Proposed Functional Additions to Support Receiver Eye Characterization

Technical Contribution

802.3 Working Group

Tom Waschura

SyntheSys Research, Inc.

(650) 364-1853

tom_waschura@synthesysresearch.com

IP & Patent Notice

- There are specialized implementation aspects of SyntheSys Research, Inc.'s Bit Error Rate testers and physical-layer measurement & analysis features which are included in this presentation that are patented or have patents pending.
- Inventions are not offered for license to other companies beyond current Licensees
- This presentation should in no-way imply an "offer to license"
- Any "offer to license" will be in the form of formal "Letter of Assurance" in accordance with IEEE procedures.

Introduction

- With relatively minor changes to the input decision circuit and MDIO control registers, 802.3ap transceivers can extend their built-in test features to measure signal integrity directly at the point of the decision in the receiver circuit.
- This enables testing after any intended or non-intended signal distortion/processing.
- Testing methods include high-resolution eye diagrams, frequency response, jitter measurement (RJ/DJ/TJ), BER contour and fast mask testing.
- This can be used for R&D characterization, production testing and in-system diagnostics.

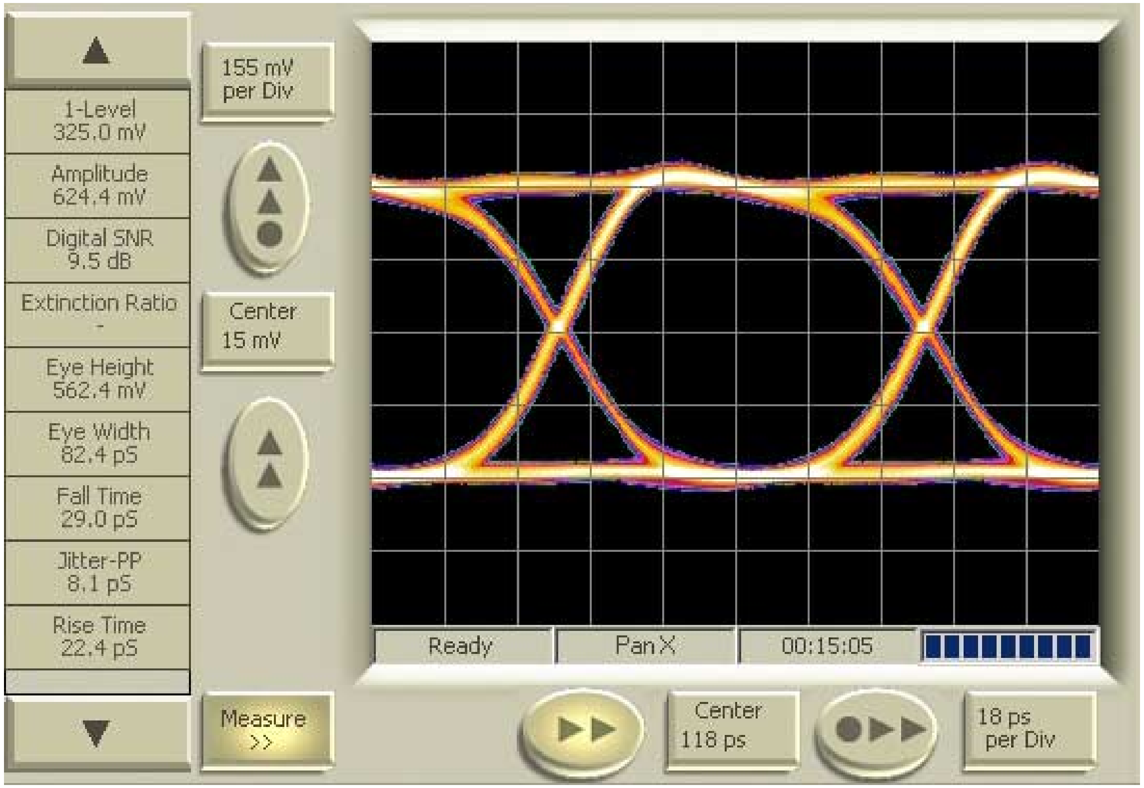
Opportunity

It has been demonstrated that…

- Eye diagrams are popular and offer a good picture of an eye condition—the deeper the better
- Extrapolation techniques can quickly estimate bit error rates – including bit error rate contours
- Mask testing offers a good grading mechanism – especially if it is fast
- Random and Deterministic jitter separation can can qualify certain failure types
- Q-factor measurements very quickly assess the digital signal-to-noise ratio of a decision circuit

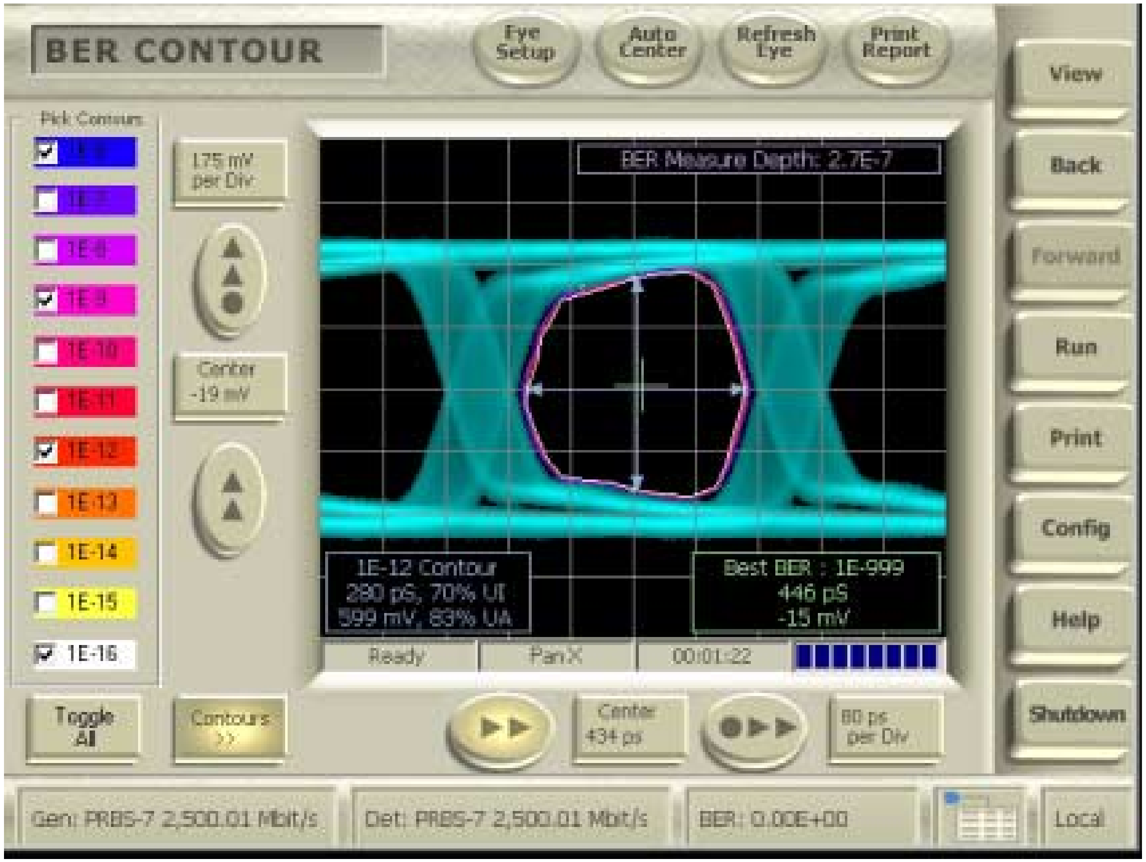
QUICK EXAMPLES OF ANALYSIS METHODS…

Eye Diagram



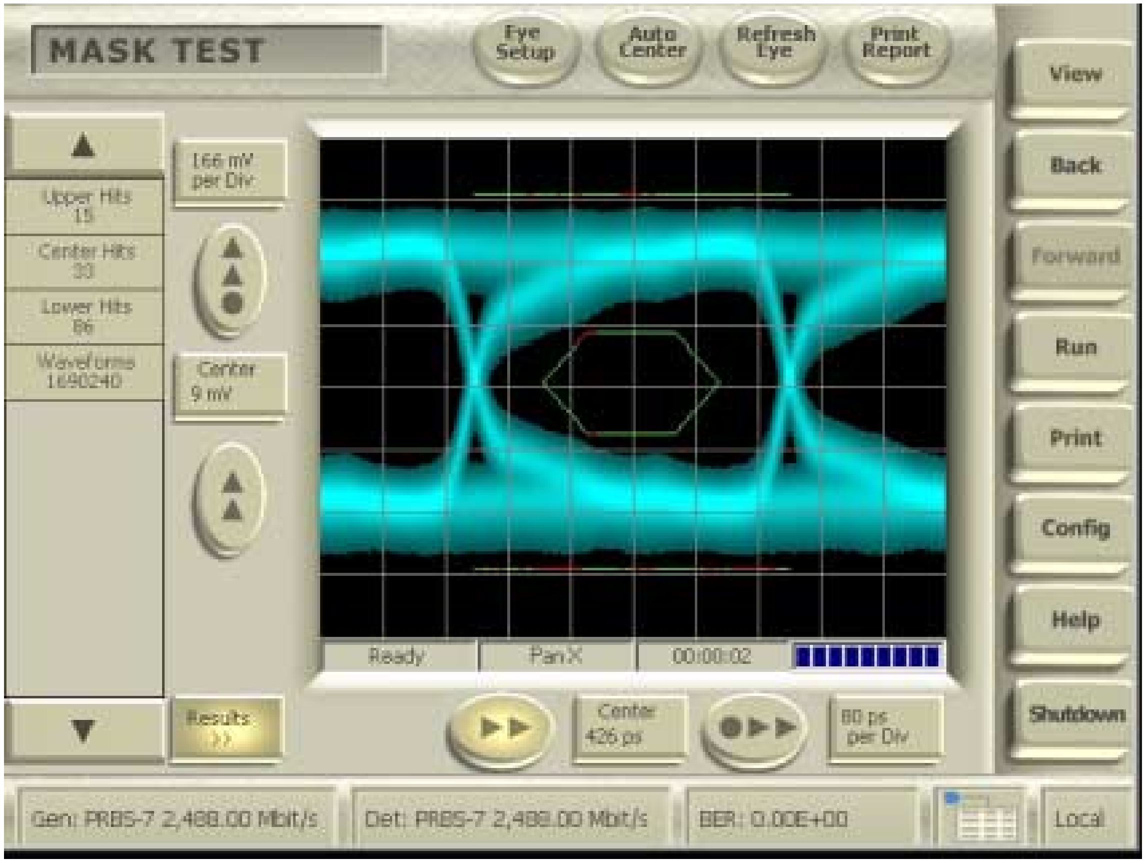
- A picture is worth 1000 words
- Diagnoses many types of issues
- Universally accepted

Bit Error Rate Contour



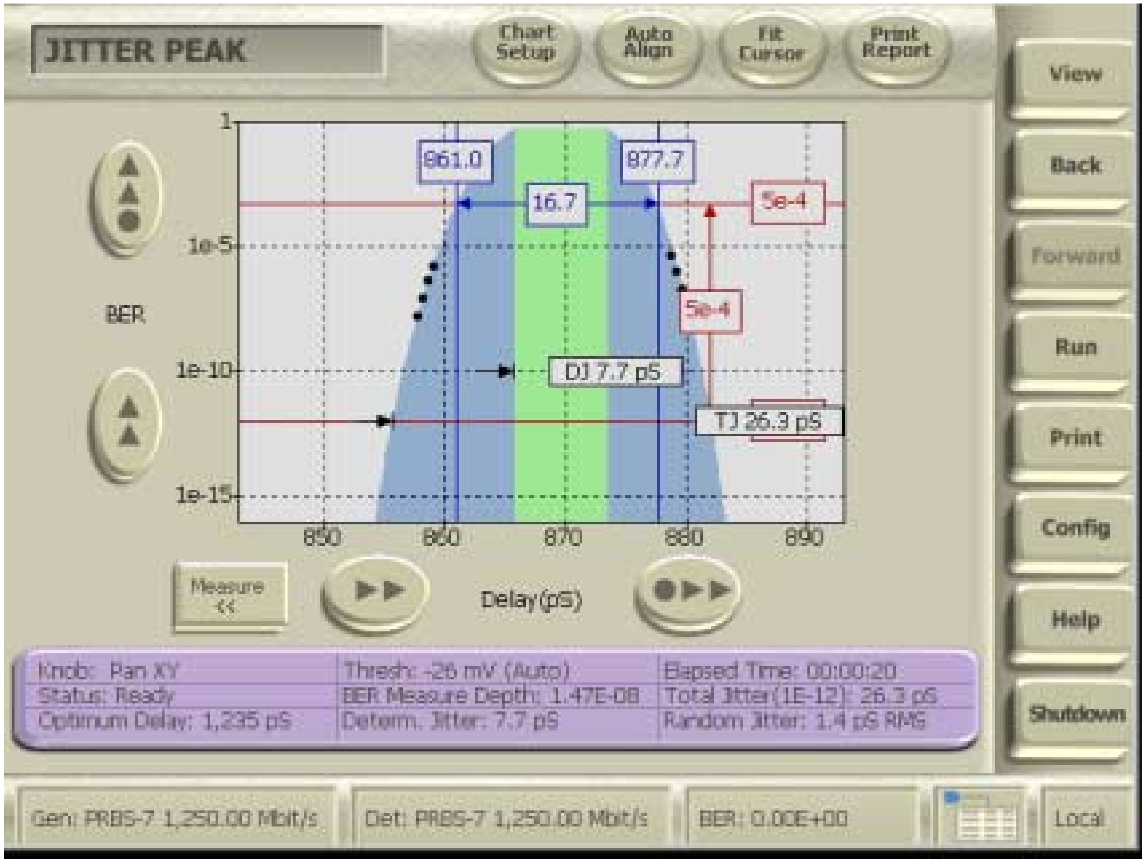
- •Measures all angles of opening
- •Basis for direct interpolation
- •Can be used to learn MASK
- •Can mathematically be “OR”ed together to create composite eye opening for many devices

Mask Testing



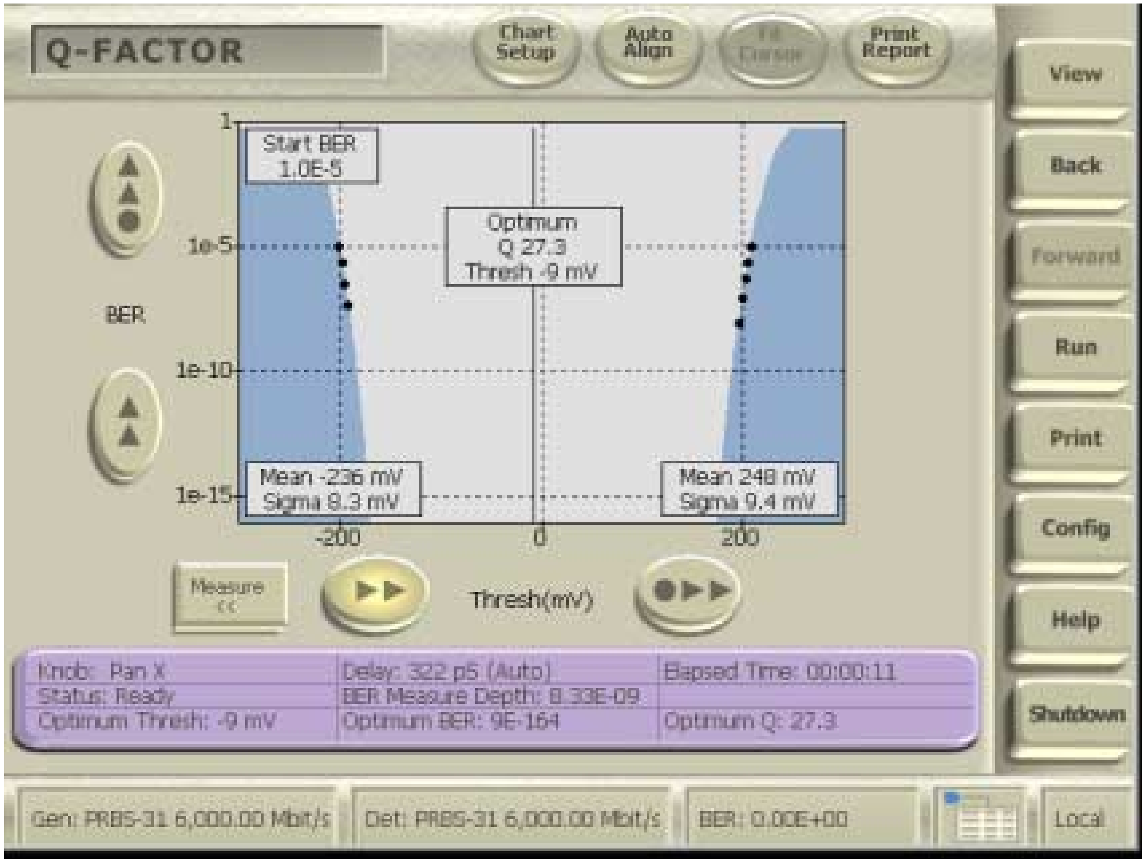
- •Popular grading method
- •Can be "marginalized" mathematically based on model
- •Recent advancements increase depth of testing dramatically
- •Fast go/no-go test

Random & Deterministic Jitter Separation



- Same information as Jitter Bathtub
- Good analysis in long patterns depends on deep measurements
- Separate RJ and DJ numbers enables better understanding of fault
- Very fast measurement (few actual measurements needed)

Q-Factor Measurement



- •Communicates vertical eye opening
- •Ratio of eye height to the sum of noise on the two rails
- •Popular in systems where bit errors come from vertical disturbances (under sea fiber)

The Problem

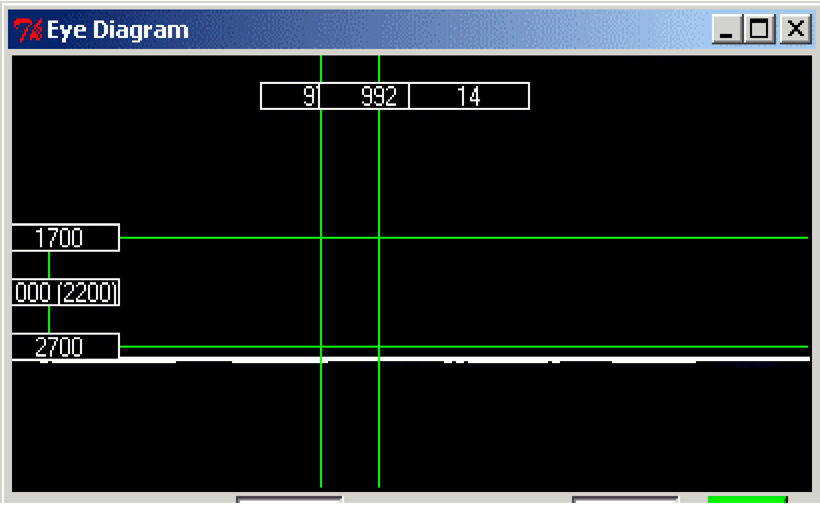
- All these types of measurements are available today—<u>but they are all measurements taken at the input to a piece of test equipment</u>
- Therefore, these analysis tools are suitable for transmitter outputs but offer little help in receiver characterization
  - This type of test equipment is used in receiver testing only to calibrate reference transmitters
- Today's systems are too fast to probe, highly integrated and include on-chip signal processing and disturbances which must be included when performing tests
- Stressed-eye testing offers little diagnostic help, is expensive to implement and difficult to calibrate

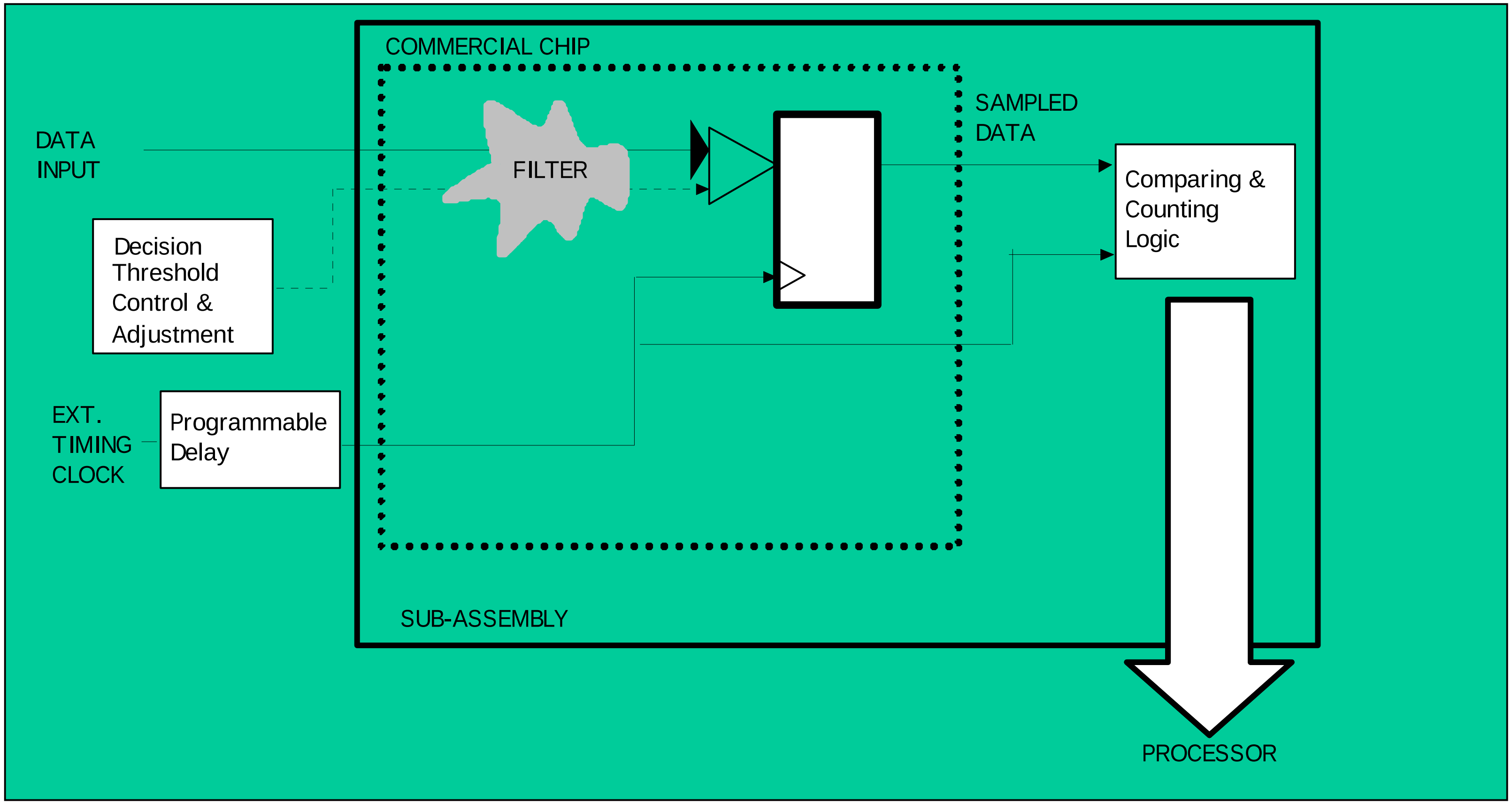
How to Overcome this Problem

- A logic decision circuit can be used to perform all of this analysis if it has variable decision threshold and timing
  - This is proven on BERTScope products
- If the logical decision circuit of the DUT were to have variable decision threshold and timing, this analysis could be done at the DUT
  - Either by using on-DUT testing extensions, or
  - Deferring the instrument’s decisions to the DUT’s decision point
- Significant Advantages
  - No Probing Necessary, completely in-circuit
  - More depth of measurement; more complete testing
  - Reduced test equipment needs
  - Can be used later to diagnose failures and monitor installations

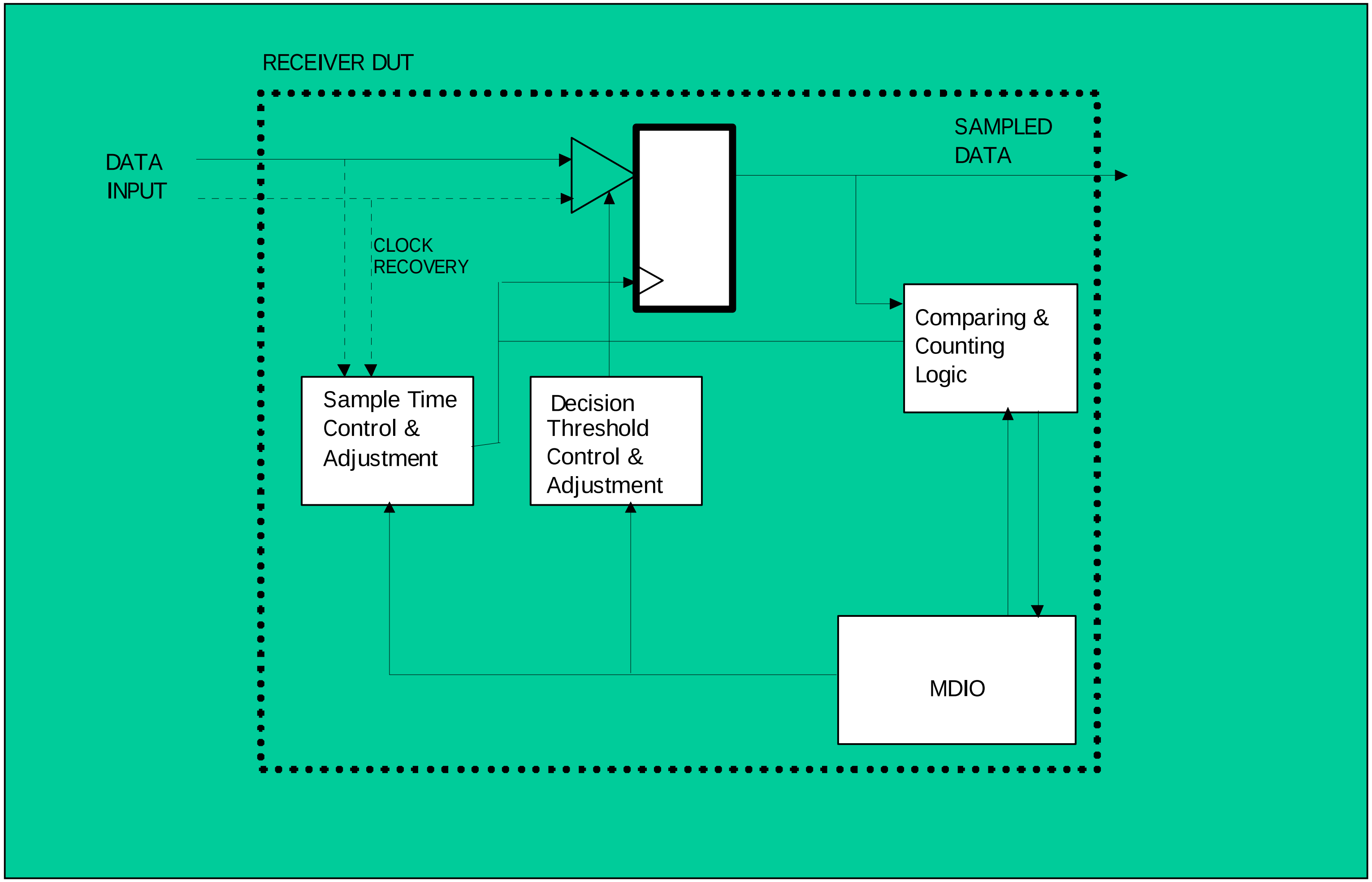
Block Diagram of Example

Image input of receiver chip
On sub-assembly from off-board stimulus

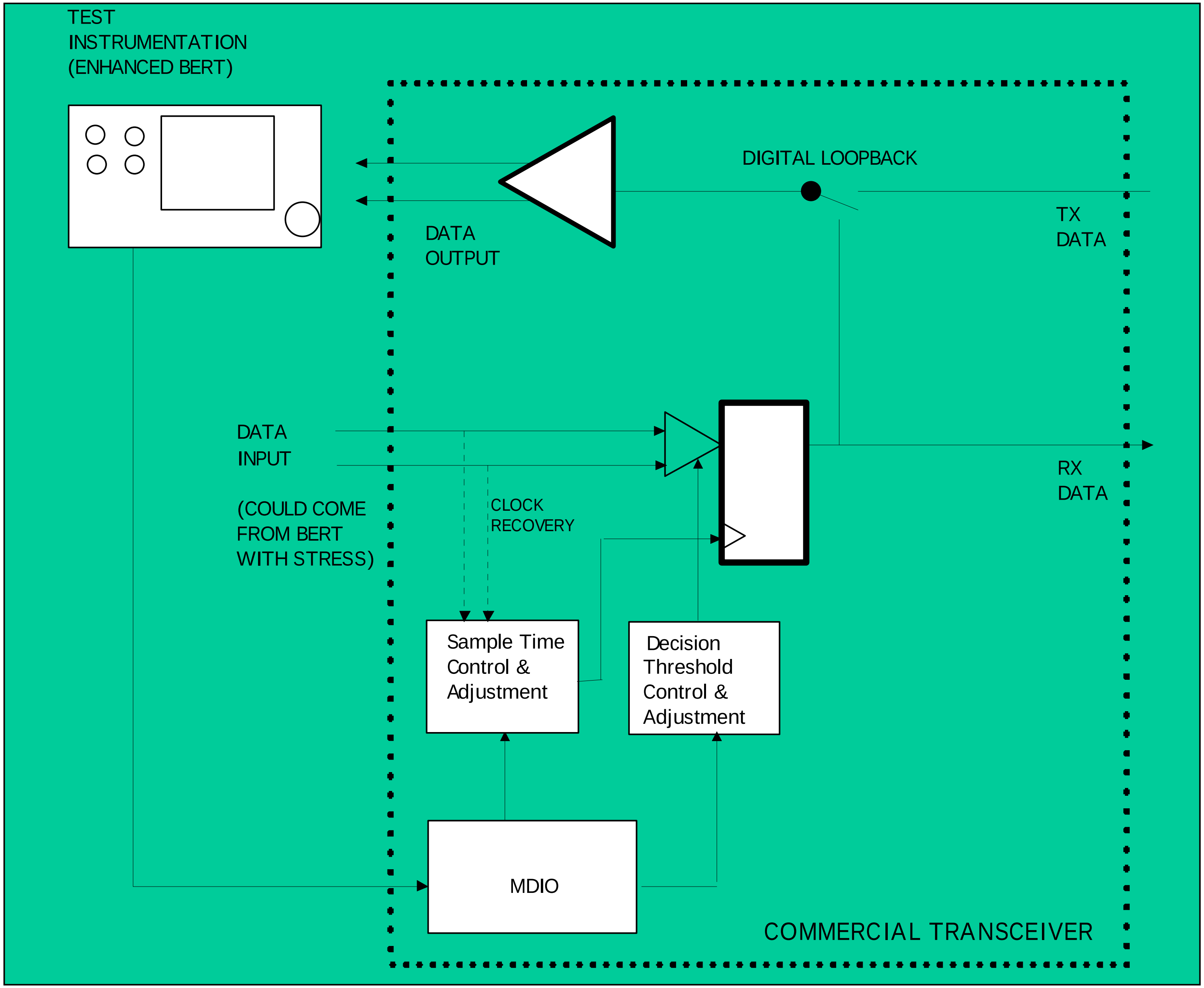




Solution #1 Diagram of BIST



Solution #2 -- Block Diagram (Deferred Analysis)



Proposed Additions to Standard

- MDIO Functional Additions
  - EYE_THRESHOLD
    - 2UA in 10-bits
  - EYE_SAMPLETIME
    - 2UI in 10-bits
  - ERROR_SAMPLE_SIZE
    - Number of bits to accumulate over
  - ERROR_COUNTING (could just extend current test pattern modes)
    - TYPE (PRBS, All-ones, All-zeros, other?)
    - ENABLE (enable counting, disable counting)
    - RESET (reset count to zero)
  - EYE_CAPABILITY
    - Advertises Capability to move Decision Point (1=yes, 0=no)
  - EYE_MEASURE_DONE
    - Status Flag bit

Analysis
Collecting data for one Eye Diagram

- Full eye diagram
  - 300 x 240 ➔ 72,000 pixels
  - Assume it is OK to take 10 seconds per eye diagram, then…
  - 138 microseconds per pixel
  - This implies reading/writing the MDIO interface around 25KHz

```
LOOP:   SET decision location
        RESET ERROR_COUNTER
        READ ERROR_COUNTER
        GOTO LOOP
```

  - 1.38M data bits per eye sample (less settle time)
  - Faster MDIO interface allows faster eye diagrams
- Eye Diagrams are the worst-case
  - Needs fast decision point movement

Analysis
Jitter (RJ/DJ) Measurement Efficiency

- Jitter peak runs well with 16 correctly-position BER measurements
  - 8 on each side of the transition
- Efficient algorithm only makes longest measurements at low BER
- Assume needing at least 10 errors to assert accurate BER
- Assume a 10 second measurement period
  - 4×10^{-10} BER can be fully measured (maximum)
  - Estimates to 1×10^{-12} still means short extrapolation

- Relatively low MDIO activity

Analysis
Mask Test Depth and Time

- Assume mask test is done in three regions
  - 100 points in top region
  - 200 points in middle region
  - 100 points in lower region
- Assume a 10 second test
- 250 Million waveforms tested (maximum)

- Relatively low MDIO activity

Analysis
Measurement Resolution

- 2 UI in 10-bits
  - Approximately 2 mUI per bit
  - Approximately 200fsec per bit (at 10GHz)
- 2 UA in 10-bits
  - 2V in 10-bits ➔ approximately 2mV per bit

Issues

- AC-coupling outputs
  - AC-coupled deferred decisions are only suitable for measurements made “inside” the eye.
  - Not good for measuring overshoot or undershoot
  - Ideally, measurements are made from DC-coupled decisions
  - AC Coupled inputs are no problem

Conclusion

- New 802.3 10G standards can be the first specification to include high fidelity in-place automated signal integrity measurement.
- This can be used for R&D characterization, production testing and system diagnostics.