Progress in Wireless Data Transmission for Detector Readout

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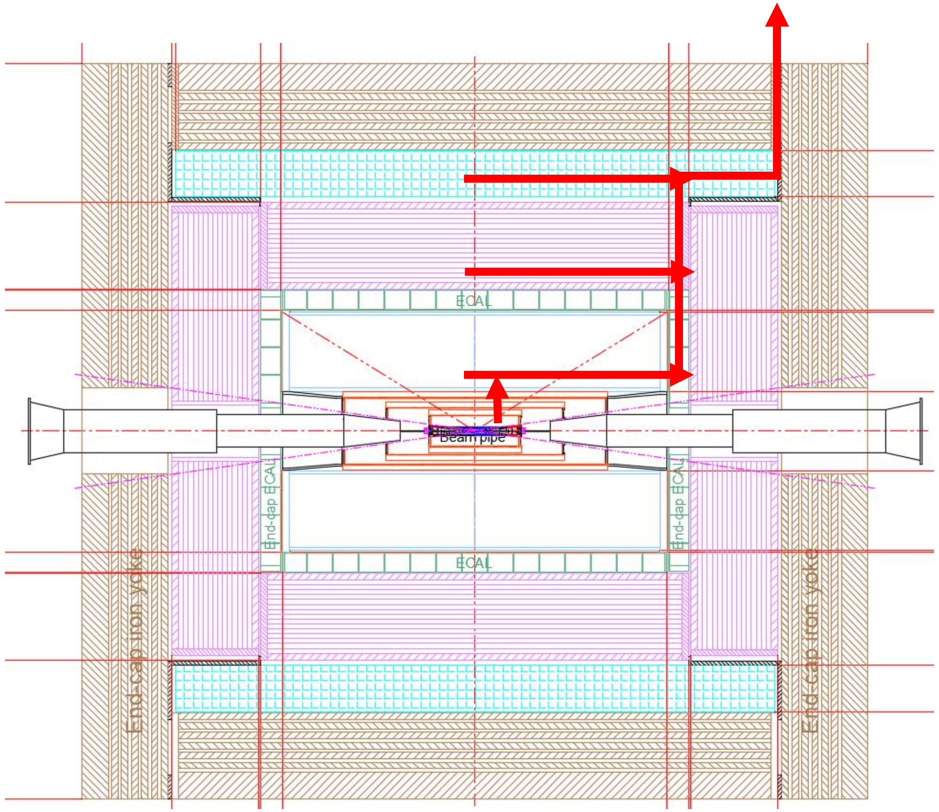
Outline

- Background
- Status of Technology Feasibility Studies
- Conclusion

Background

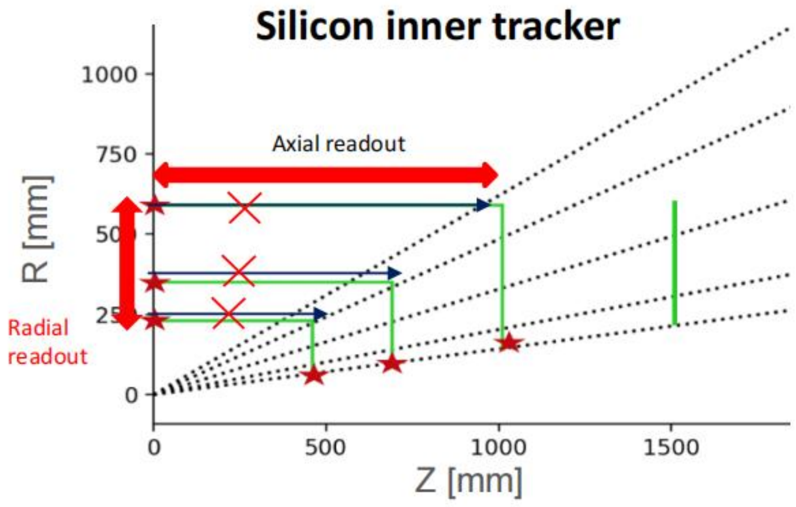
- Wireless transmission advantages include:
  - **Reducing material budget**: Minimize cables, fibers and connectors, while also reducing the dead zone.
    -> Significantly enhance the detection efficiency and resolution!!!
  - **Convenience for installation and maintenance:** Simplify the placement of the transceiver.
  - **Cost Reduction**: Removal of cables, fibers and connectors.

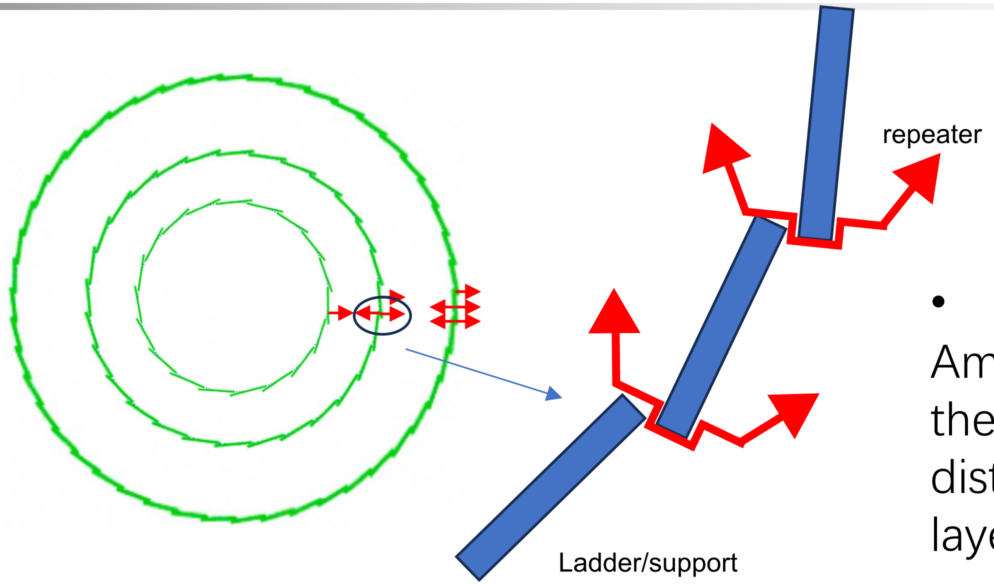
- Application ideas for CEPC detector
  - **Radial data readout between barrel layers:** Provides a new data exchange pathway compared to traditional data readout methods.
  - **Axial data readout from barrel to endcap**: Serve as an alternative to optical fibers, minimizing space and material usage.
  - **Data readout in the endcap:** Concentrates the data at the edge of endcap to simpify the complexities of cables routing



CEPC Detector Geometry

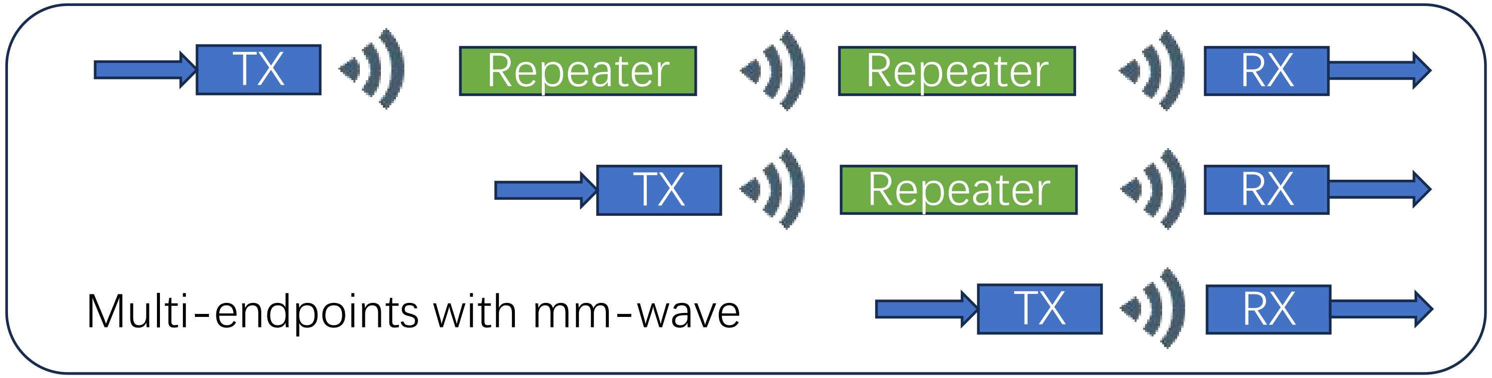
Radial data readout



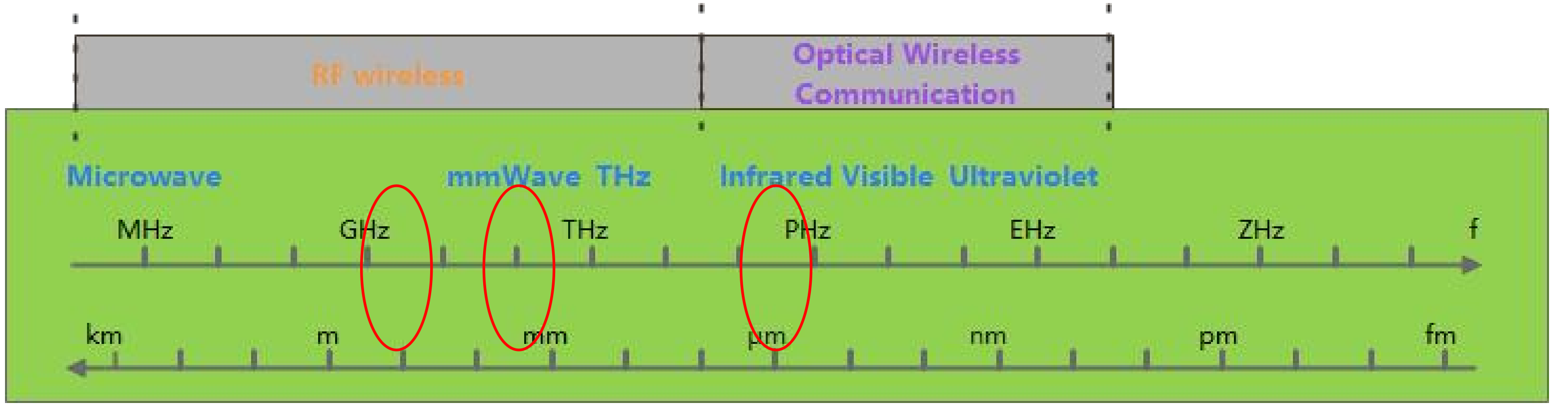


- **Repeater**: Amplify and re-transmit the RF signals over long distances or through layers.

- Radial readout between inner layers
  - 12- 24 cm transmission distance
- Axial readout to endcap / outside
  - Only at the outermost layer or dedicated aggregation layer.



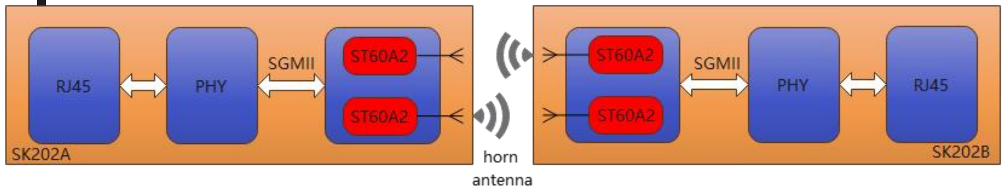
Wireless Technology

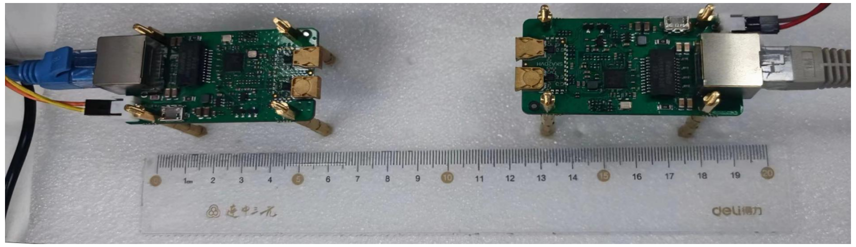


Electromagnetic Spectrum

- **WiFi** (2.4GHz, 5GHz)
  - large antenna volume, high power consumption, narrow frequency band, and high interference
- **Millimeter Wave** (24GHz, 45GHz, 60GHz, 77GHz)
  - Huge bandwidth with lower power, Small antenna size,High density possible
- **Optical wireless communication** (OWC) / **Free Space Optical** (FSO)
  - Focusing on extremely distance transmission, application in accelerator synchronization systems

MM-wave commercial module





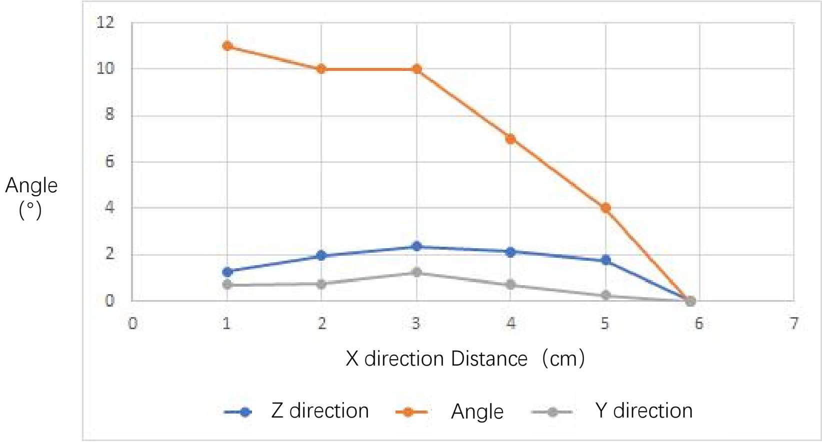
Distance (cm)	Bandwidth (Mbps)	Packet loss rate
1	914	0.031%
3	917	0.061%
5	915	0.05%
6	913	0.13%
>6	No link	No link

Test result at different distances of TX/RX

Material	Thickness	Penetration Ability
Paper	2mm	√
Plastic ruler	2mm	√
FR4 PCB	1.6mm	×
Flex	0.2mm	×

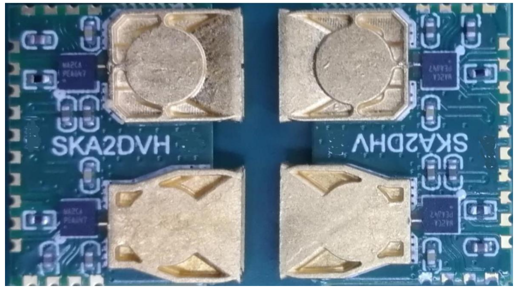
Penetration Test with 3 cm distance

- Test with evaluation boards – SK202
  - Based on the commercial 60GHz RF chip, **ST60A2G0** transceiver from STMicroelectronics.
  - The transmission speed can exceed 900Mbps when the distance is less than **6 cm**.
  - The 60GHz mm-wave signals can easy penetrate materials such as paper, plastic; but **cannot** pass through FR4 PCBs or Flex cables due to the copper's shielding.
  - Compared to optical communication, mm-wave requires less precise alignment.
  - Power comsuption: Approximately **0.5W** (TX+RX)



Alignment test

Improvement



Available modules with ST chips

- Disadvatages:
  - Current **data rate** is 1Gb/s, which is not enough for our requirements.
  - Horn **antenna** offers good performance but come with high matieral and large form factor.
  - The **transmission distance** is limited to only 6 cm, which may not be enough for many applications,
- We need a new solution!!!

- We attempted to find other On-off keying(OOK) modulation transceiver with higher transmission power.
  - The available commercial modulation chips on the market are almost use coherent modulation schemes, which perform well,but has high power consumption and are complex to use.
  - Currently, the cost of custom chips is quite high, and we have not found a willing partner to assist us with the chip design.

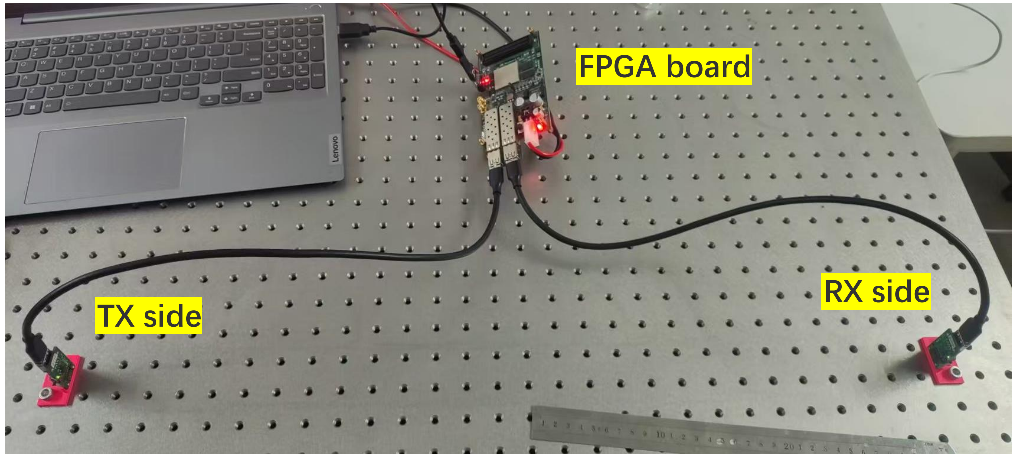
- We have adopted an alternative solution, which is adding a Low Noise Amplifier after TX to increase the transmission distance.

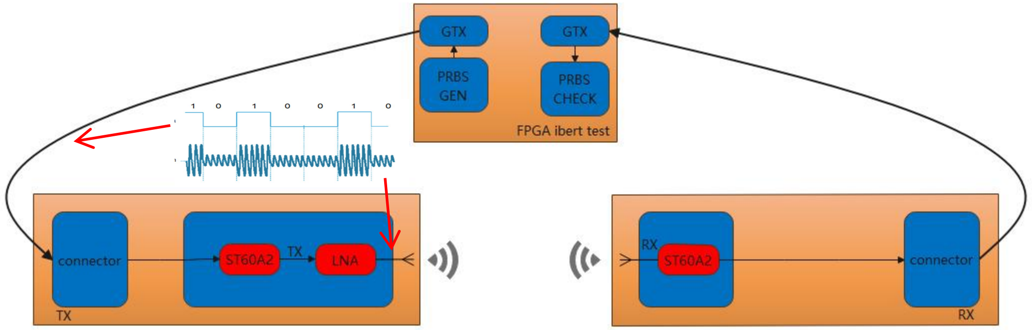
SK60A2 + LNA + patch Antenna

alternative solution

New module

- Integrate with commercially components
- PCB patch antenna
- Size :1.3cm X 0.95cm



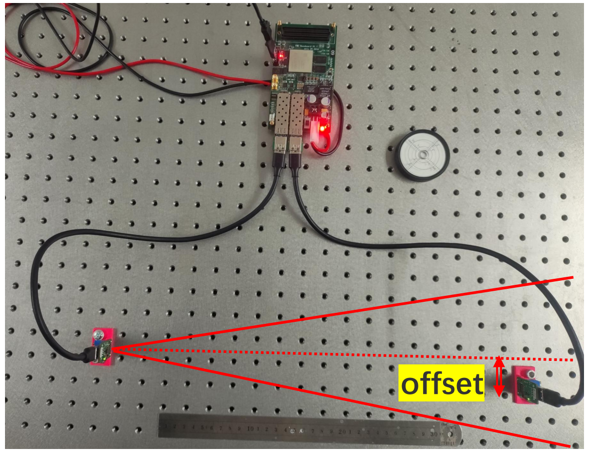


Test setup

- The new module's data interface directly use the high-speed serial transmission
  - Be compatible with Xilinx's GTP Transceiver
  - A Kintex 7 FPGA board is used to perform the IBERT PRBS testing to verify the communication.

Transmission performance

- The maximum stable transmission distance is 67.5 cm at 1.25 Gbps.
- The maximum line rate can reach up to 6.6 Gbps at 22.5 cm distance.
- The antenna is optimized around 5 Gbps, aiming to transmit as far as possible, with an alignment accuracy of ±2.5 cm at 45 cm distance.



Alignment test

Name	TX	RX	Status	Bits	Errors	BER	BERT Reset	TX Pattern	RX Pattern
Ungrouped Links (0)									
Link Group 0 (1)							Reset	PRBS 7-bit	PRBS 7-bit
Link 0	Quad_115/MGT_X0Y0/TX (xc7k325t_0)	Quad_115/MGT_X0Y0/RX (xc7k325t_0)	5.000 Gbps	1.017E12	0E0	9.832E-13	Reset	PRBS 7-bit	PRBS 7-bit

1X10^-12 BER @ 5 Gbps

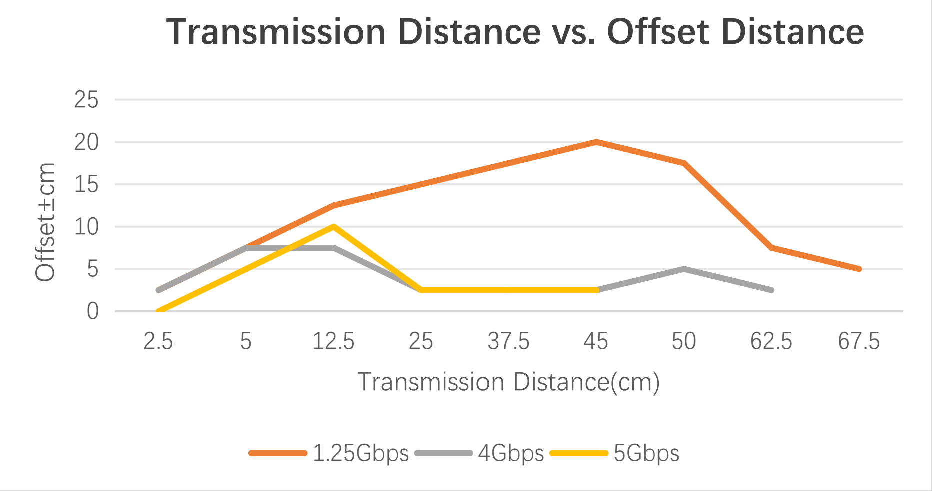
Name	TX	RX	Status	Bits	Errors	BER	BERT Reset	TX Pattern	RX Pattern
Ungrouped Links (0)									
Link Group 0 (1)							Reset	PRBS 7-bit	PRBS 7-bit
Link 0	Quad_115/MGT_X0Y0/TX (xc7k325t_0)	Quad_115/MGT_X0Y0/RX (xc7k325t_0)	6.600 Gbps	1.014E12	0E0	9.861E-13	Reset	PRBS 7-bit	PRBS 7-bit

1X10^-12 BER @ 6.6 Gbps

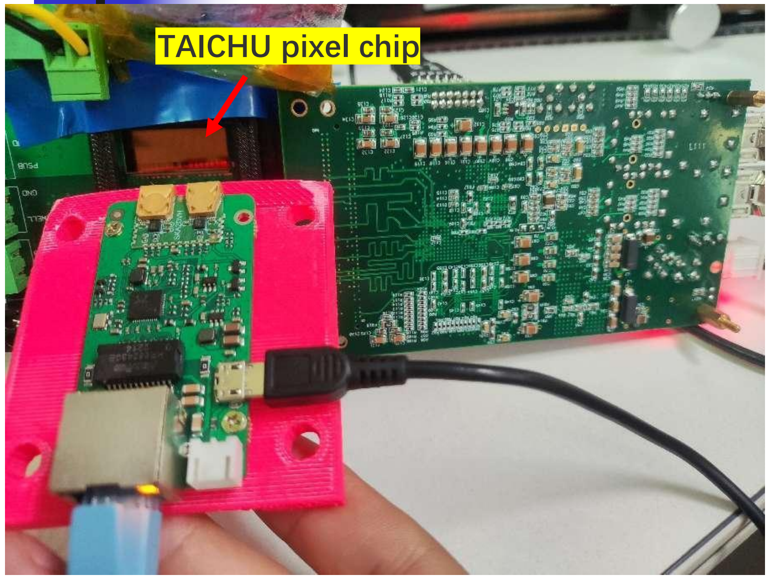
IBERT results

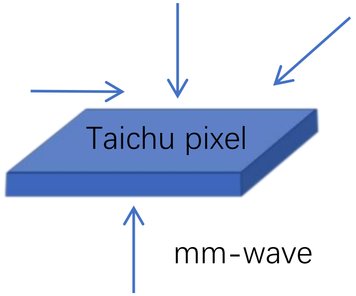
Line rate (Gbps)	Stable distance (cm)	Connection distance (cm)
1.25	**67.5**	80
4	50	70
5	45	60
6.6	22.5	37.5

The maximum transmission distance under different line rate

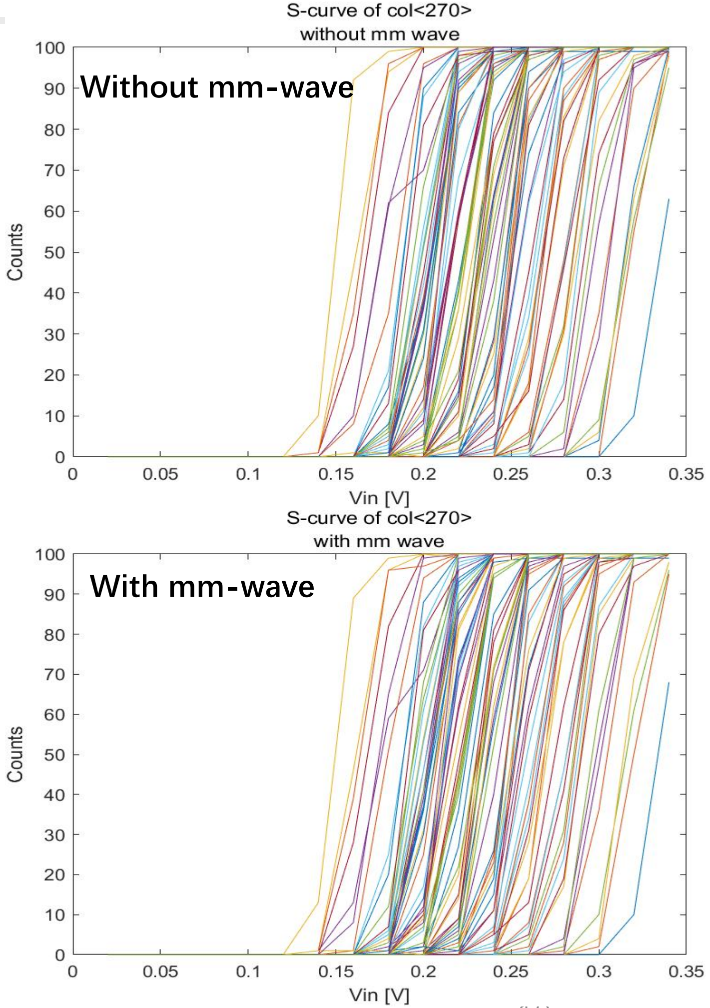


Crosstalk with pixel chip



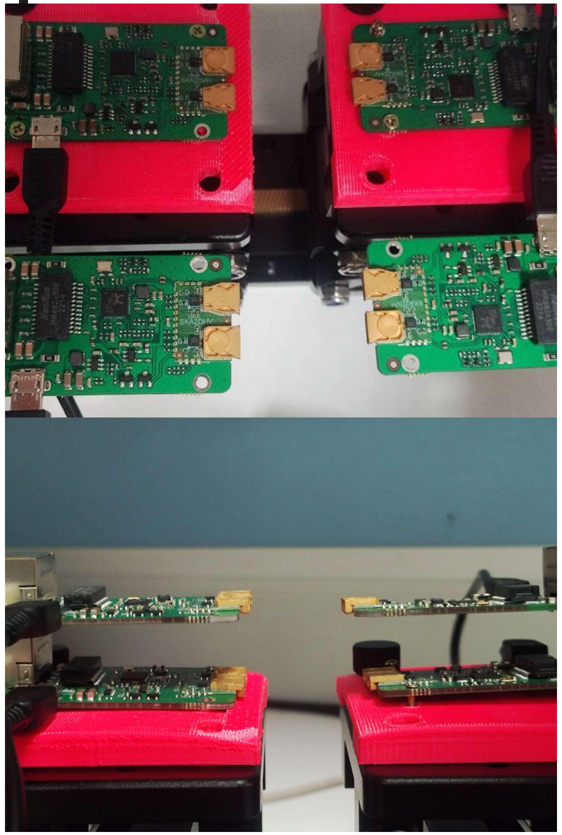


- Preliminary test using the Vertex pixel prototype chip TAICHU3, including
  - With both low power and high power modules
  - From various directions and distances
  - Evaluate the S-curve to determine the impact on the chips
- The results indicate that it is difficlut to identify the effects of 60 GHz millimeter waves on the pixel chip.
- More detailed testing are needed to analyze the impact.



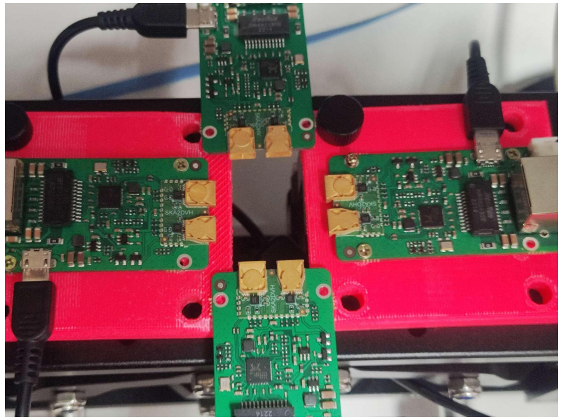
S-curve of 1 collum results

Crosstalk with each other



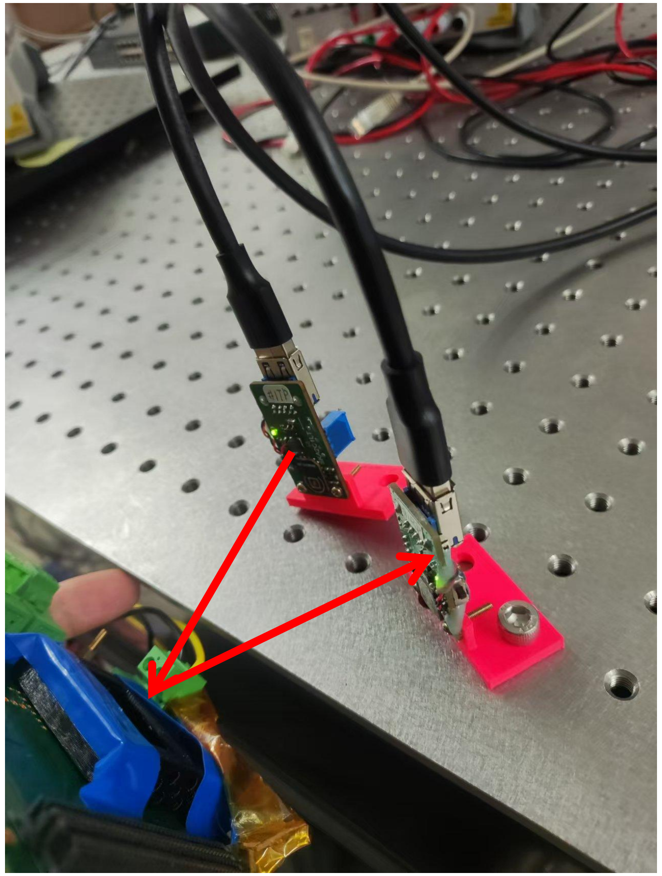
Parallel placement allows for a density of 3 cm

- We have only one set of the new module, so we will first use two sets of low-power modules to test the interference.
- The reuslt shows if placed in parallel, whether vertically or horizontally, a distance of **3 cm** does not affect transmission, allowing for a high density of placement
- However, if placed in a crossed configuration, transmission is not possible.



No link under cross placement

Reflection



- With high-power modules, We found the reflected RF signals can still be recognized and establish communication.
- This means we need to consider how to prevent these reflected signals from being incorrectly received by other modules on the detector.
  - Design shielding structures.
  - Design antennas to tune directions.
  - Find low materials with high absorption.

MM-wave development plan

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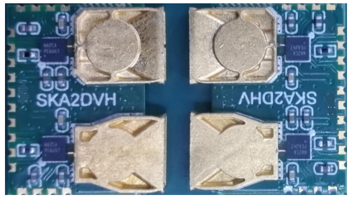

- **Step 0**: Full commercial module
- Basic performance test

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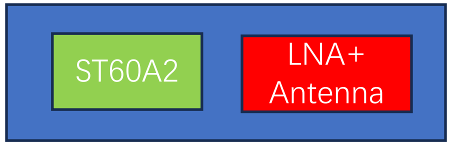

- **Step 1**: Design a small PCB module with ST60A2. LNA and custom antenna.
- Higher bandwidth test
- Evaluate the interference with detector and each other

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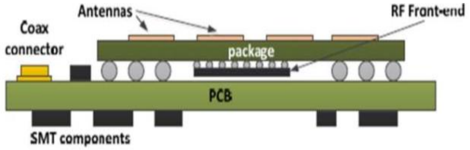
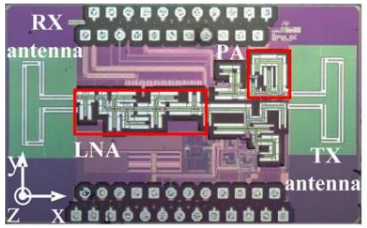


Step 2: Integrate the Antenna and available mm wave RF chips (45G/60G/77G) into the package (AIP)

- mature technological
- Radiation hard test

in the future



Step 3: Custom radiation RF front-end + custom Antenna On one Chip (AOC)

- Final solution of minimum material budget.
- The most challenging, significant R&D costs

Conclusion

- A new millimeter wave module has been designed, featuring a smaller size, higher speed, and extended transmission distance to meet our requirements. Related testing is still ongoing.
- Based on this module, we plan to further miniaturize the AIP chip and begin the repeater design, finally intergrate a demostrator with a detector.
- Additionally, we have been listed as observer of DRD7.1.c (advanced high density data transmission), which may provide us with access to some new technologies and innovative ideas.

Thank you

BACKUP