Improved Definition of CRU (Comments 151, 152, and 153)

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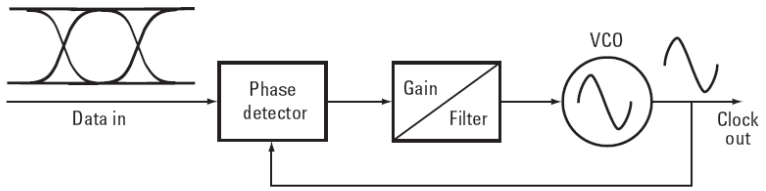
Background

- **In 802.3 standards our definition of Golden CRU has been rather sloppy by only defining the 1st order clock recovery unit at 20 dB/dec slope and a corner frequency of 4 MHz (4.27 MHz in case of inner FEC)**
  - OTN defined CRU maximum jitter peaking of 0.1 dB
  - XFP MSA INF-8077i defined instrument grade CRU with maximum jitter peaking of 0.1 dB and defined the Ethernet grade CDR with maximum jitter peaking of 1 dB
- **Improved definition of Golden CRU definition improves measurement accuracy and variability**
  - Golden CRU is a metrology grade instrument and can be specified to be better than standard Ethernet CRU's
- **Ghiasi & Le Cheminant ghiasi_3bs_01_0715 contribution provide background on jitter transfer, jitter peaking, and CRU.**

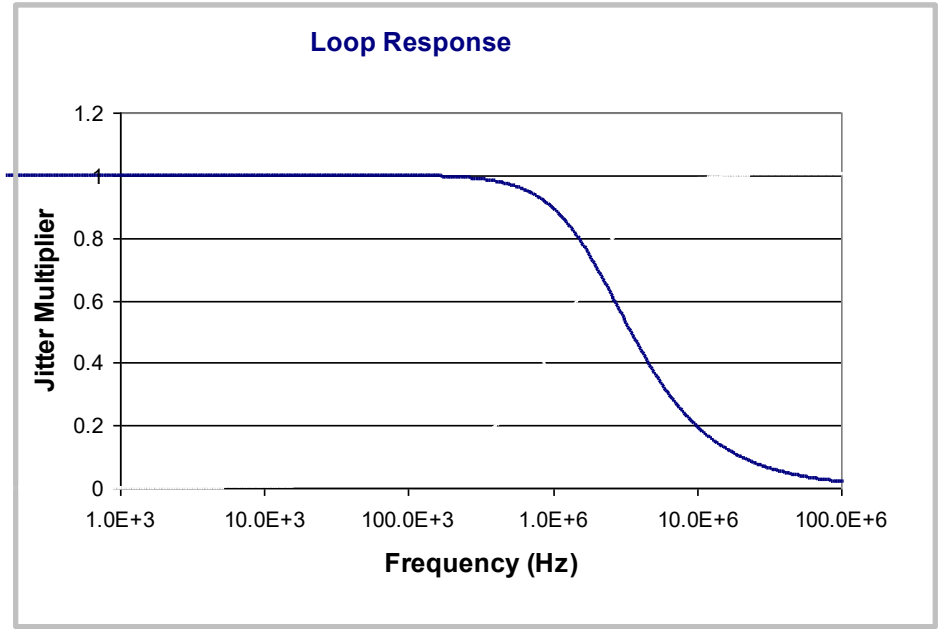
PLL concepts: PLL jitter transfer indicates how *recovered clock* (jitter out) tracks the data (jitter in)

- **The response of the PLL is generally a low-pass function, sometimes referred to as the jitter transfer response or JTF**

$$\text{Closed loop gain} = \frac{\phi_{out}}{\phi_{in}} = \frac{A(s)}{1 + A(s)} = G(s) = |G(s)|e^{j\phi(s)}$$



Low frequency jitter is transferred to the clock, high frequency jitter is filtered by the golden PLL

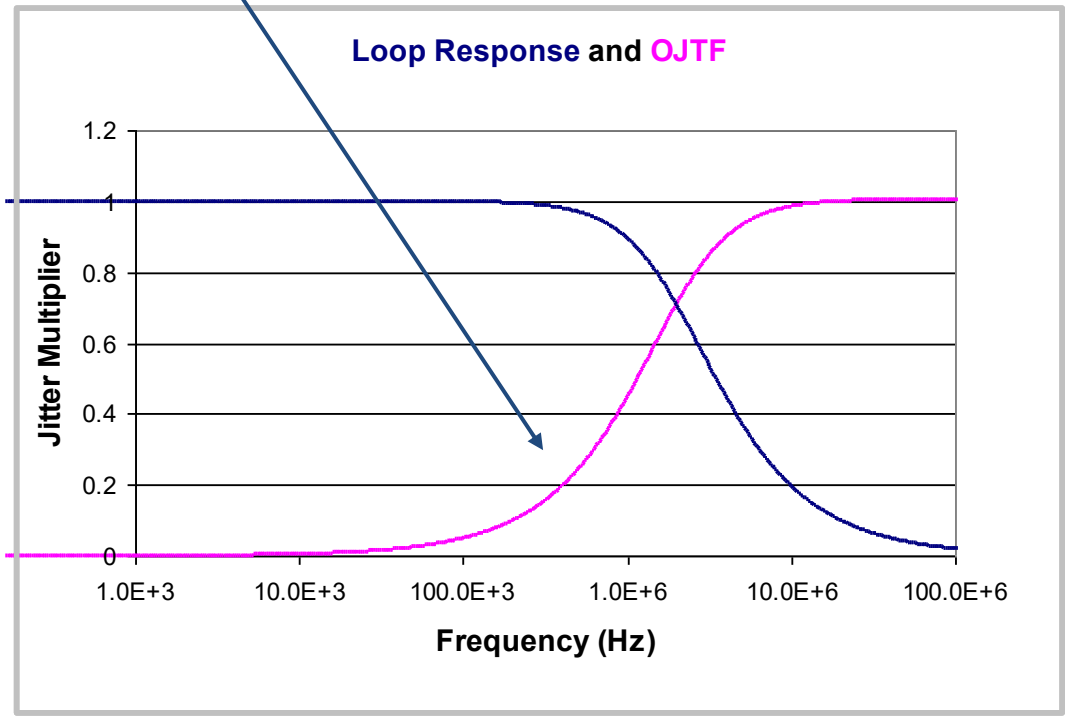


Slide from Ghiasi & Le Cheminant [ghiasi_3bs_01_0715]

The observed jitter transfer function (OJTF, the jitter that is observed by a receiver, or on the instrument clocked/triggered by the recovered clock)

- **The observed jitter is a complement to the PLL jitter transfer response**
- **OJTF=1-JTF (Phase matters!)**
- **As the jitter on the recovered clock trigger rolls off, common mode effect is reduced**
- **As jitter frequency gets large, eventually there is no jitter on the recovered clock and all the higher frequency jitter on the data stream is observed**

$$\mathrm{OJTF} = 1 - G(s) = 1 - \left|G(s)\right| e^{j\phi(s)}$$



Slide from Ghiasi & Le Cheminant ghiasi_3bs_01_0715

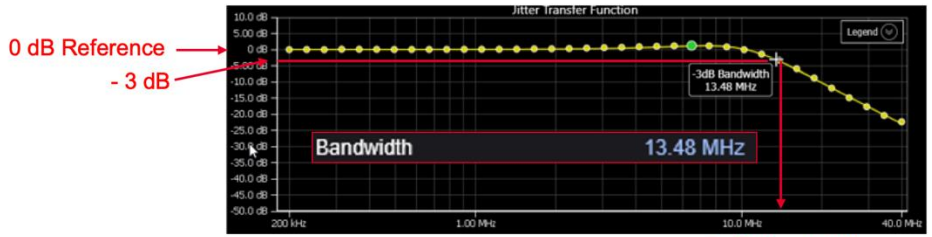
Wide Varieties of CDR Implementations

- **Jitter Transfer Function (JTF) of several 56 GBd CDR's were investigated by calvin_3dj_01a_2411**
  - A Retimer (CDR) has a JTF BW of 13.48 MHz with 1.37 dB peaking – 2nd/3rd order PLL with 1.37 dB jitter peaking has good tracking but high BW may result in excessive jitter generation
  - A Retimer (CDR) with dual has tracking BW of 2 MHz may fail input JTOL while having excellent jitter transfer BW 42 kHz – 1st order PLL has no jitter peaking and excellent jitter transfer but 2 MHz tracking may fail input JTOL.

PLL Bandwidth and Peaking

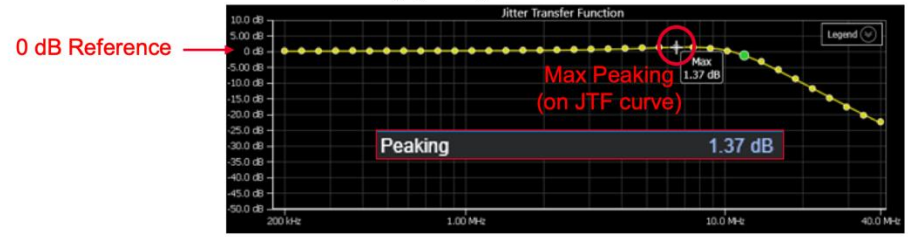
Standards typically specify PLL bandwidth and peaking (measured on the Jitter Transfer Function)

- PLL 3dB Bandwidth



- 3 dB Bandwidth (on JTF curve)

- PLL Peaking (max)



KEYSIGHT

TP1a->TP2 (Electro-Optic) JTF is observed when the reference modulator is replaced with an actual 800G Transceiver.

- The JTF of a retimed module measured up to 2MHz showing the characteristic PLL response however at frequencies much lower than expected.
- PLL BW is 42Khz in this case. 2 decades lower than specs.
- Low frequency impairments are being directly transferred to the TP2 output. The "instrumentation" performing TDECQ at TP2 is performing analog equivalent 4MHz PLL operations and nominally blind to any impairments to the left of this PLL bandwidth. Discrepancies will be significant.

KEYSIGHT

… cont. Wide Varieties of CDR Implementations

- The subject of jitter transfer characteristics is an important place for future improvements (past 802.3dj); not addressed here.
- Similarly the jitter peaking specification can use improvements, likely a future activity as well; not addressed here.
- **What can we do today to help the implementers: Clarity of definition**

Jitter specification – clarity of definition

- **179.9.4.2.1 — TX equalizer coefficient measurement (electrical AUI, new dj clause):**
  "The reference clock recovery unit (CRU) used in the measurement acts as a high-pass jitter filter with a -3 dB corner frequency of 4 MHz and a slope of 20 dB/decade."
- **179.9.4.7 — Output jitter (same clause, few pages later):**
  ~~"Measurement is performed with a clock recovery unit (CRU) with a corner frequency of 4 MHz and a slope of 20 dB/decade.“~~ *use the above*
- **180.9.2 — Reference receiver (optical PMD family, ~106.25 GBd):**
  "~~The CRU has a corner frequency of 4 MHz and a slope of 20 dB/decade.~~ *use the above*. **The CRU may be implemented in hardware or software depending on oscilloscope technology."**
  (This is the definition that 180.9.6's TDECQ test references by pointer, rather than restating.)
- **182.9.2 — Reference receiver (optical PMD family, ~113.4375 GBd):**
  "~~The CRU has a corner frequency of 4.27 MHz and a slope of 20 dB/decade.~~ *use the above/with 4.27MHz* **The CRU may be implemented in hardware or software depending on oscilloscope technology."**
- **182.9.6 — TDECQ exceptions list (same clause 182):**
  ~~"The clock recovery unit (CRU) has a corner frequency of 4.27 MHz." — slope not restated here.~~ *use the above/with 4.27MHz*
- **183.9.2 — Reference receiver (parallel optical PMD family):**
  ~~Identical wording to 182.9.2, value 4.27 MHz.~~ *use the above/with 4.27MHz*
- **183.9.6 — TDECQ exceptions list:**
  ~~Identical wording to 182.9.6, value 4.27 MHz, slope not restated.~~ *use the above/with 4.27MHz*

Golden CRU Definition

- **The current definition**
  - "The CRU has a 3 dB corner frequency of 4 MHz and a slope of 20 dB/decade. The CRU may be implemented in hardware or software depending on oscilloscope technology".
  - The above CRU definition certainly is not a Golden CRU definition but rather a Bronze CRU definition!
- **Proposed improved CRU definition (with Inner FEC)**
  - "The reference clock recovery unit (CRU) is first order with a 3 dB high-pass corner frequency of 4 MHz when measured with Pattern 3 or 5 and a slope of 20 dB/decade up to at least 40 MHz (42.7 MHz)."
  - The improved CRU definition adds 1st order response to at least to 40 MHz. CRU/CDR tracking BW varies with transition density and therefore test pattern should be defined.

Thank You!