Soft Decision Analyzer

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Communication System
with Open-Loop Testing

Data to Transmit → Source Coding → Channel Coding → Modulate & Transmit

Soft Decision
Analyzer

Received Data ← Source Coding ← Channel Coding ← Receive & Demodulate

Communication Channel
High-Performance Soft Decision Block Codes

• Modern block decoders can operate at 10% SER or higher
• The decoder cannot operate on a PRBS BERT pattern
• If you break the link to change the data pattern, it reacquires with a different alignment, and you change the performance
• For testing soft-decision block codes with practical receivers and a practical channel, an instrument was needed that could
  – Analyze framed code-blocks (“live data” not just PRBS)
  – Detect and track receiver threshold effects like slips and rotations
As Modern Error Correction Approaches the Shannon Limit, Receivers Must Contend with Ultra-Low SNRs
Communication System with Closed-Loop Testing

Data to Transmit → Source Coding → Channel Coding → Modulate & Transmit

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Soft Decision Analyzer

Communication Channel
SDA Measurable Parameters

- Acquired Clock
- Acquired Data
- Stable Carrier
- Stable Clock
- Stable Data
- Modulation Quadrant
- Symbol Error Rate
- Loss of Signal Detection, Recovery, & Rate
- Rotation Detection, Recovery, & Rate
- Slip Detection, Recovery, & Rate
- Data Run Length
- Delay
- Data Rate
- Data Distribution Histograms
- Signal-to-Noise Ratio
- LDPC Combining Ratio
- Inter-symbol Interference
- Inter-channel Interference
- Decision Threshold Imbalance
- Data Imbalance
- Channel Imbalance
Connecting Test Points

1) Receiver Test with Transmitter and Channel, no Decoder

Encoder → Transmitter → Channel → Receiver → Clock and soft Data, as received → Soft Decision Analyzer

2) Receiver Test with Transmitter and Channel, Translation for Decoder

Encoder → Transmitter → Channel → Receiver → Soft Decision Analyzer → Decoder

3) Receiver Test with Transmitter and Channel, Integrated with Decoder

Encoder → Transmitter → Channel → Receiver → Decoder
Hard vs. Soft Decision

• For binary communications, hard decisions are simply the 1’s and 0’s. Soft decisions also contain the 1’s and 0’s, but also a level of confidence.

• The number of confidence levels is determined by the number of bits used for soft decisions.

• Example of 3-bit soft decision:
  – 011 (Strongest 0)
  – 010
  – 001
  – 000 (Weakest 0)
  – 100 (Weakest 1)
  – 101
  – 110
  – 111 (Strongest 1)
Input and Output Scaling

- Input and output scale tables are used to accommodate variation in bus widths, number representation, and statistical average.
- Problems with logic polarity and pin swapping can be corrected at the click of a mouse.
- The output bus allows SDA to translate between a transmitter and a receiver built to different specifications.
Correlators

- SDA can acquire and maintain reliable correlation between Reference and Test data streams at SERs in excess of 30%. At 17% SER, the SDA can recover from a slip in less than 600 bits.
- Alignment is continuously monitored. Each symbol interval, correlation is evaluated in each of four quadrants for each of nine alignments. The window is re-centered after each slip detection.
- A variable-width correlator (16 to 512 bits) is available, trading resolution for stability.
- Three parameters control hysteresis and squelch
  - Variable-length running totals of how many times each alignment has been best, used to select a winner
  - A variable-length lock-out following an alignment change
  - A correlation quality threshold invokes flywheeling
Maintaining Alignment

On-time correlator “Early-0” (E0) wins

Receiver slips a bit

Sequence Count (each count is one REF clock cycle in duration)
Slips, in a Real Symbol Synchronizer

- Phase jitter trend measured during a slip on the I channel
- Transition time of the slip depends on the loop bandwidth, here it took 300 bits
Constellation Rotations

- QPSK rotation by one quadrant (a 90° slip of the carrier tracking loop) causes channel swapping.
- Channel swapping means symbol synchronizer swapping.
- Due to symbol staggering, the symbol synchronizers are now integrating mid-bit to mid-bit.
- A half-bit slip one direction or the other must ensue to compensate.
Es/No Estimations

- Es/No from hard decision SER and inverse $Q()$ (practical meaning and highly stable)
- Es/No from fitted bell curve (high stability but assumes Gaussian noise)
- Es/No from mean and standard deviation of correlated soft decisions (direct compare for many SNR estimators)
- Es/No from median and long-tail standard deviation of correlated soft decisions (less influenced by clipping, and no distribution assumed)
Quantified Imbalances

• Not just one, but 8 histograms are run concurrently and then analyzed for:
  – Data Imbalance
  – Logic Threshold Imbalance
  – Channel Imbalance
  – Transition Density
  – choice of Inter-Symbol Interference (ISI) or Inter-Channel Interference
Actual Receiver Performance

- Probability of Error is much higher for bits sent as a “1” following a “0” – but only for one of the two channels.
Correlated Histograms and Anomalous Behavior

Most symbols have low amplitude, but most are correct. Why?

Uncorrelated

Correlated

Underlying Phenomenon
Data Logging

• Continuous Historical Record
  – Slips, rotations
  – Long runs
  – External triggers

• Publish on Demand
  – Configuration
  – BER and Es/No measurements
  – User notes
Data Reinvestigation

- Average symbol amplitude data taken from SER curves, plotted as amplitude droop

"Es/No" from SER (input to decoder)
Supporting Measurements

• Run Lengths ($2^{15} - 1$ pattern shown here)
• Discrete Programmable Test Points
  – Slips, rotations, long runs, clock phase lock, correlator lock, copy of data or clock...
  – General purpose test points with selectable functionality
• Channel Simulator
Sweeping Degradation From Baseline

Test Results, Constant Jitter

Revised Model Results, Constant Degradation

Figure 16. BER degradation surface plot as a function of peak jitter and jitter rate for $\zeta = 0.4$. 
Use-Case Example

Orion Transponder – Baseband Processor Integration