A Challenge to Real-time Compensation for QAM Signal Distortion using Optical SVM Classifiers

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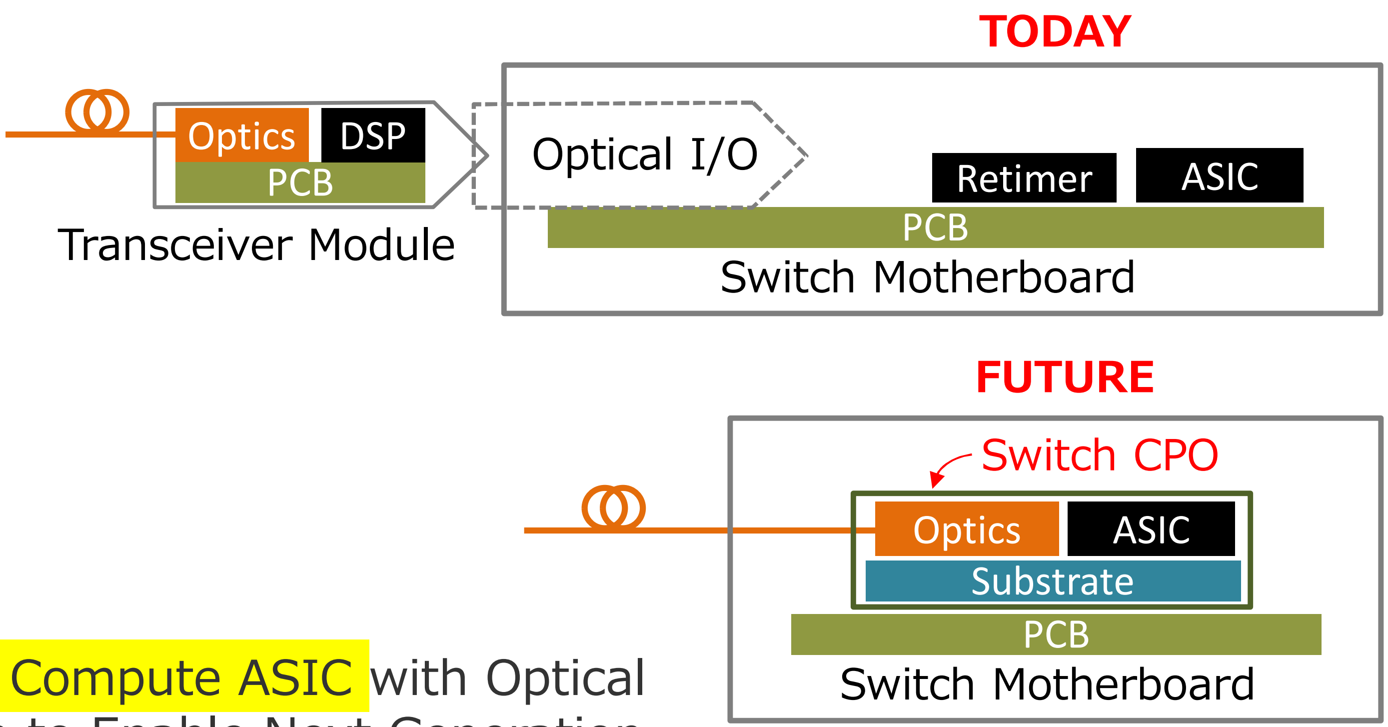
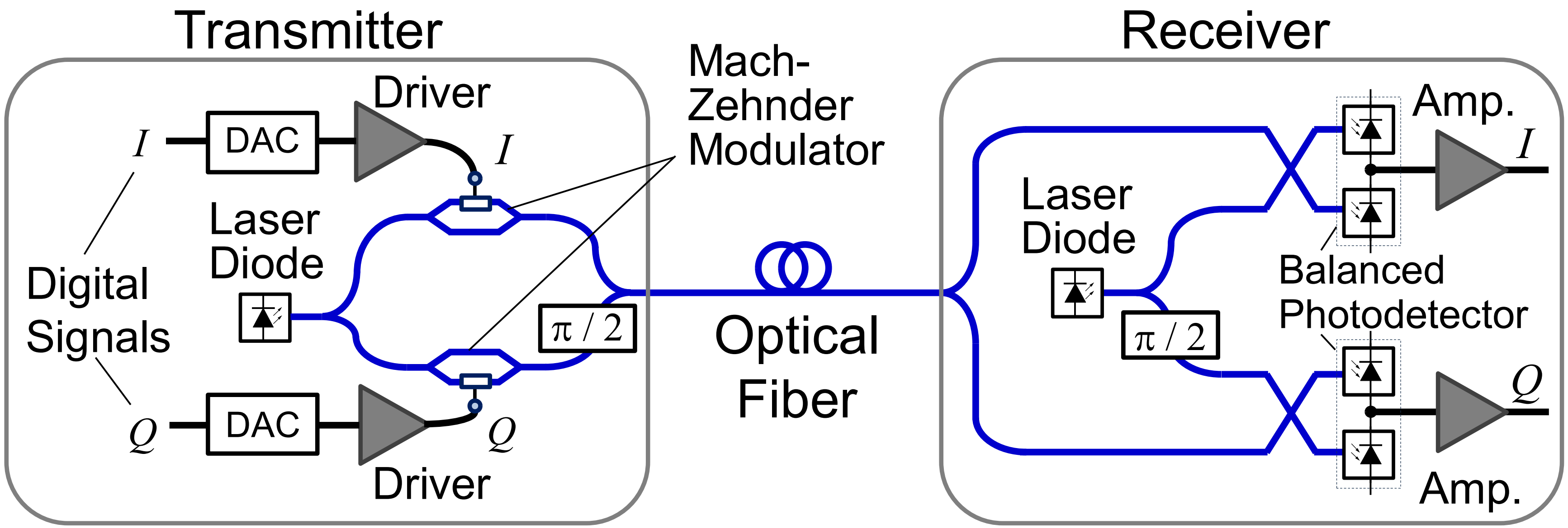
AI Compute ASIC in Communication

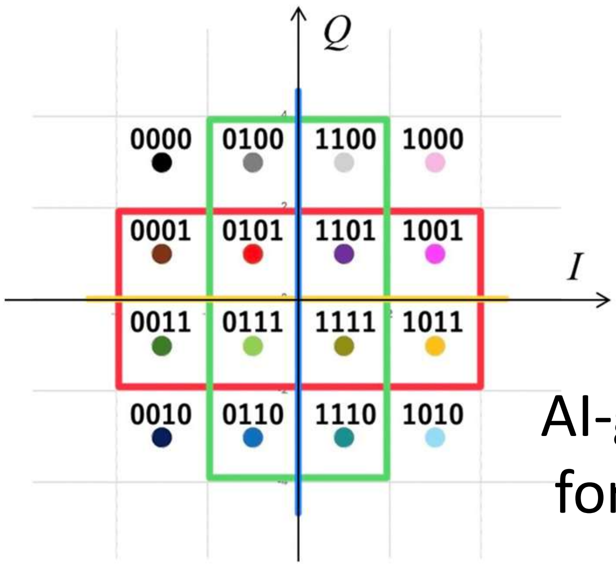
- Today's most AI ASIC targets image classification
- Broadcom shows AI ASIC for communication



"An AI Compute ASIC with Optical Attach to Enable Next Generation Scale-up Architectures," HOTCHIPS 2024.

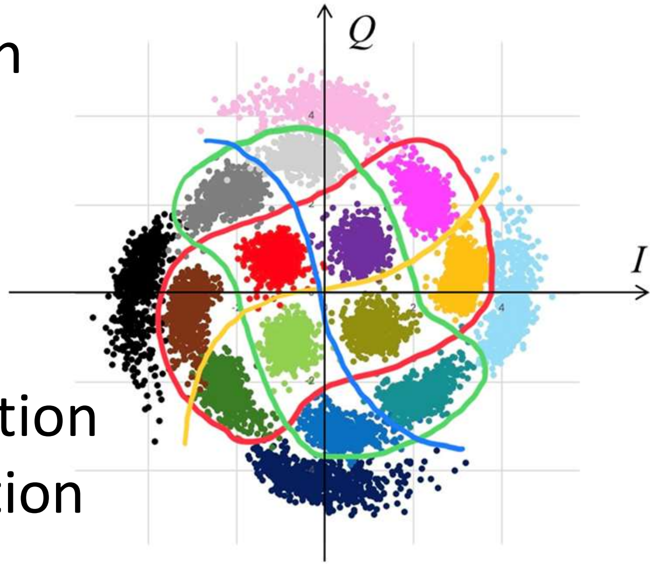
What is AI ASIC in Communication





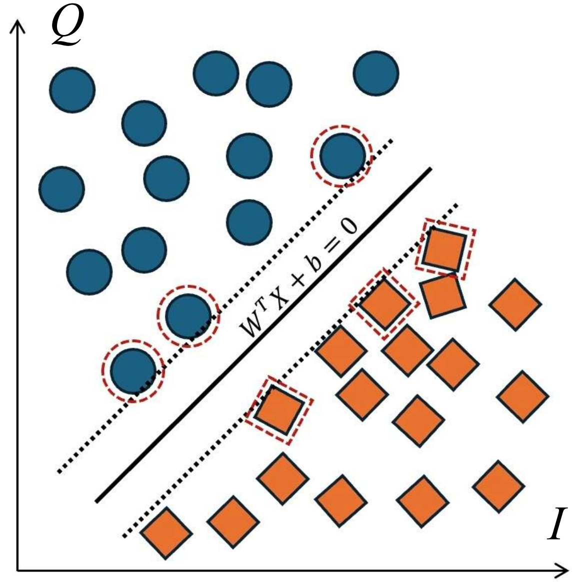
Signal distortion in
16-QAM format

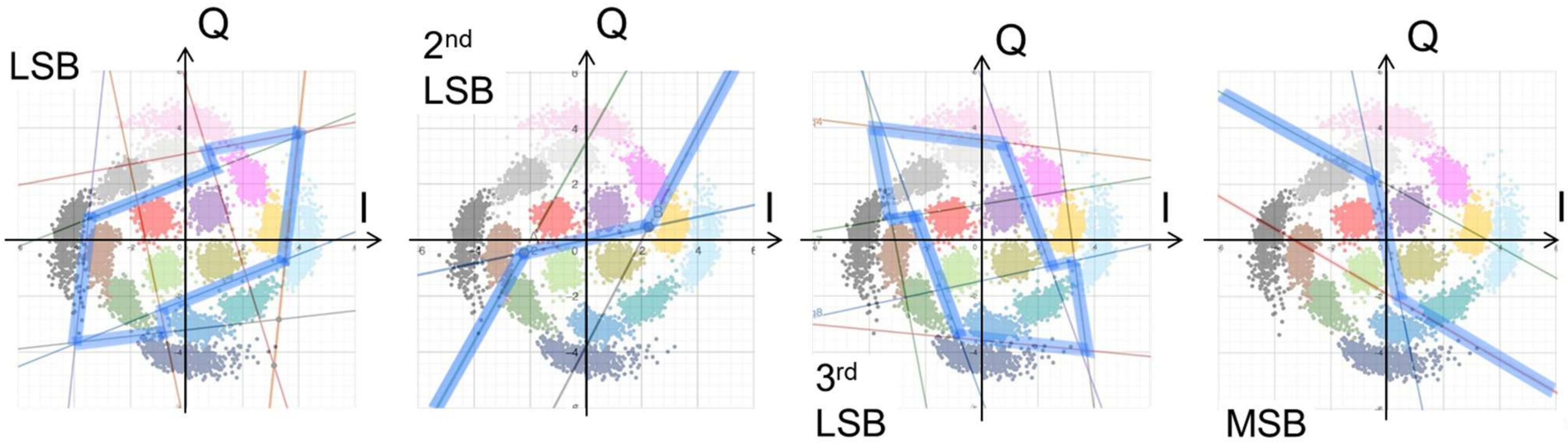
AI-guided compensation
for the signal distortion



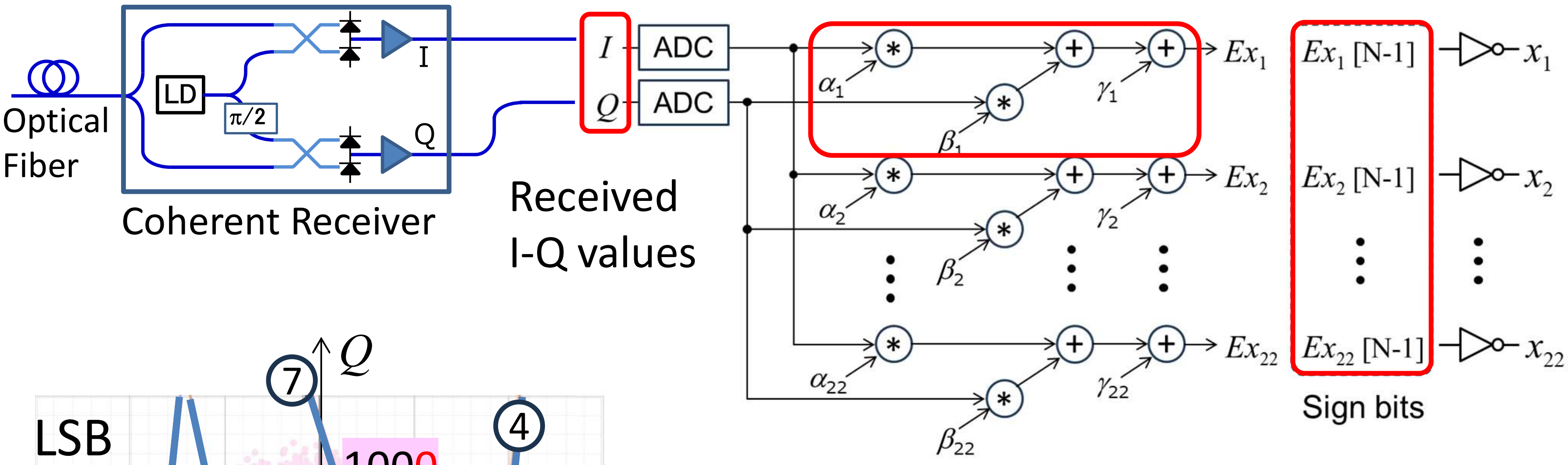
SVM Classifier for QAM Receiver

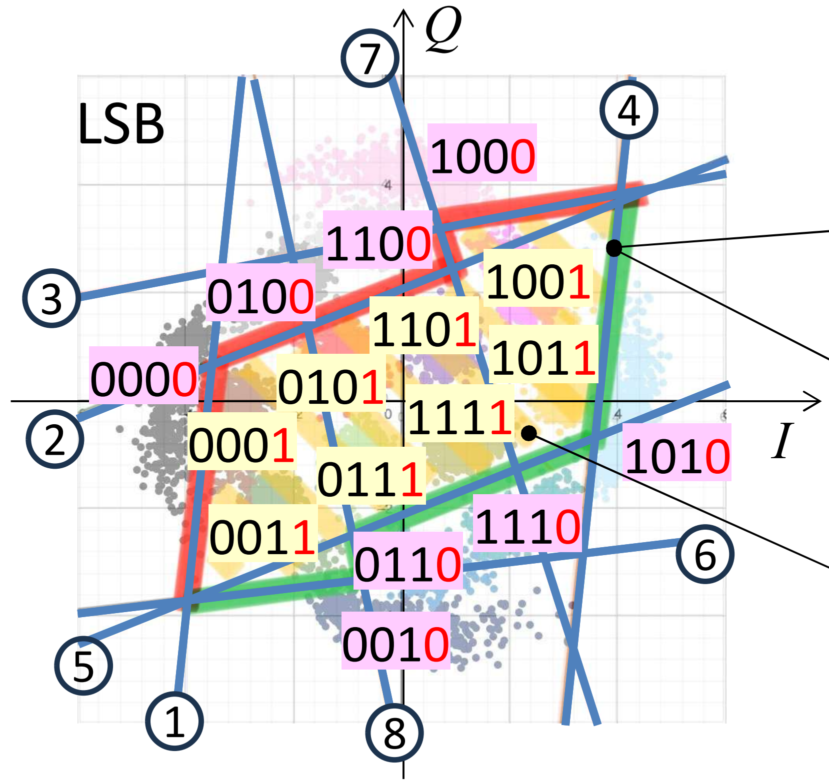
- Support Vector Machine (SVM) is one of the most popular supervised ML models.
- Linear SVM draws a boundary between the two classes in the dataset maximizing the margin between the classes.





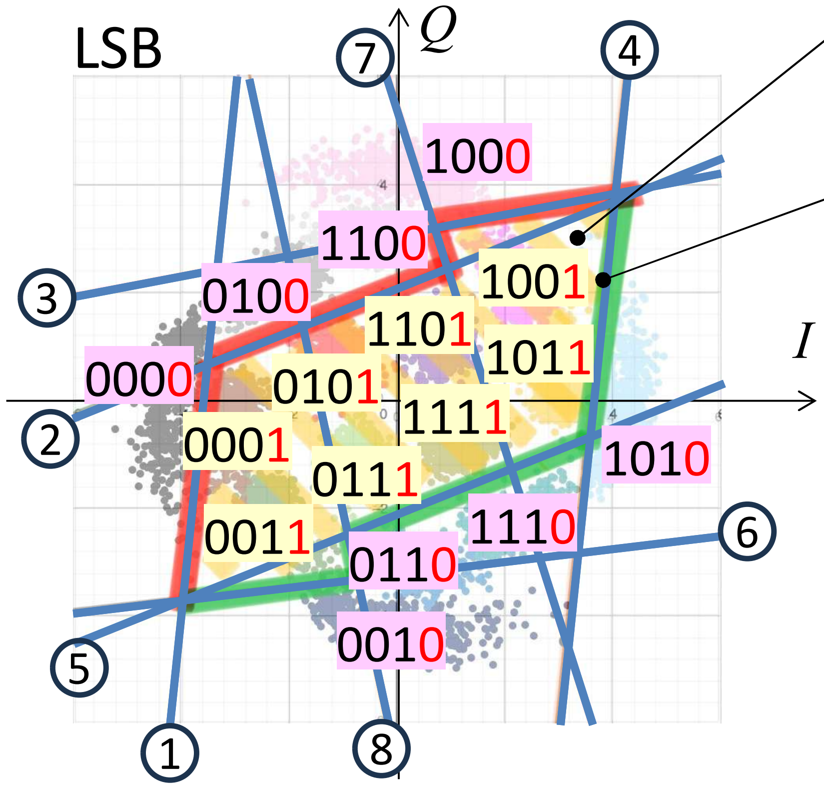
Bit-Wise SVM Classification



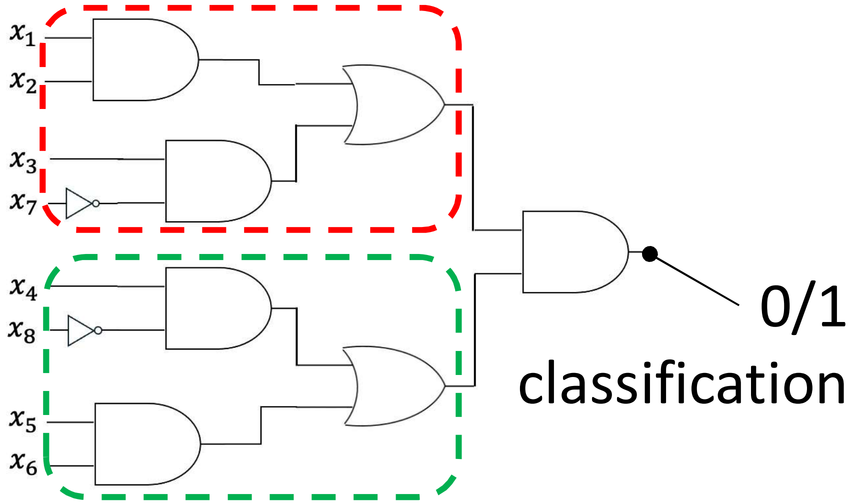


- Line segment is expressed by $\underline{Ex = \alpha I + \beta Q + \gamma}$
- Sign bit of Ex specifies the side of the line.
- Specify a bounded region by two zigzag boundaries.

CMOS Digital SVM Classification



- Sign bit of $\underline{Ex = \alpha I + \beta Q + \gamma}$ specifies the side of the line.
- The bounded region can be specified by logic operation.



$$code[0] = (x_1 \cdot x_2 + x_3 \cdot \overline{x_7}) \cdot (x_4 \cdot \overline{x_8} + x_5 \cdot x_6)$$

Accuracy of Digital SVM Classifiers

SVM model	Classification accuracy	The number of MAC operations required
Linear SVM (OvO)	99.04%	240
Linear SVM (OvR)	96.39%	32
Proposed SVM	99.01%	44

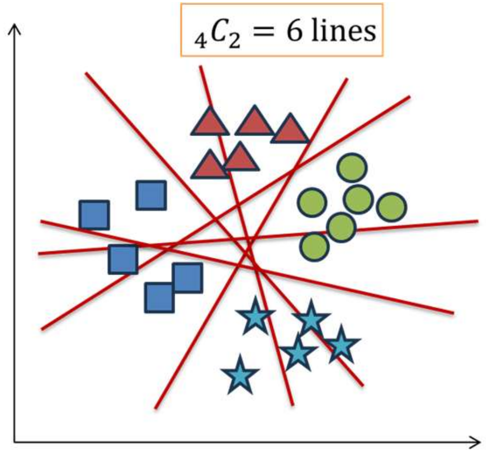
0.03% down

2.62% up

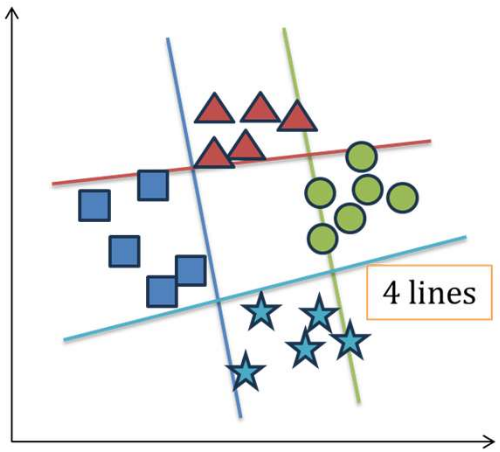
81.7% down

37.5% up

One vs One (OvO)

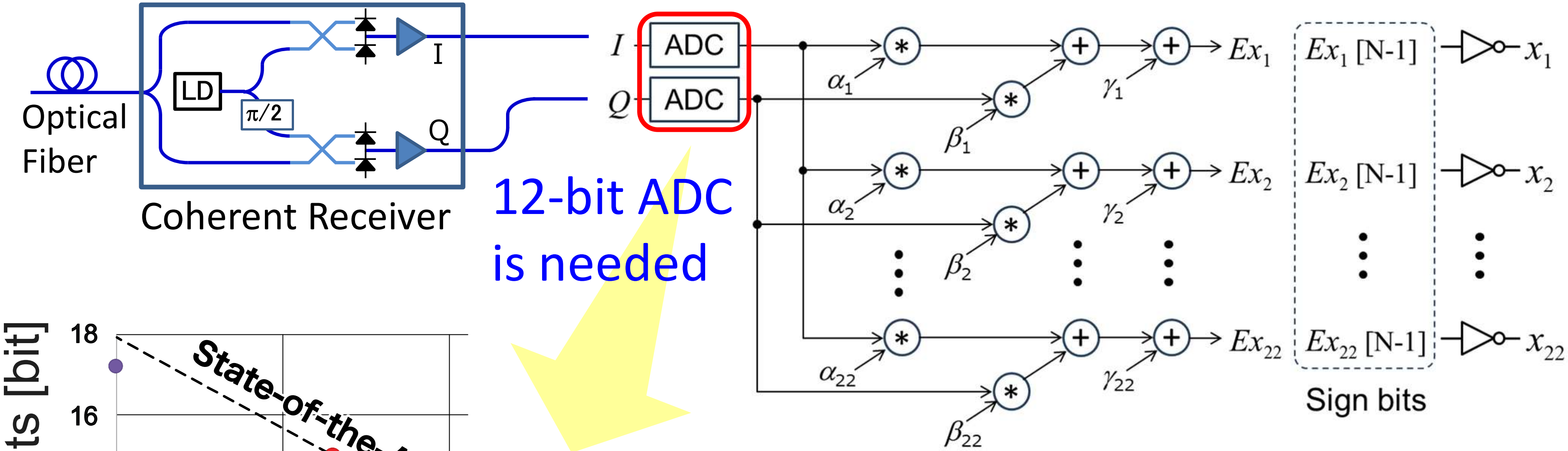


One vs Rest (OvR)

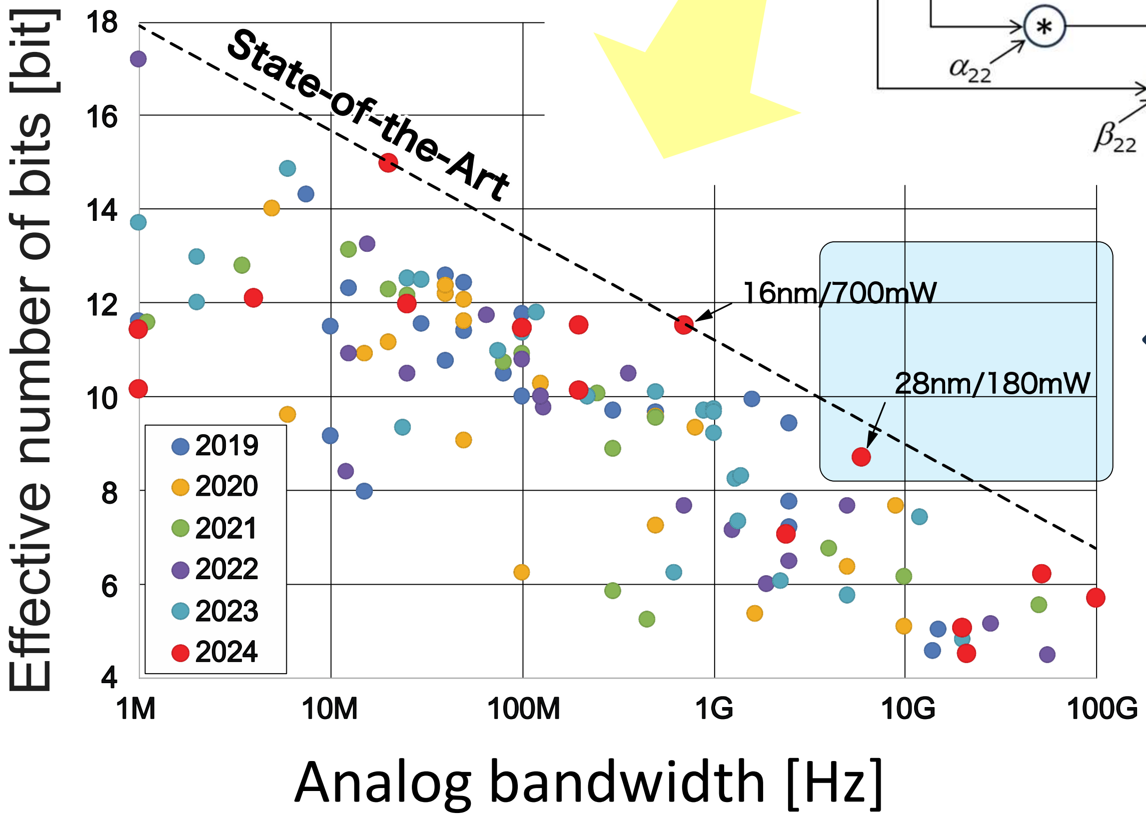


Example of 4-class classification

ADC Bandwidth Limits Performance



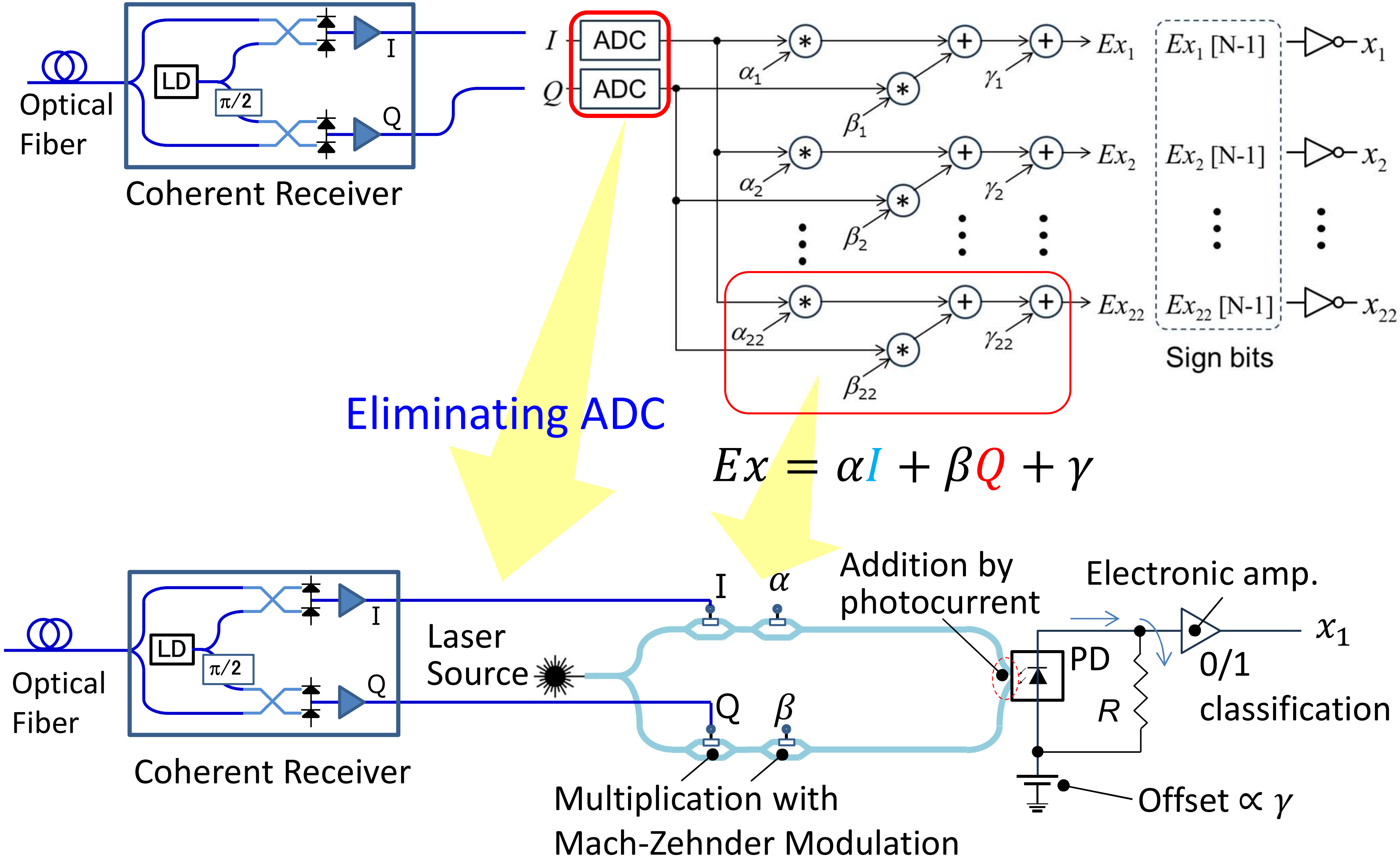
12-bit ADC
is needed



Required region

ADC bandwidth limits performance of QAM receiver

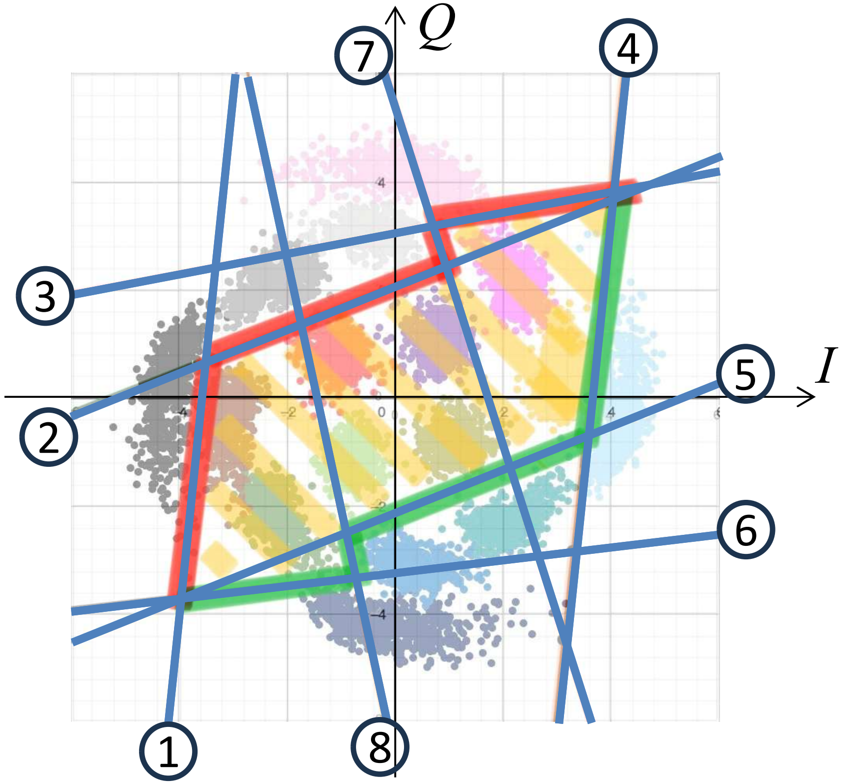
Challenge to Optical SVM Classifier



$$Ex = \alpha I + \beta Q + \gamma$$

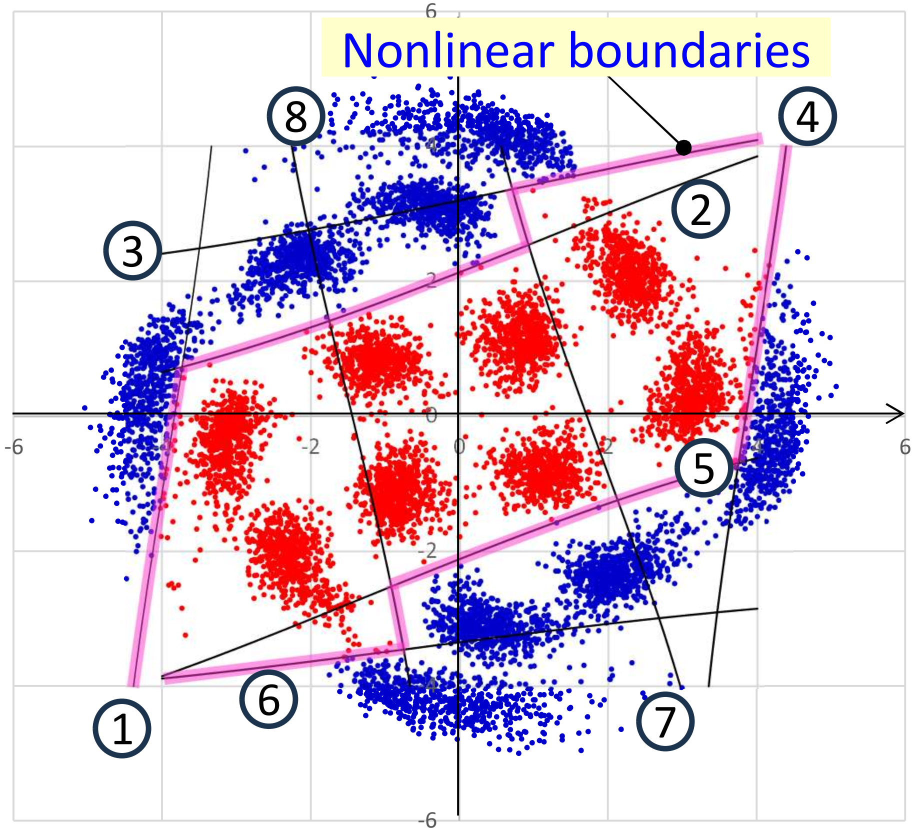
Optical AI Compute ASIC

Multiplication with 12-bit digital multiplier



Classification accuracy for 4-bit code : 99.01%

Multiplication with Mach-Zehnder modulator



Classification accuracy for 4-bit code : 98.94%

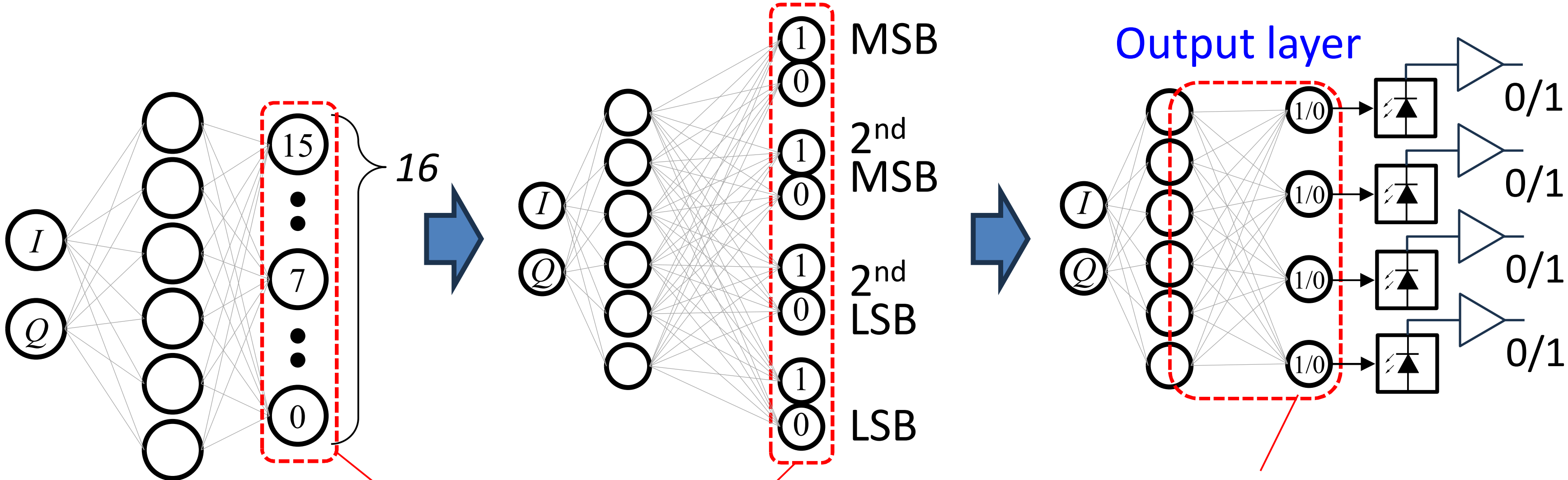
Generalization

Any NN-based n-class classifier can be transformed into multi-output ($\log_2 n$) 2-class NN classifier.

Typical *16*-class NN-based classifier

4-output *2*-class NN-based classifier

4-output *ADC-less* SVM classifiers



Softmax is hard to implement as an optical circuit

Fine-tuning using SVM

Conclusions

- SVM classifier for QAM receiver is proposed
  - Concatenation of lines is used for QAM equalization
    - Each line segment is drawn by a linear SVM classifier
  - CMOS digital implementation shows good accuracy
    - 80% area reduction with sufficient accuracy is achieved
- Challenge to optical SVM classifier is presented
  - Optical modulator and multi-input photodetector are used for multiplication and addition, respectively.
  - Considering nonlinearity of optical components in SVM classification is our future work.

Acknowledgement

This research work is supported by

- **MEXT/JSPS KAKENHI** Grant Number 24H00072
- **JST CRONOS** Grant Number JPMJCS24K1
- **JST CREST** Grant Number JPMJCR21C3