On Complexity and Reliability

Contribution to 802.3dm Task Force

July 28, 2025

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Introduction

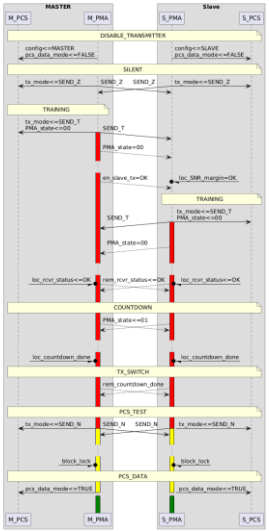
- Reliability and safety are extremely important in automotive applications
- This presentation evaluates the complexity of the state diagrams for 802.3ch, ACT, and New-TDD*
- This analysis includes Cyclomatic Complexity evaluation that is commonly used in SW development
- The analysis shows that the New-TDD state diagram has very high complexity, resulting in testability concerns

* This presentation uses the term New-TDD to refer to TDD proposal described in https://www.ieee802.org/3/dm/public/0525/Baseline_Text_TDD_051125.pdf

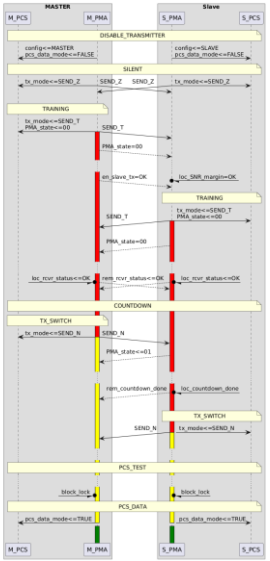
Sequence Diagrams

- The figures on the right show the Sequence Diagrams for the 802.3ch, the ACT proposal, and the TDD proposal
- The 802.3ch and the ACT proposal are very similar, while the TDD proposal is much more complex
- The difference between ACT and TDD state transitions is actually much bigger than this, due to the complexity of switching transmit directions in TDD

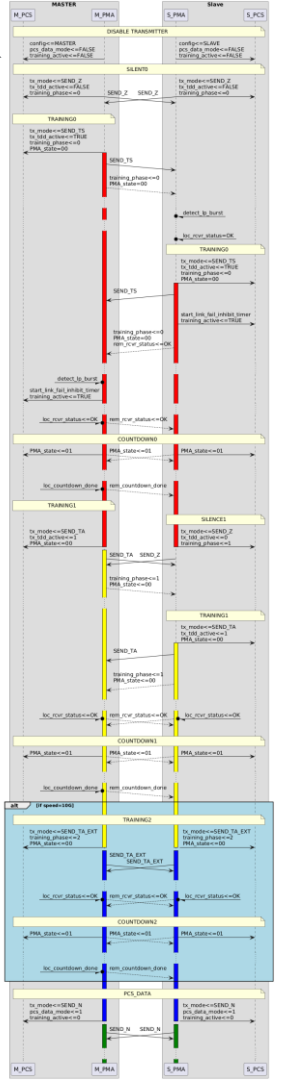
802.3ch



ACT



TDD

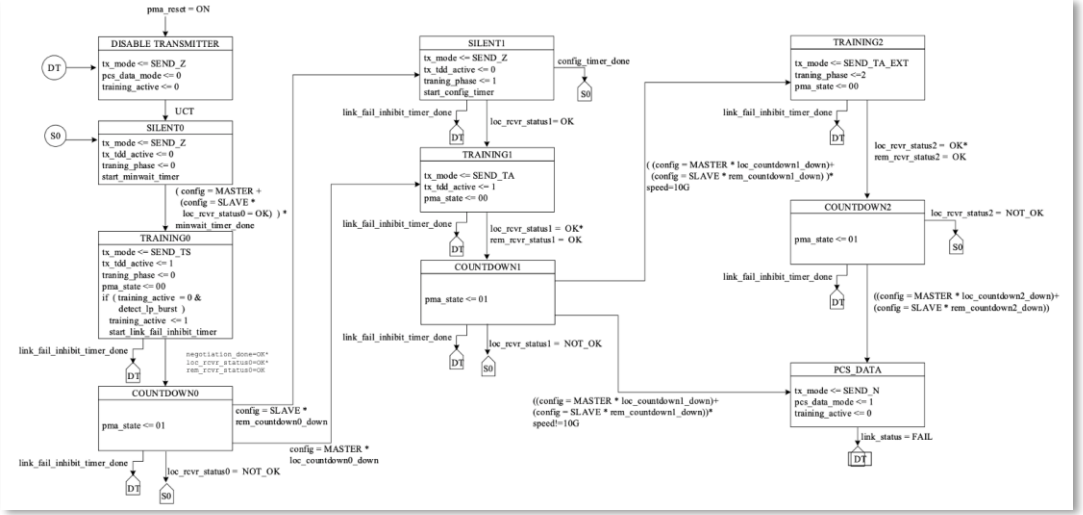


New-TDD

Activity Diagrams

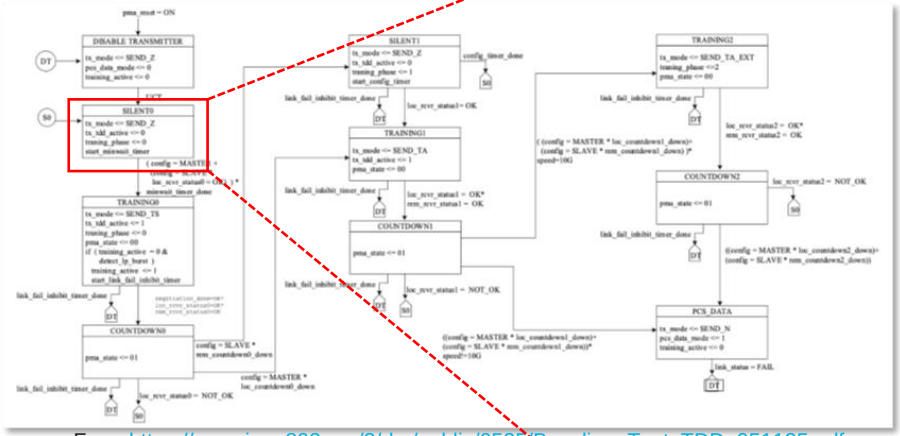
New-TDD Control State Diagram

- The control state diagram for the New-TDD was introduced in [Baseline_Text_TDD_051125.pdf]
- The state diagram has 10 different states, and insides some of these states there are sub-states related to the TDD operation
- The following slides show an attempt to describe at a high level the control flow for PHYs based on the New-TDD



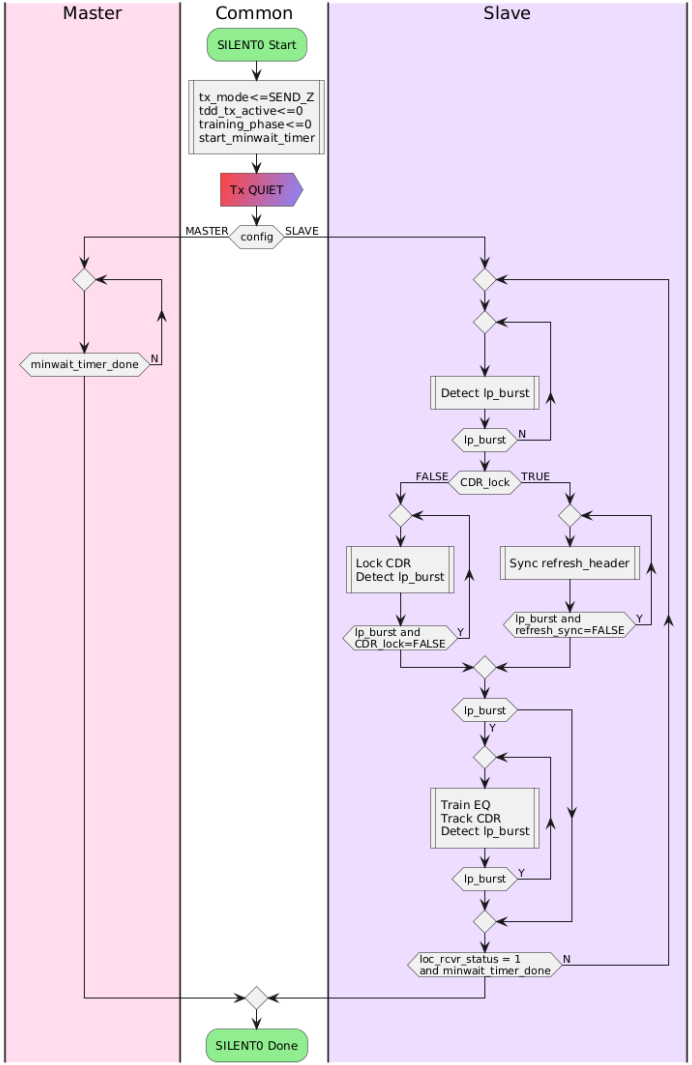
From https://www.ieee802.org/3/dm/public/0525/Baseline_Text_TDD_051125.pdf

SILENT0 State

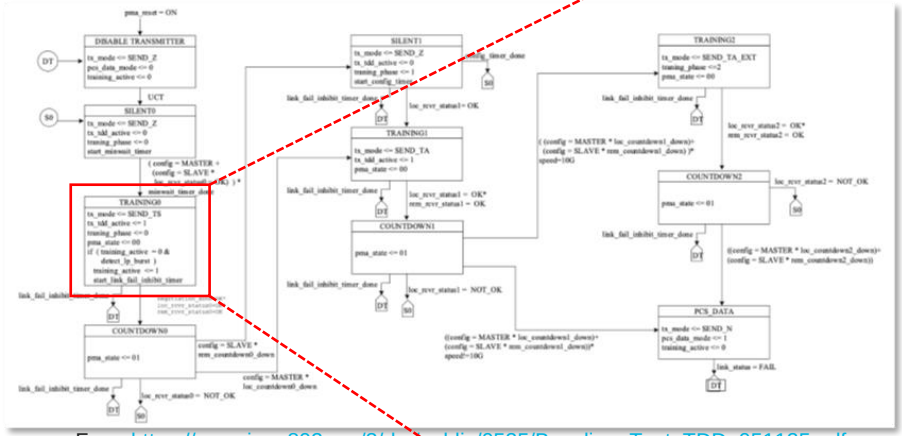


From https://www.ieee802.org/3/dm/public/0525/Baseline_Text_TDD_051125.pdf

E-N = 9

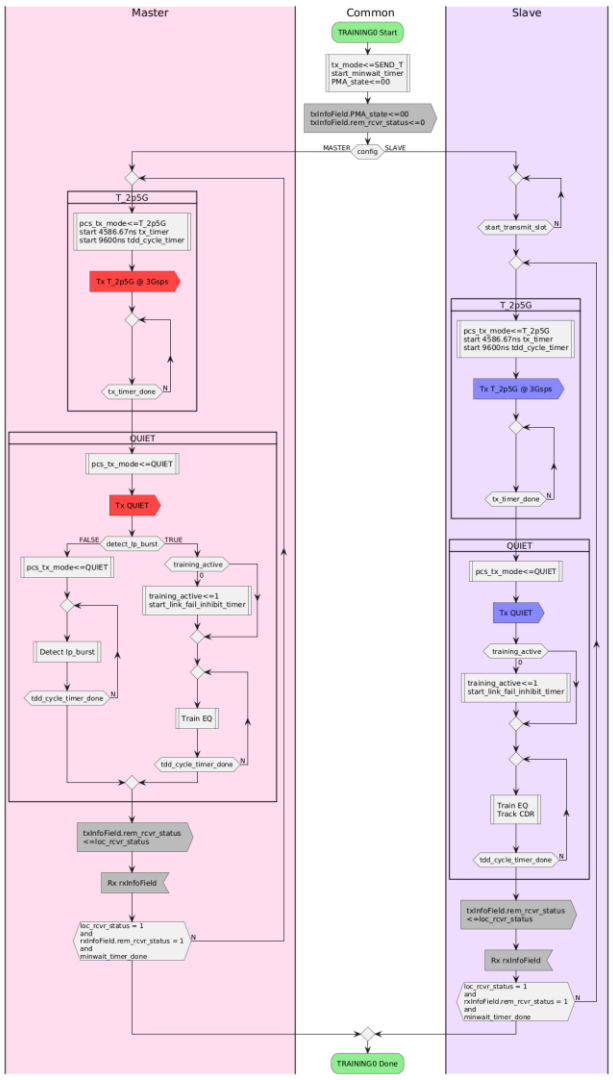


TRAINING0 State

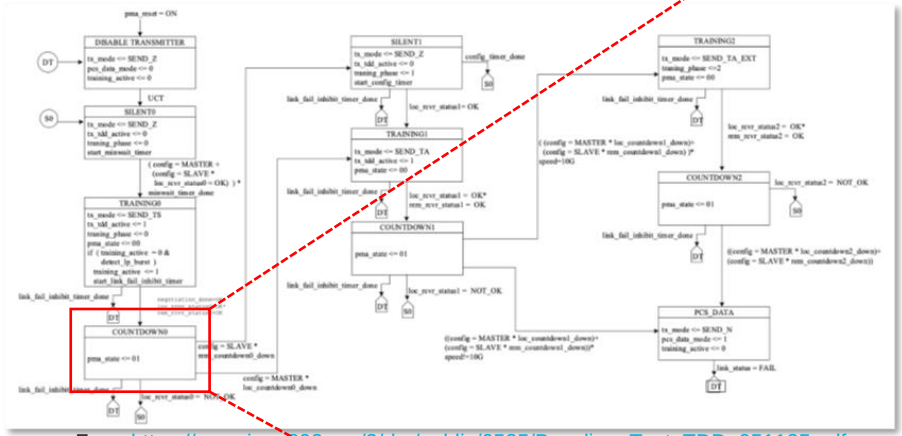


From https://www.ieee802.org/3/dm/public/0525/Baseline_Text_TDD_051125.pdf

E-N = 12

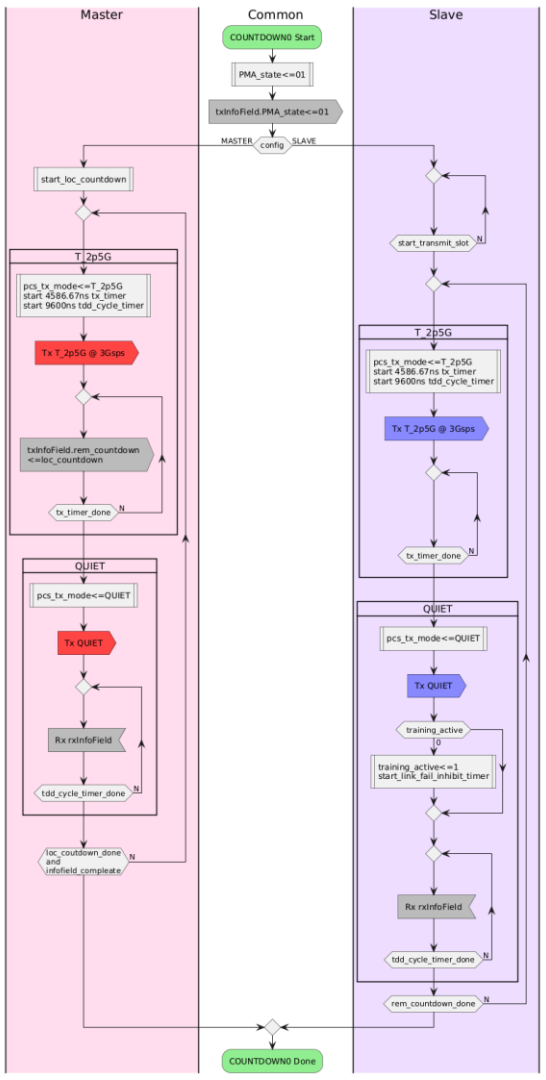


COUNTDOWN0 State

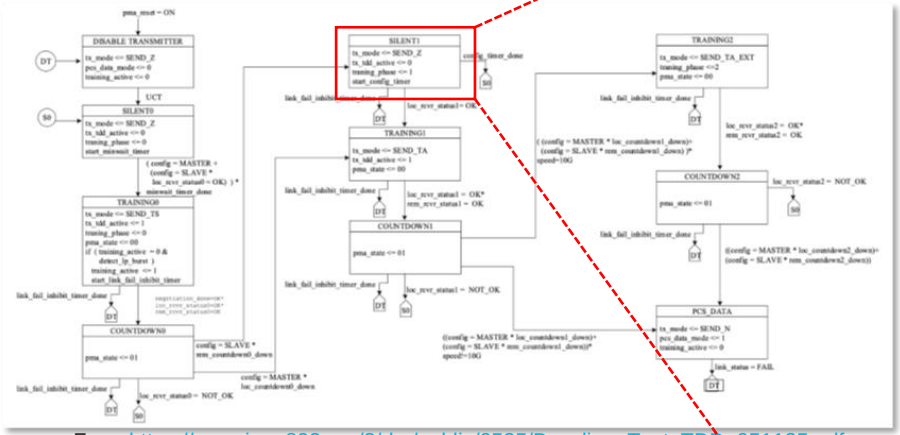


From https://www.ieee802.org/3/dm/public/0525/Baseline_Text_TDD_051125.pdf

E-N = 9



SILENT1 State



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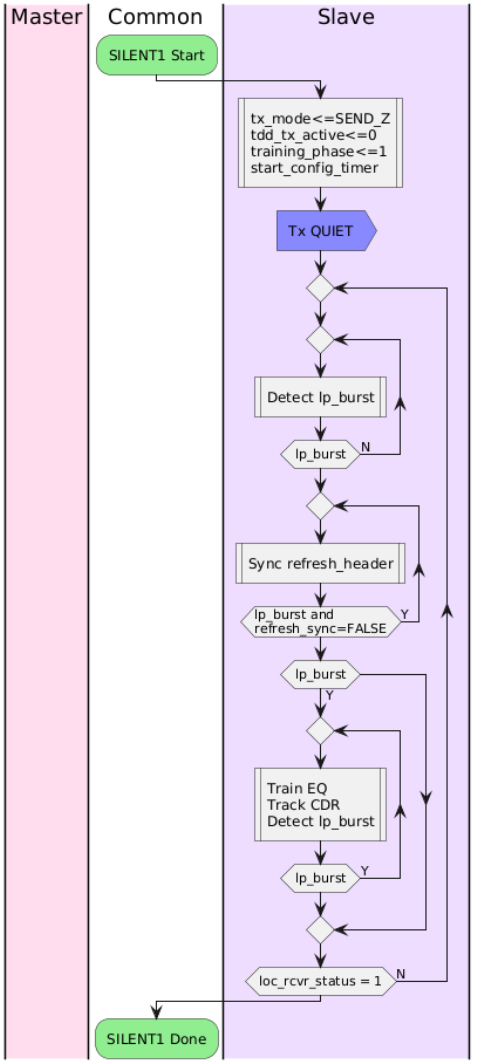
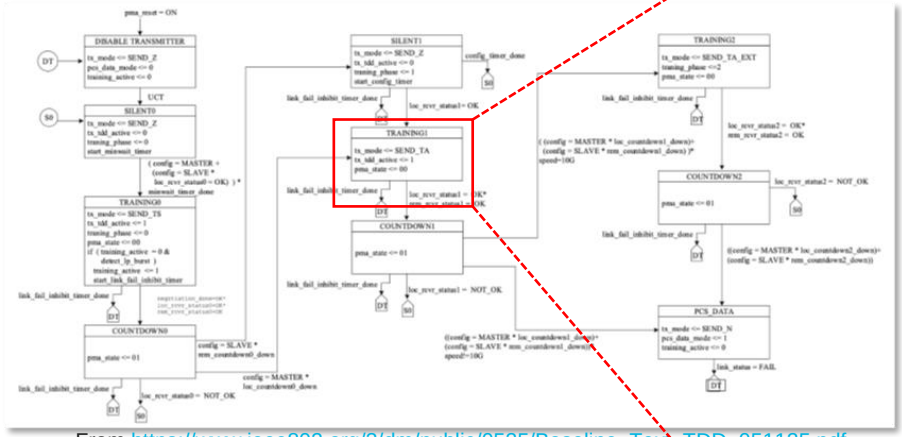
E-N = 5



TRAINING1 State



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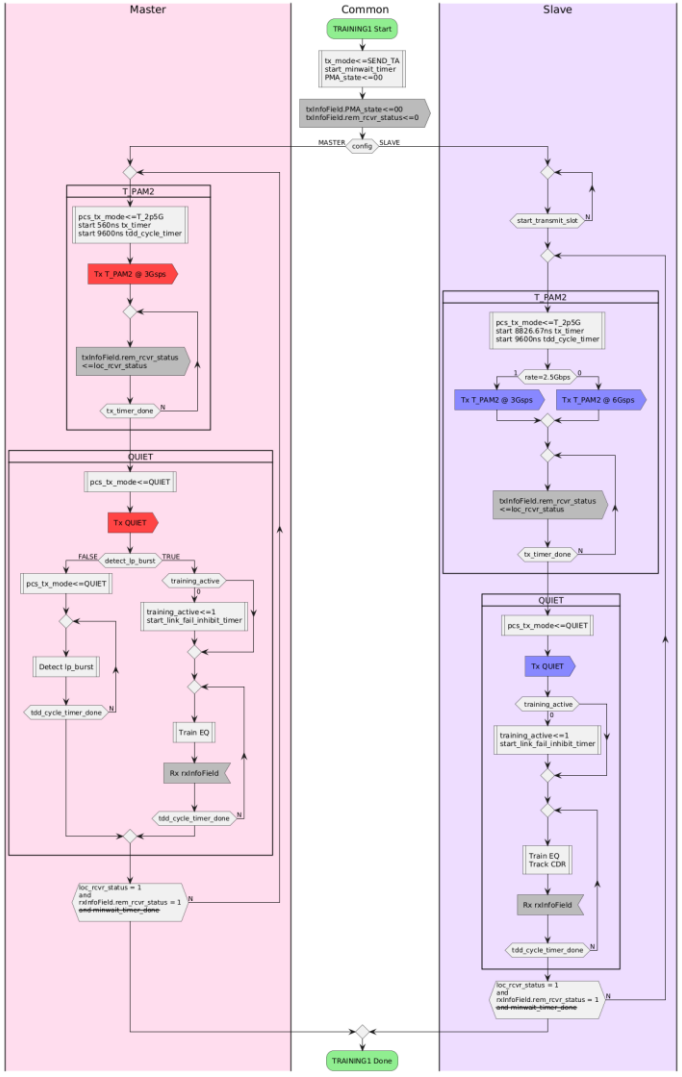
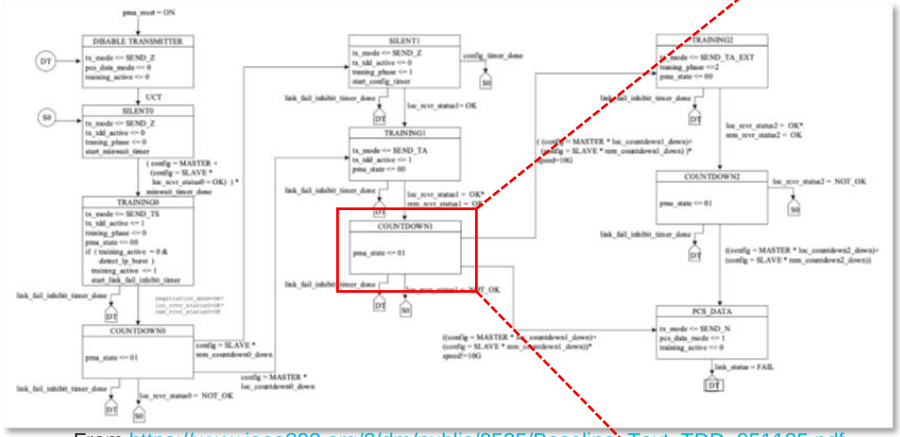
E-N = 13

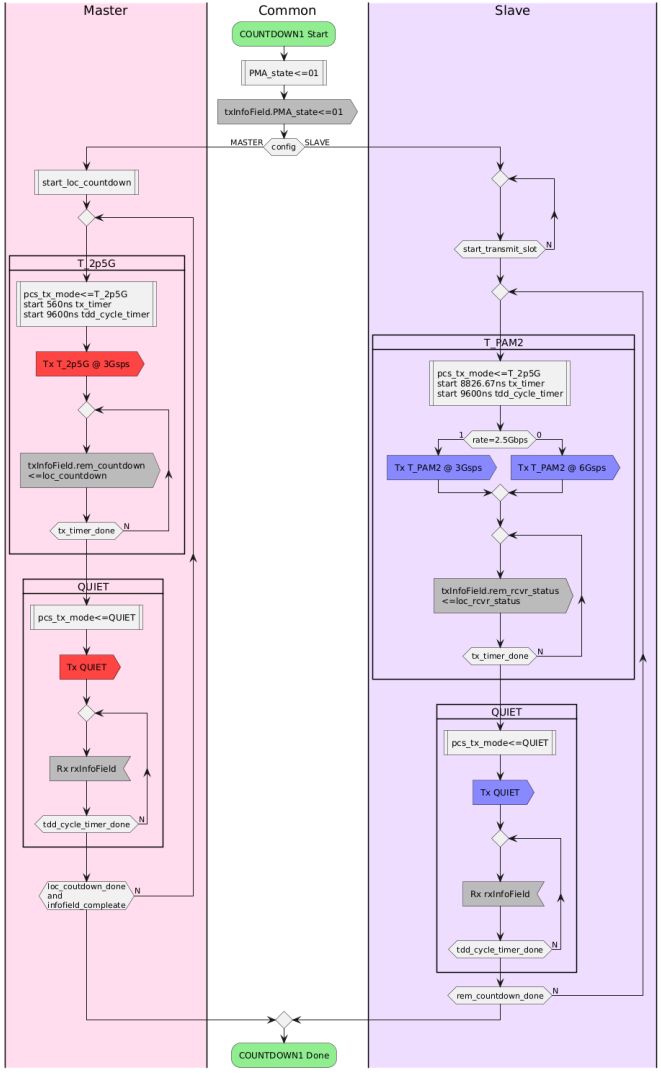


COUNTDOWN1 State

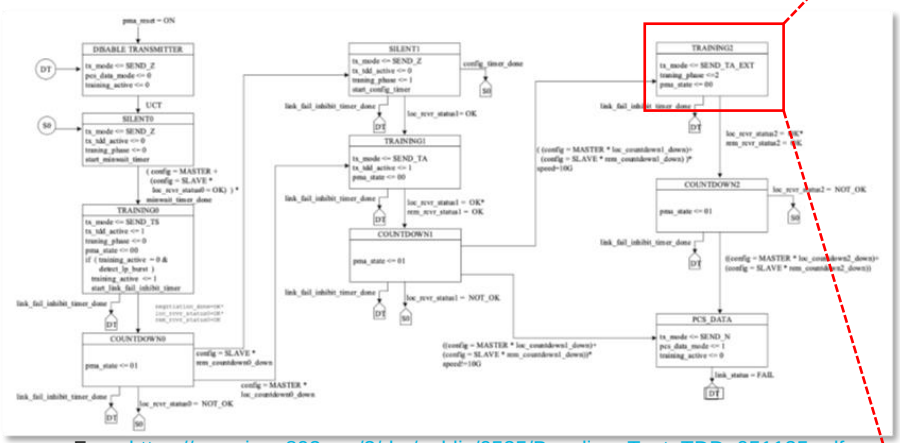


From https://www.ieee802.org/3/dm/public/0525/Baseline_Text_TDD_051125.pdf

E-N = 9

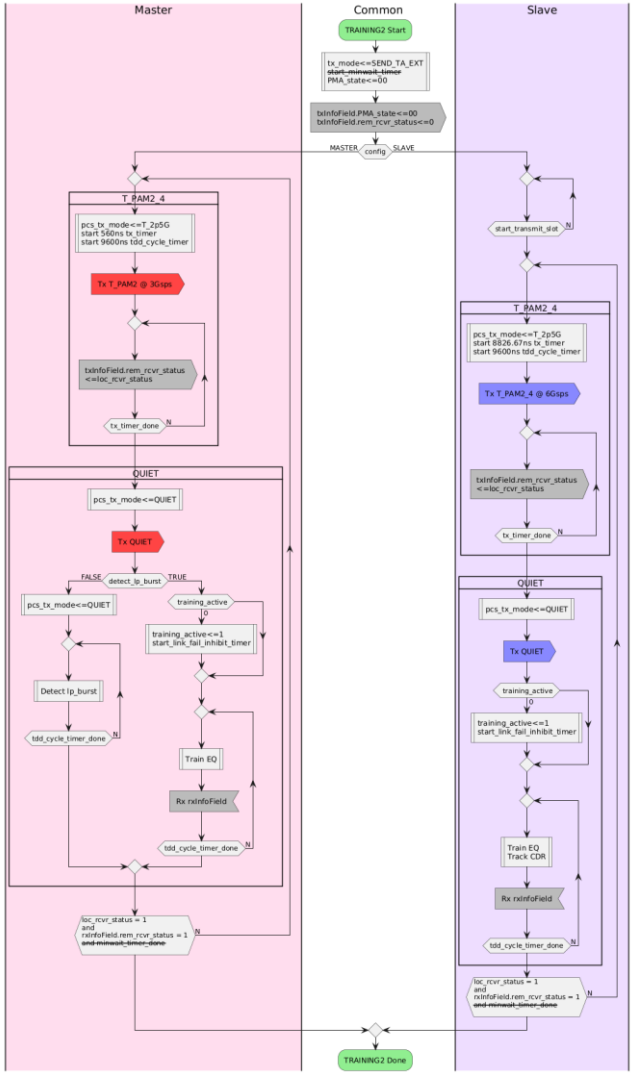


TRAINING2 State

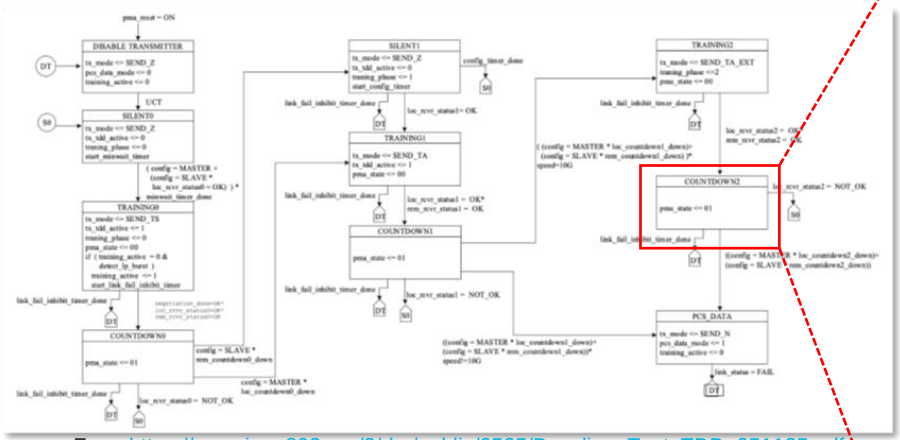


From https://www.ieee802.org/3/dm/public/0525/Baseline_Text_TDD_051125.pdf

E-N = 12

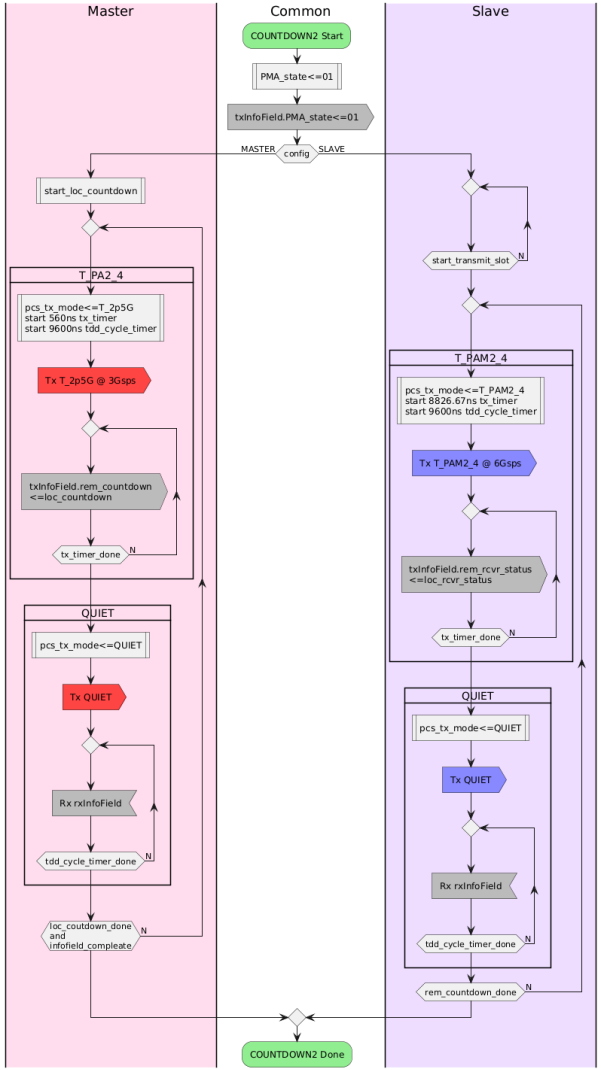


COUNTDOWN2 State

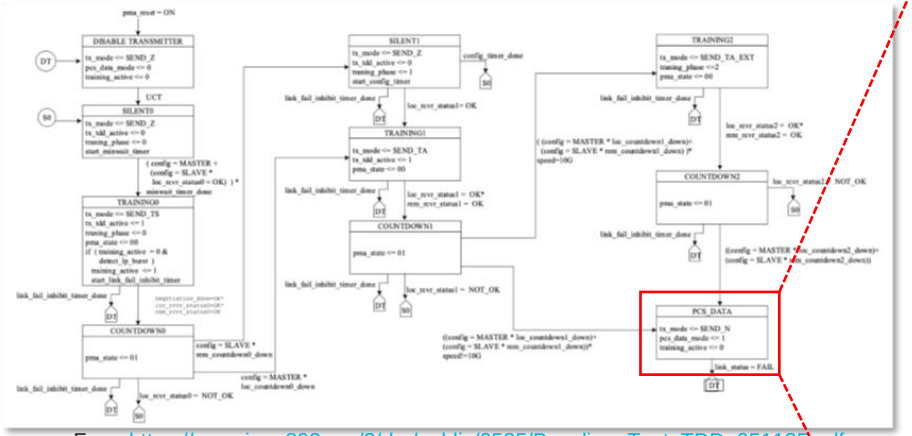


From https://www.ieee802.org/3/dm/public/0525/Baseline_Text_TDD_051125.pdf

E-N = 8



PCS_DATA State



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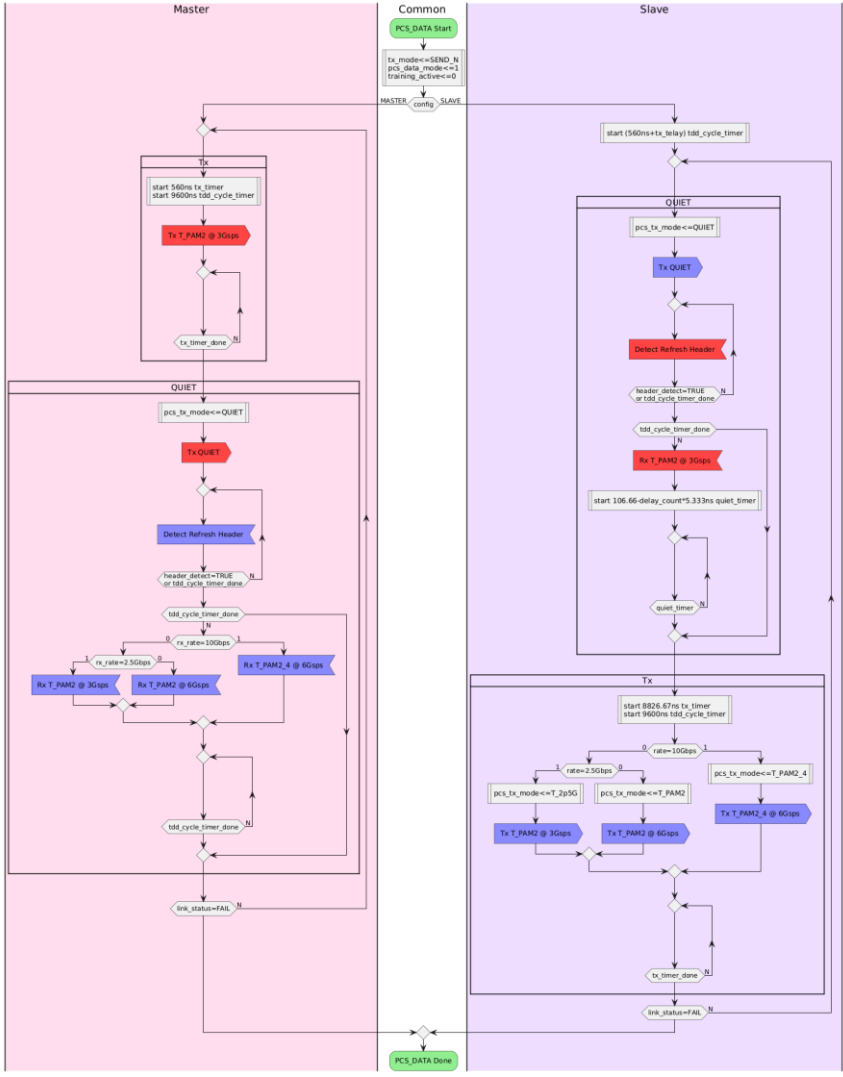
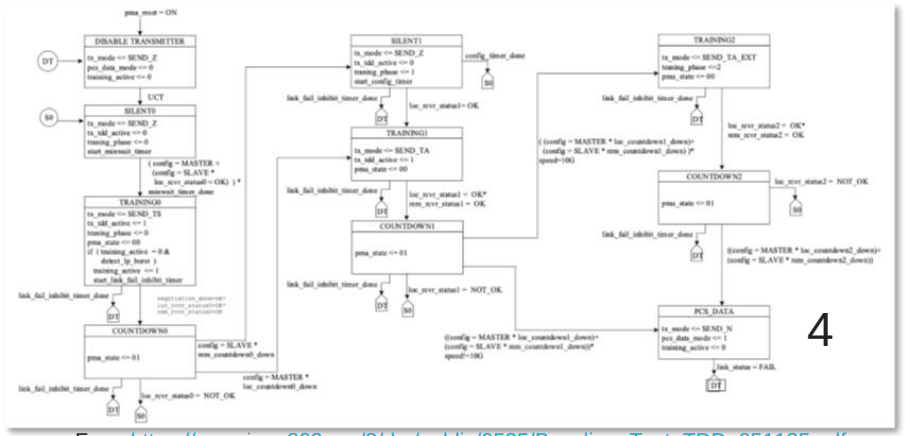
E-N = 15

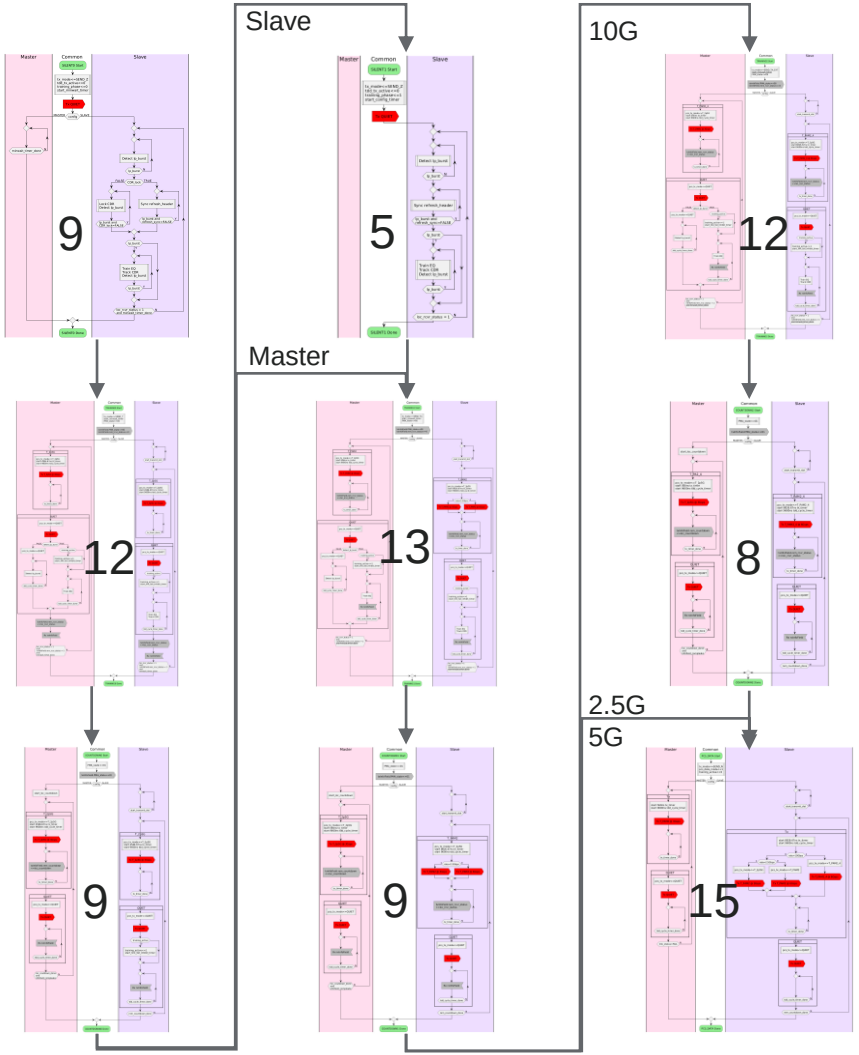


New-TDD Combined



From https://www.ieee802.org/3/dm/public/0525/Baseline_Text_TDD_051125.pdf

E-N = 9+12+9+5+13+9+12+8+15+4 = 96



802.3ch and ACT

Activity Diagrams

802.3ch Control State Diagram

- The control state diagram for 802.3ch is captured in Figure 149-32
- The state diagram has 7 different states, but each state is relatively simple
- The single activity diagram further to the right shows the activity for **the whole PHY control state** diagram

E-N = 7

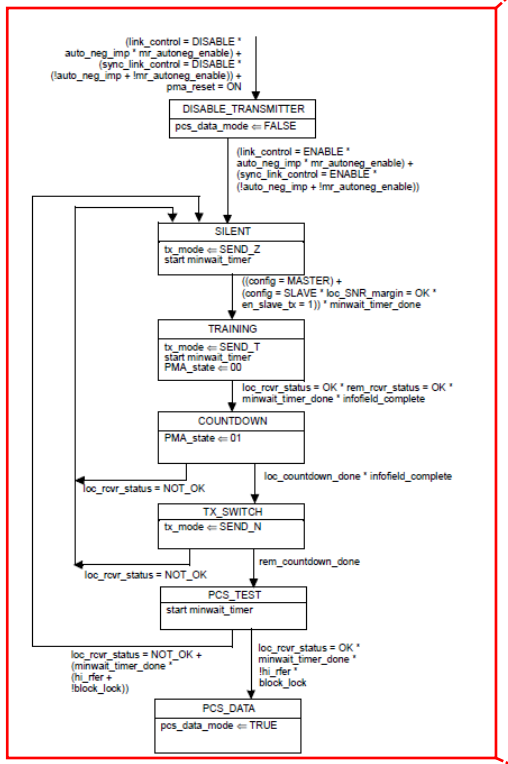
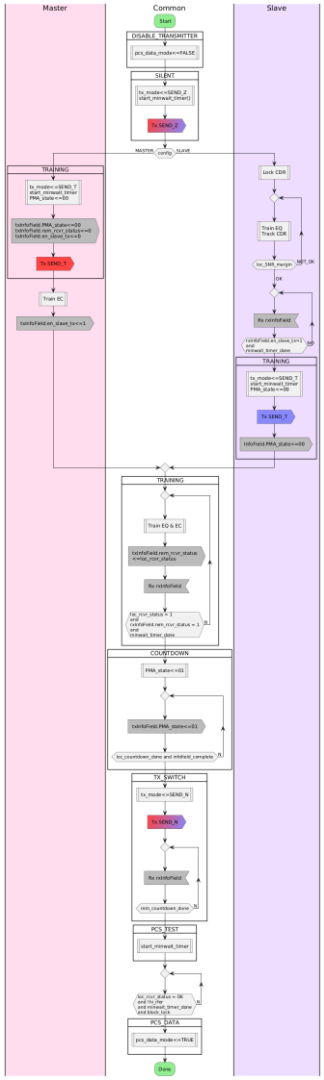


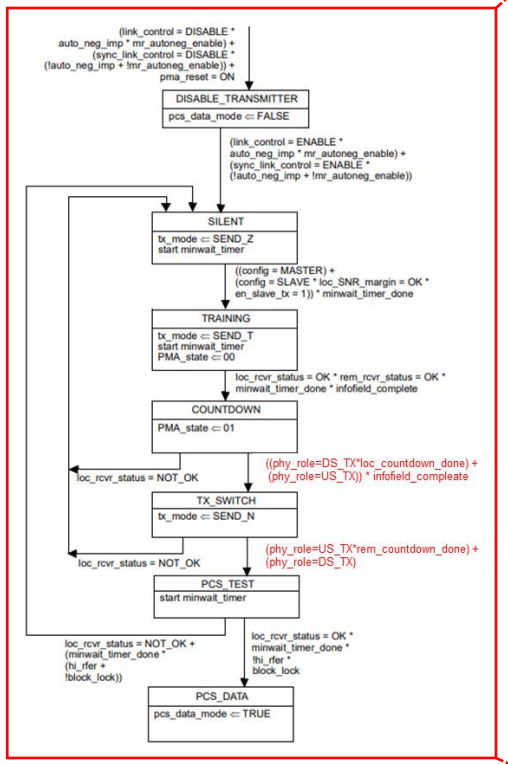
Figure 149–32—PHY Control state diagram

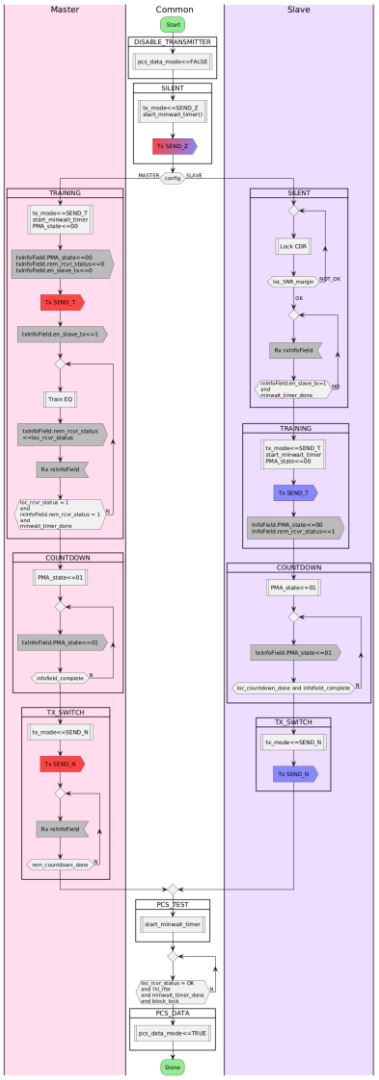


ACT Control State Diagram

- The control state diagram for ACT is captured in the figure on the right
- The state diagram has 7 different states, but each state is relatively simple
- The single activity diagram further to the right shows the activity for **the whole PHY control state** diagram

E-N = 8





Evaluating Complexity and Risk

Cyclomatic Complexity

Cyclomatic Complexity

- Cyclomatic complexity is a quantitative metric that evaluates the complexity of algorithms based on control-flow graphs
  - See https://en.wikipedia.org/wiki/Cyclomatic_complexity
- There are several metrics that can be derived from the control-flow, including:
  - *M1* = *E* – *N* + *2P* (McCabe original metric)
  - *M2* = *E* – *N* + *P* (Betty number)
  - *M3* = Number of loops in control-flow diagram
  - *M4* = Number of paths through the control-flow diagram

where

- *E* is number of edges
- *N* is number of nodes
- *P* is number of connected components
- *S* is number of exit points

Cyclomatic Complexity of SILENT0

The SILENT0 diagram on the right has been marked up with

- Blue cycles for edges
- Black diamond for notes
- Orange squares for loops

This gives the complexity metrics:

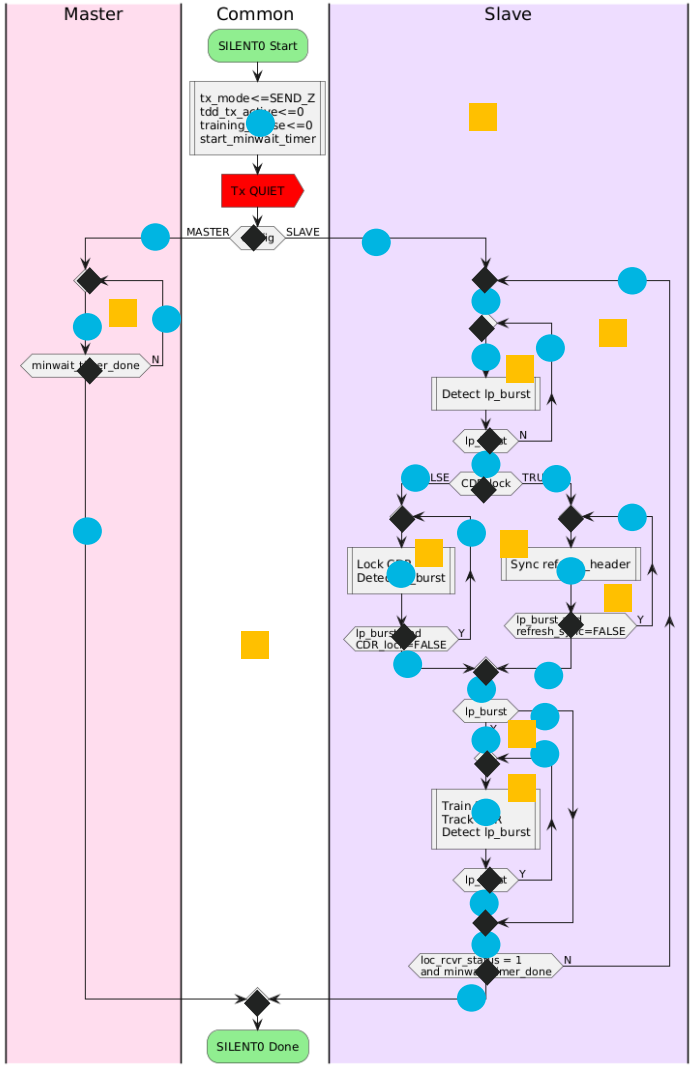
E-N = 9

M1 = E – N + 2P = 26-17+2 = 11

M2 = E – N + P = 26-17+1 = 10

M3 = num. loops = 10

M4 = num. paths = (2 + 2*2*(2+2)*(2+1)) = 50



Edges minus Nodes

- On slides 6-15 the number of edges minus nodes is given as “E-N” on each slide
- These numbers are summarized in the “M+S” column in the top table on the right
- The “Master” and “Slave” columns show the number of edges – nodes, assuming that the Master and Slave state diagrams are implemented separately
- The bottom table includes the main paths from the top table, but also includes the timeout paths

State	M+S	Master	Slave
SILENT0	9	1	7
TRAINING0	12	6	5
COUNTDOWN0	9	3	5
SILENT1	5	0	5
TRAINING1	13	6	6
COUNTDOWN1	9	3	5
TRAINING2	12	6	5
COUNTDOWN2	8	3	4
PCS_DATA	15	7	7
Top Level	4	1	1
Total	96	36	50

Paths	M+S	Master	Slave
Main Paths	96	36	50
Timeout Paths	24	12	12
All Paths	120	48	62

Cyclomatic Complexity and Risk

M1 Value	Complexity	Risk
1 - 10	Simple Procedure	Little Risk
11 - 20	More Complex	Moderate Risk
21 - 50	Complex	High Risk
> 50	Untestable Code	Very High Risk

See https://en.wikipedia.org/wiki/Cyclomatic_complexity

Cyclomatic Complexity and Functional Safety

- The ISO 26262 functional safety standard defines Automotive Safety Integrity Levels (ASIL)
- Cyclomatic Complexity requirements that are commonly used in the industry are shown in the table on the top right
- The Herstellerinitiative Software (HIS) Source Code Metrics requirements document *HIS-SC-Metriken.1.3.1* specifies that the Cyclomatic Complexity should be in the range 1-10

Commonly Used Complexity Requirements

ASIL Level	Cyclomatic Complexity
ASIL A	< 20 to 30
ASIL B	< 20
ASIL C	< 10
ASIL D	< 10

Note: The limits in the table are reference levels common in the industry and not limits set by ISO 26262

New-TDD Cyclomatic Complexity and Risk

- The table on the top right shows the calculated M1 Cyclomatic Complexity for the New-TDD state diagram
- All the M1 numbers are very high and correspond to “High” or “Very High” risk, as captured in the table below

M1 Cyclomatic Complexity

Paths	M+S	Master	Slave
Main Paths	98	38	52
All Paths	122	50	64

Estimated Risk for the TDD State Diagram

Paths	M+S	Master	Slave
Main Paths	Very High	High	Very High
All Paths	Very High	High	Very High

The complexity of the New-TDD State Diagram makes it very high risk

New-TDD State Diagram and Testability

- The Cyclomatic Complexity analysis for New-TDD state diagram is not only high risk, but also very hard to test
- It is common to state that code that has Cyclomatic Complexity above 50 is "**untestable**"
- I have spent significant time simulating the New-TDD state transitions and found that my simulation code is of such high complexity that it is probably "**untestable**"

M1 Cyclomatic Complexity

Paths	M+S	Master	Slave
Main Paths	98	38	52
All Paths	122	50	64

Complexity of the TDD State Diagram

Paths	M+S	Master	Slave
Main Paths	Untestable	Complex	Untestable
All Paths	Untestable	Complex	Untestable

The complexity of the New-TDD State Diagram probably makes it "untestable"

Cyclomatic Complexity of 802.3ch

- The Cyclomatic Complexity for 802.3ch State Diagrams is shown in the table on the top right
- 802.3ch has significantly lower Cyclomatic Complexity than the New-TDD
- The estimated risk for 802.3ch is low to moderate
- The low complexity of the PHY state diagram has probably helped with successful 802.3ch interoperability between multiple vendors

802.3CH M1 Cyclomatic Complexity

Paths	M+S	Master	Slave
Main Paths	9	6	8
All Paths	15	9	11

802.3CH Estimated Risk

Paths	M+S	Master	Slave
Main Paths	Low	Low	Low
All Paths	Moderate	Low	Moderate

802.3CH Complexity

Paths	M+S	Master	Slave
Main Paths	Simple	Simple	Simple
All Paths	More	Simple	More

Cyclomatic Complexity of New-TDD

- The Cyclomatic Complexity for the New-TDD State Diagrams is shown in the table on the top right
- The New-TDD has high to very high Cyclomatic Complexity with high to very high risk
- The high complexity of the PHY state diagram is likely to be a hindrance for interoperability between different vendors

802.3CH M1 Cyclomatic Complexity

Paths	M+S	Master	Slave
Main Paths	98	38	52
All Paths	122	50	64

802.3CH Estimated Risk

Paths	M+S	Master	Slave
Main Paths	Very High	High	Very High
All Paths	Very High	High	Very High

802.3CH Complexity

Paths	M+S	Master	Slave
Main Paths	Untestable	Complex	Untestable
All Paths	Untestable	Complex	Untestable

Cyclomatic Complexity of ACT

- The Cyclomatic Complexity for the ACT State Diagrams is shown in the table on the top right
- 802.3ch has the lowest Cyclomatic Complexity
- The estimated risk for ACT is low to moderate
- The low complexity of the PHY state diagram should facilitate interoperability between vendors
- The low complexity of the ACT PHY should facilitate ASIL compliance

802.3CH M1 Cyclomatic Complexity

Paths	M+S	Master	Slave
Main Paths	10	6	6
All Paths	16	9	9

802.3CH Estimated Risk

Paths	M+S	Master	Slave
Main Paths	Low	Low	Low
All Paths	Moderate	Low	Low

802.3CH Complexity

Paths	M+S	Master	Slave
Main Paths	Simple	Simple	Simple
All Paths	More	Simple	Simple

Summary

- This presentation analyzed state diagrams for 802.3ch, ACT and the New-TDD, including the Cyclomatic Complexity
- The New-TDD state diagram is significantly more complex than the 802.3ch and ACT state diagrams
- Unlike the New-TDD, there are no significant complexity concerns related to the 802.3ch or ACT state diagrams
- The complexity of the New-TDD state diagram is so high that
  - The New-TDD state diagram is high risk or very high risk
  - The New-TDD state diagram is probably ”untestable”
  - The New-TDD state diagram will probably not satisfy any typical ASIL levels

The current New-TDD State Diagram is not viable for automotive applications

Essential technology, done right™