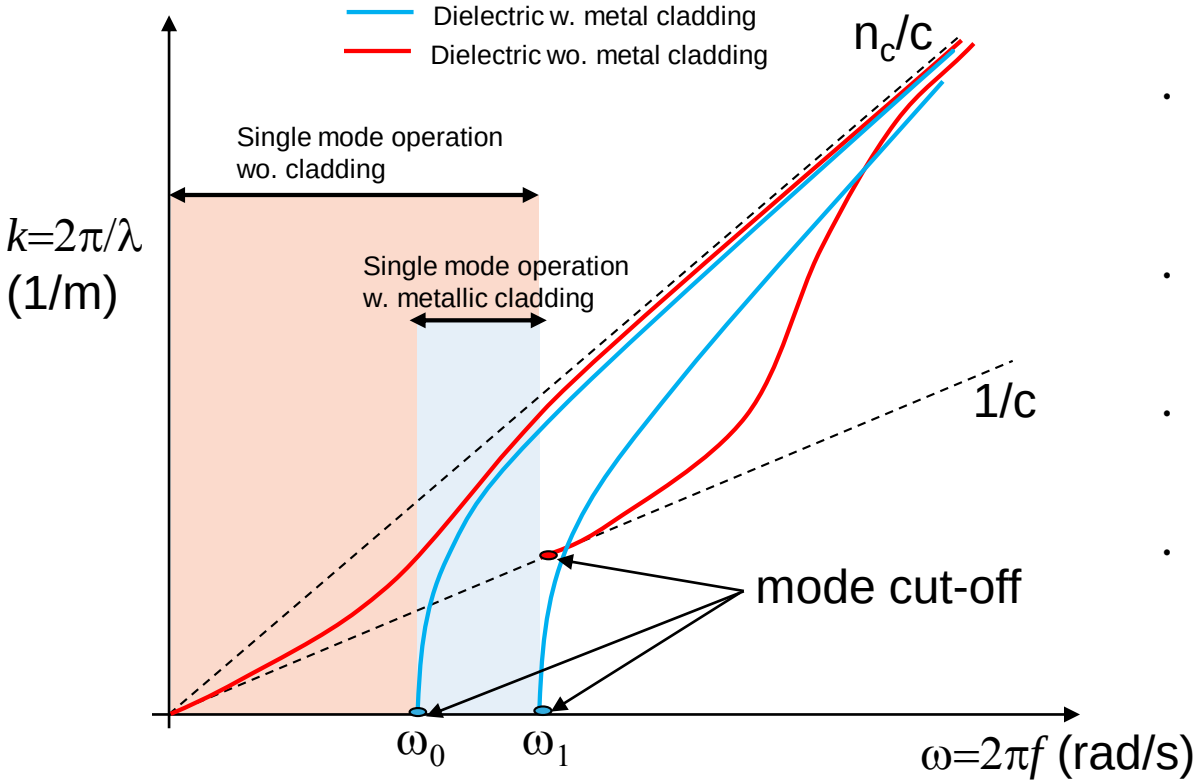
mm-wave signal

➔ high BW, low dispersion, low latency

coherent detection

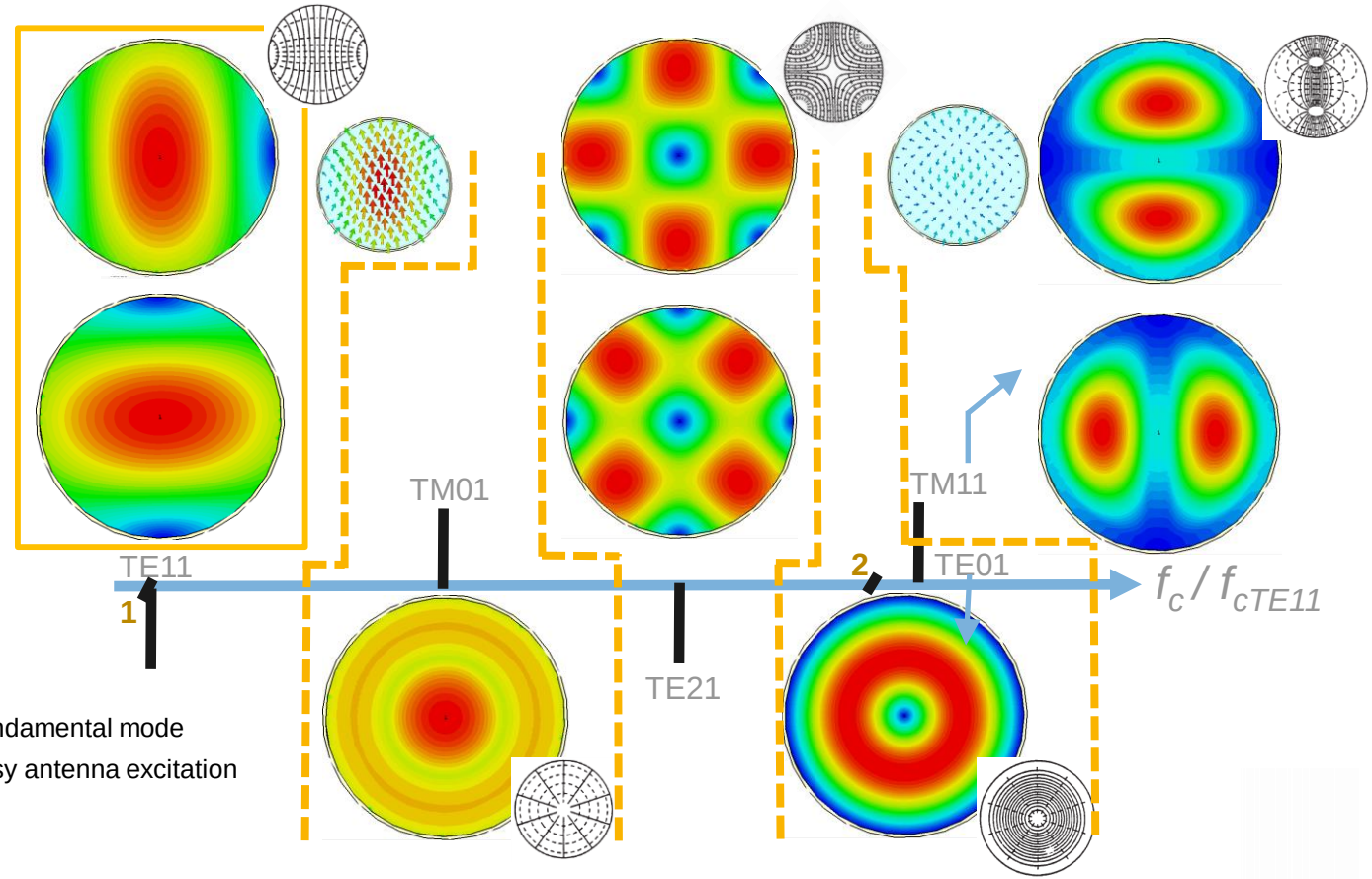
➔ high data-rates

Dispersion and bandwidth considerations



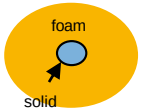
- Fundamental mode in dielectric waveguide has no cut-off, but has large portion of field outside core at low frequencies
- Fundamental mode in metallic waveguide has cut-off. No propagation is possible below cut-off
- Fundamental mode in metallic waveguide has high dispersion near cut-off
- Bandwidth of single mode operation in metallic waveguide is smaller than for dielectric waveguide

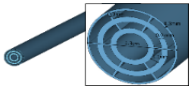
Fiber design - circular waveguide modes

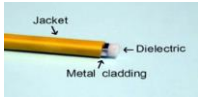


- TE11 mode:
  - Fundamental mode
  - Easy antenna excitation

Attenuation and loss considerations





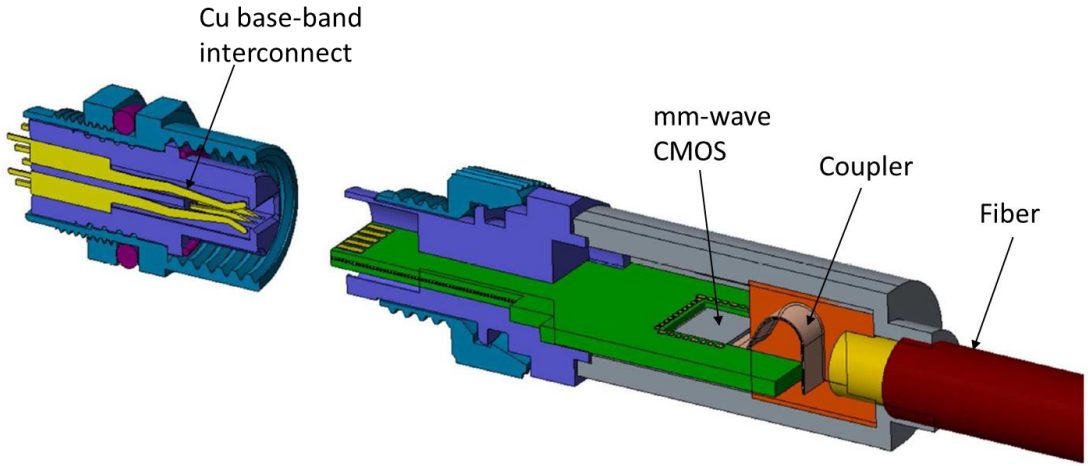


	Hollow core KUL[1]	Solid core KUL	Cladded Solid TE	Hollow Bragg TUD[2]	Cladded Solid KAIST[3]	Hollow metallic waveguide [4]
Frequency	120 GHz	120GHz	60GHz	90-125GHz	55-75GHz	80 / 120GHz
Core	PTFE/Air	PTFE	Doped PP	PTFE/Air	PE Foam	Air
Cladding	Air	Air	PP Foam	Spray coated, poor conductivity metal	Metal foil	Silver
Dimensions	Outer diam. ~2mm Inner diam. ~1mm	Outer diam.~6mm	Outer diam. ~7mm Inner diam. ~2.7mm	Outer Diam.=13mm	4X2mm	3X1.5mm / 2X1mm
Attenuation	2.5 dB/m	4 dB/m	8 dB/m	2 dB/m	4 dB/m	2 / 4 dB/m
Bending loss	1.5dB (R=25mm, 180deg)			1dB (R=40mm)	<2dB (R=4.7mm, 2X90deg.)	NA

	Micro strip line on mm-wave PCB [5]	Co-axial cable	Hollow, silver cladded waveguide	Polymer fiber
Loss (dB/m) @ 80GHz	85	12	2	3

[1] Wouter Volkaerts, Niels Van Thienen, Patrick Reynaert," An FSK Plastic Waveguide Communication Link in 40nm CMOS" ISSCC2015
[2] Maria Alonso, Nuria Llombart and Marco Spirito, TUD, WiCon internal communication, Simulation results
[3] Ha Il Song, Huxian Jin & Hyeon-Min Bae "Plastic straw: future of high-speed signaling" Nature Scientific Reports | 5:16062 | DOI: 10.1038/srep16062, 2015
[4] Shimabukuro et. al. IEEE Trans. Microwave Theory & Technol., V.36, 1988, pp.1160-1166
[5] As measured for 5mil RO3003, 17.5um copper with immersion silver finish.

Product concept (example)

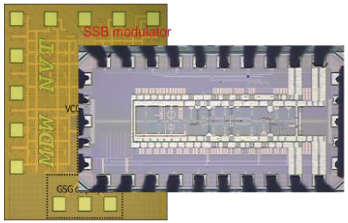


WICON project description

Application domains:
- In-Vehicle Networks
- Industry 4.0

Duration: 2015-2018
Size: 45PY in total

mm-wave CMOS



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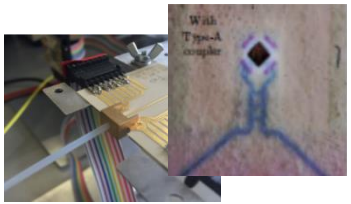
Fiber interface



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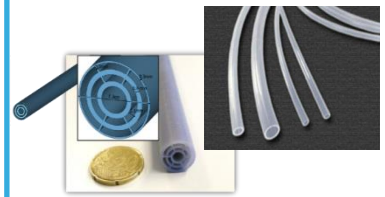
TE connectivity

NXP

Fiber



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TE connectivity

TU Delft

WICON demonstrators

	Link distance	Data rate
80 GHz demo	>8m*	1Gbps 1000base-T (2Gbps max.)
140 GHz demo* **	4m** (2m*)	10Gbps** (20Gbps*)

*full-duplex
**simplex

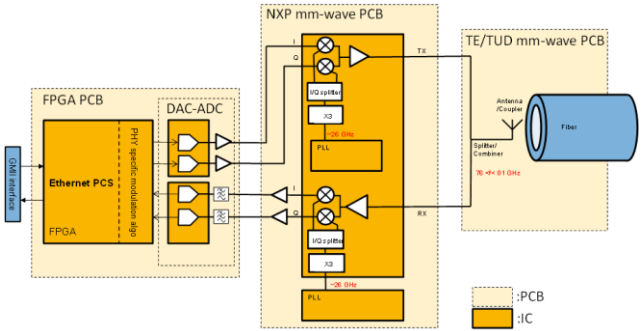
Parameter to be varied	80 GHz demo	140 GHz demo***
High/low frequency	80 GHz	140 GHz
Metal/dielectric cladded fiber	Metal cladding	Foam cladding
Linear/circular polarization	TE11 Circular (TE01***)	HE11 Linear
Full Duplex	Polarization + Frequency diversity	Polarization diversity only

***Not covered in this presentation

WICON demonstrators

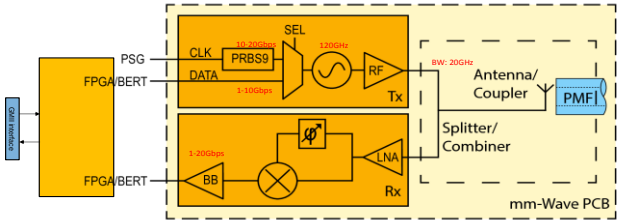
80 GHz demo

- Transceiver in 40nm CMOS by NXP
- Targets medium data rate over long distance (> 1Gbps, >8m)
- Supports 1000Base-T1 Automotive Ethernet



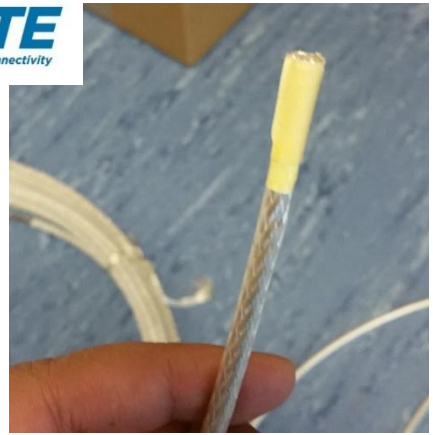
140 GHz demo*

- Transceiver in 28nm CMOS by KULeuven
- Targeted for high data rate over medium distance (>10Gbps, 2m)



*Not covered in this presentation

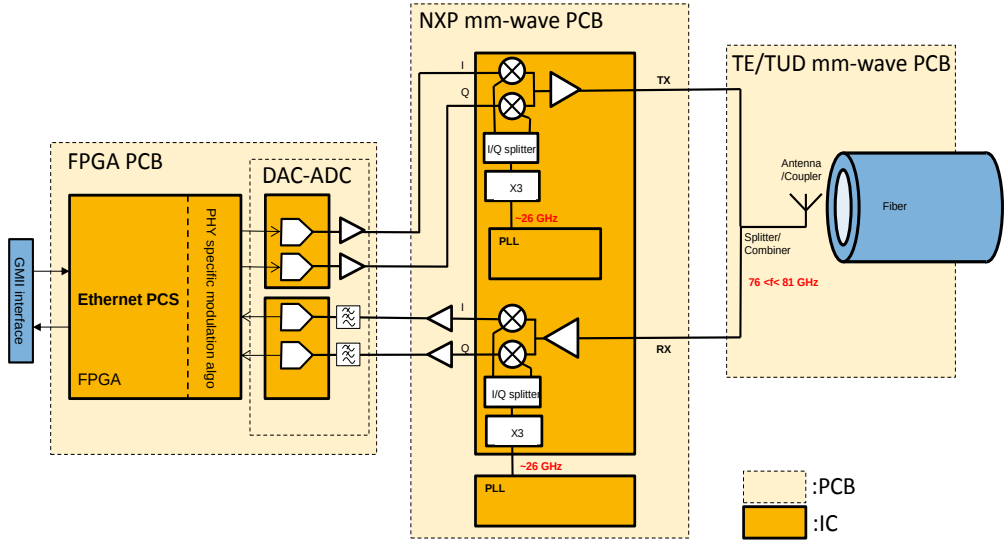
WICON fibers

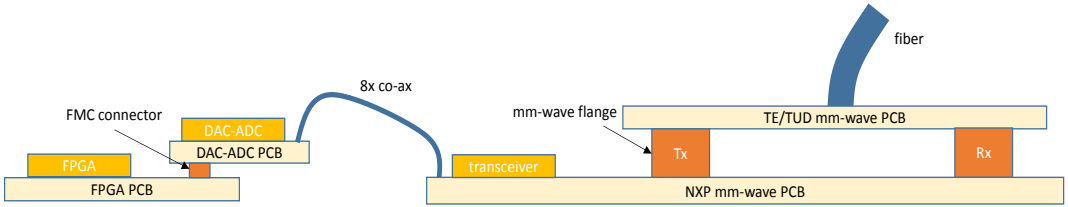


80GHz demo
LDPE core, 3.8 mm diamm.
Cu/Ag cladding
3.3dB/m loss

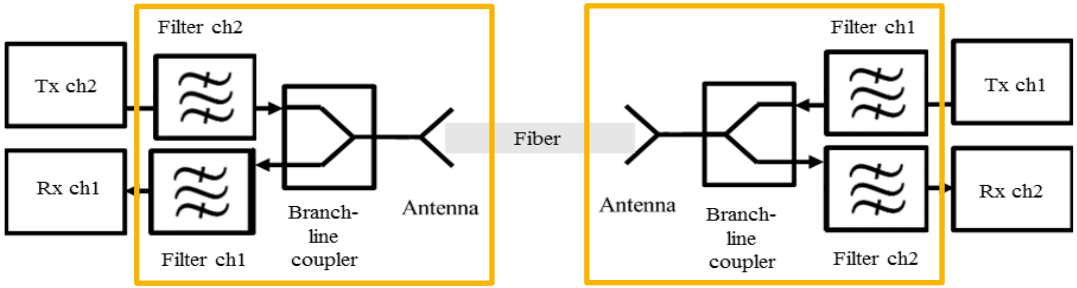
140GHz demo
PTFE core, 2 mm diamm.
PTFE foam cladding, 6 mm diamm.
5-6dB/m loss

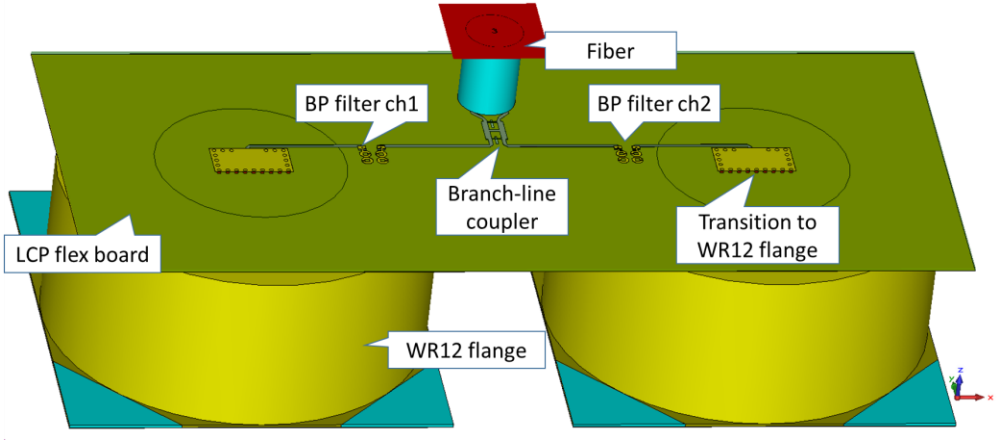
80GHz demo hardware build-up





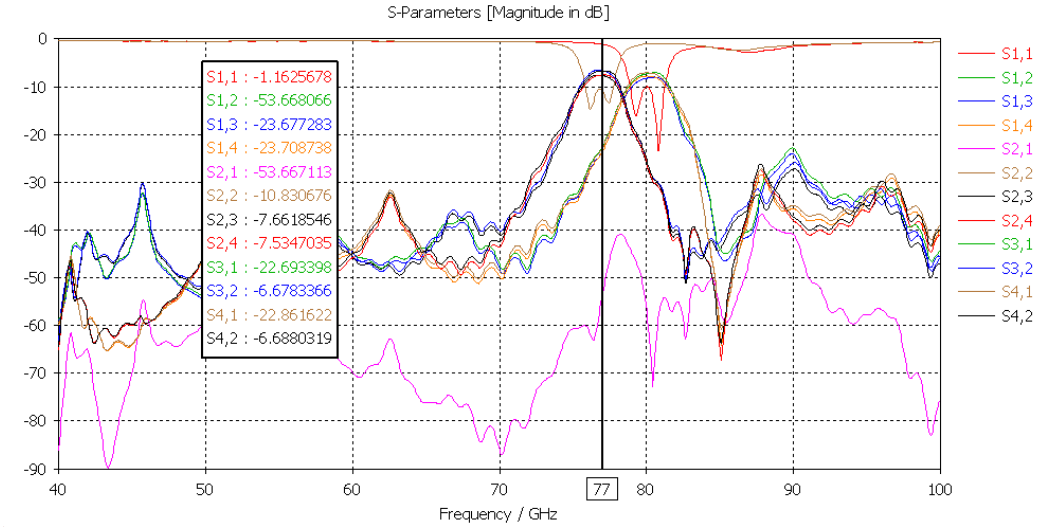
80 GHz duplexer



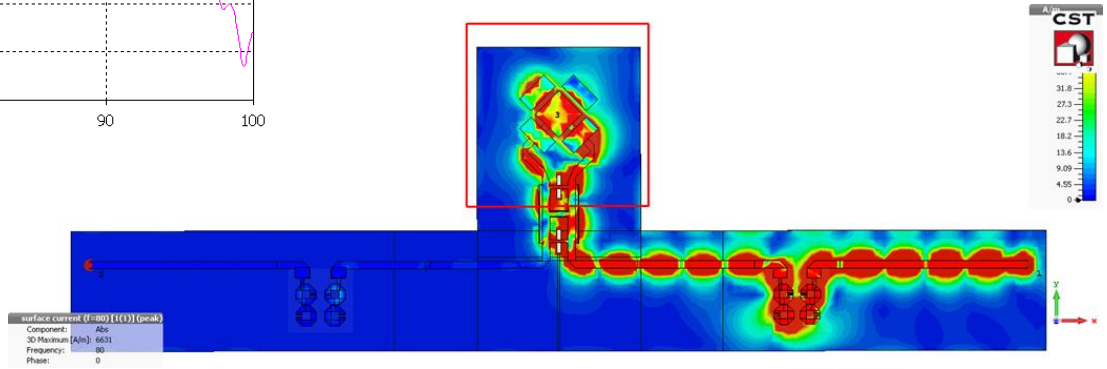


Channel 1	76-78GHz
Channel 2	79-81GHz

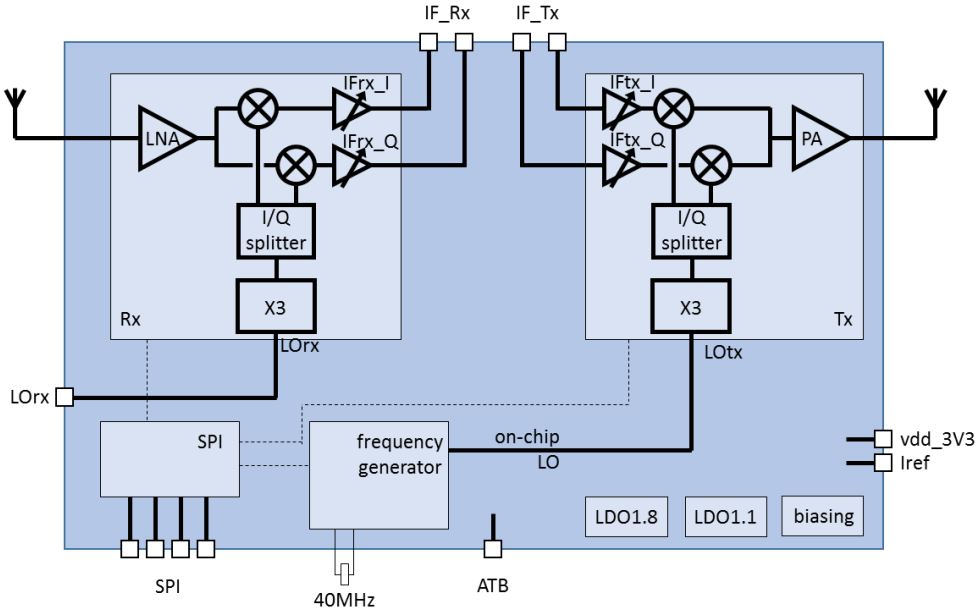
80 GHz duplexer

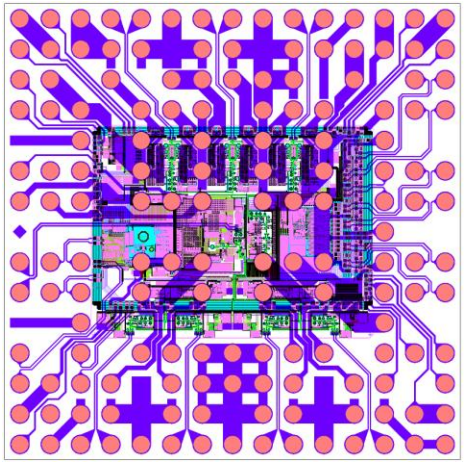


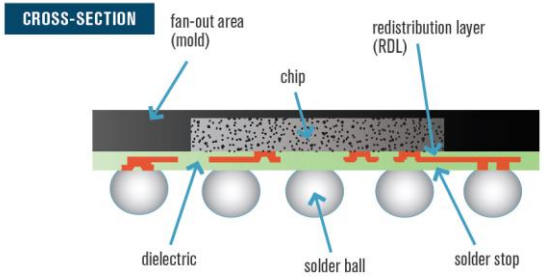
Antenna-system loss	7dB
Isolation	>40dB



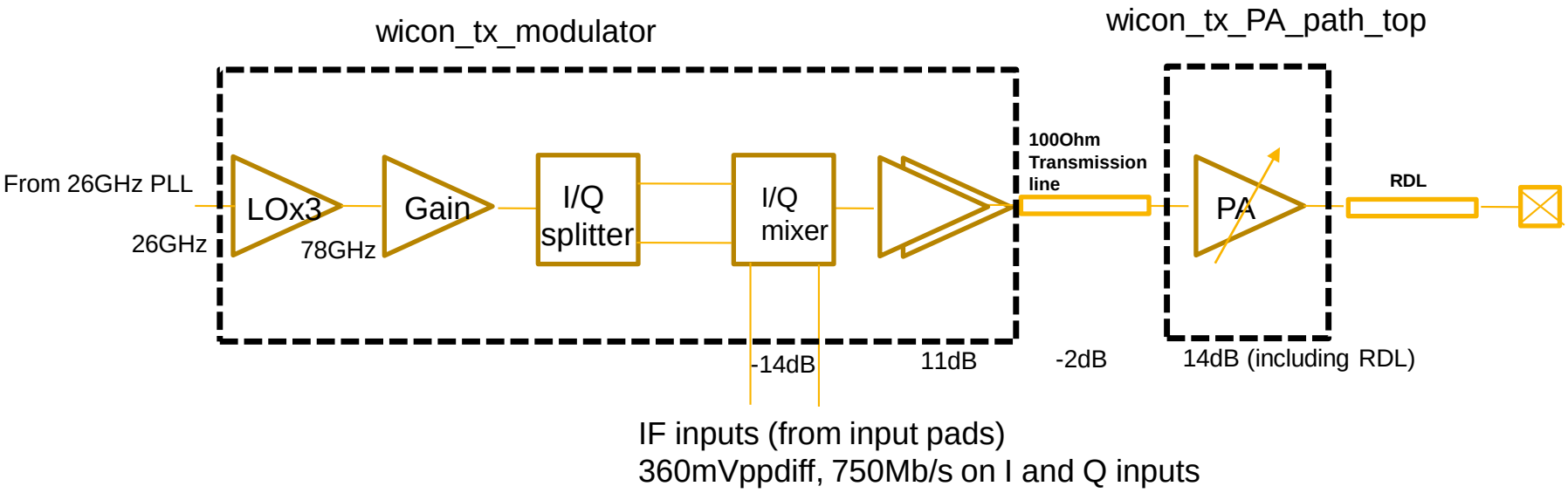
80GHz Transceiver



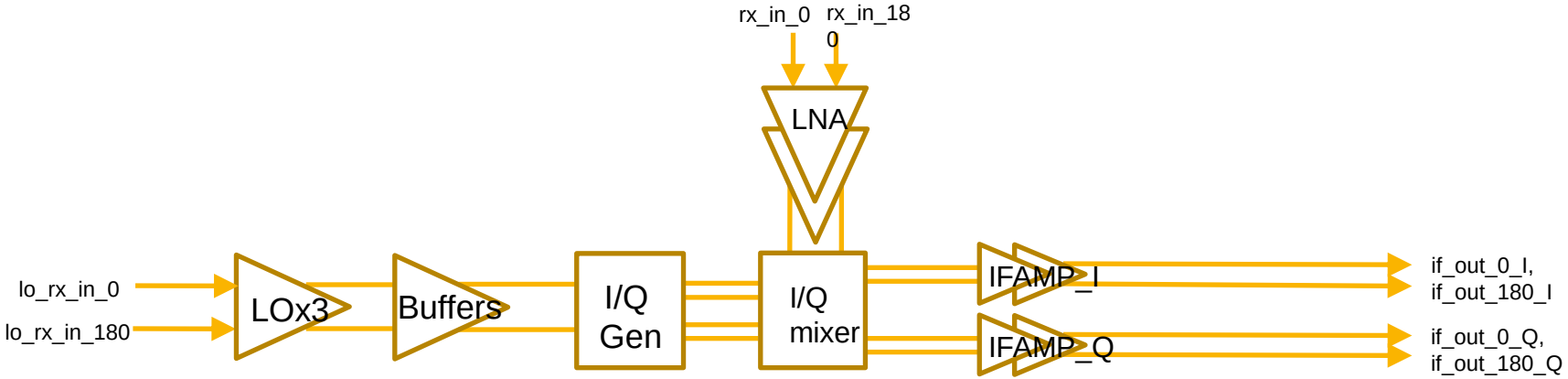




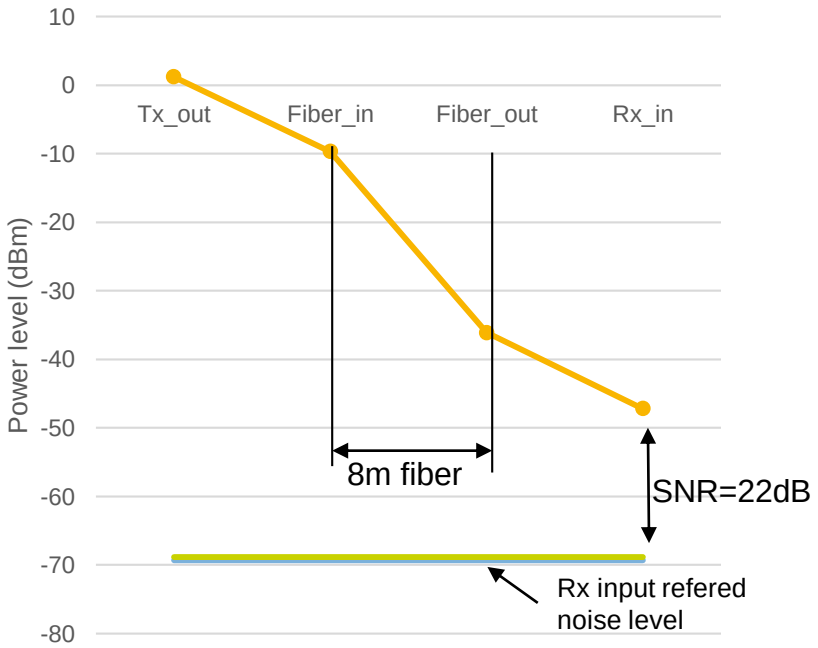
Block diagram Tx



Block diagram Rx



Link budget analysis for 1Gbps full-duplex



Signal strength requirements		
SNR achieved	22	dB
Eb/N0 achieved	21.5	dB
Eb/N0 required (QPSK, BER 1e-12)	14	dB
Link Margin	+7.5	dB

Bandwidth requirements		
Target Data Rate	1.0	Gbps
Baud Rate excl. encoding (QPSK)	0.50	GBd
Baud Rate incl. encoding (RS + 6b/8b)	0.75	GBd
Raised-Cosine filter roll-off	0.5	
Required IF Signal Bandwidth*2	1.1	GHz
Available IF Signal Bandwidth*2	2.4	GHz
Excess bandwidth	+1.3	GHz

Conclusion

- Future applications for In-Vehicle Networks will require ultra-high data-rates
- Polymer microwave fibers potentialy supports high data rates at low BoM
- Within Wicon, demonstrators are developed at 80GHz and 140GHz
- 80GHz demo buidling blocks have been designed/built
  - Metal cladded fiber
  - Fiber coupler incl. patch antenna, branche-line coupler, and duplex filter
  - mm-wave IQ transceiver
  - 1000Base-T1 Automotive Ethernet PCS on FPGA
- 80GHz demo will be capable of supporting >1Gbps full-duplex over link distance of >8m

Acknowledgements

- NXP
  - Cristine Badiao
  - Salem Eid
  - Kostas Doris
  - Marcello Ganzerli
  - Yuan Gao
  - Romeo Ghinea
  - Jake Lee
  - Pieter Lok
  - Chuang Lu
  - Jan Niehof
  - Mani Panchapakesan
  - Nader Rohani
- NXP
  - Antony Joseph
  - Christophe Mertens
  - Bart Willemsen
- TE
  - Mohadig Rousstia
  - Saoer Sinaga
- KUL
  - Maxime De Wit
  - Patrick Reynaert
- TUD
  - Marco Spirito

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