Serial Link Analysis Terminology

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SiSoft

- Signal Integrity

Presentation Goals

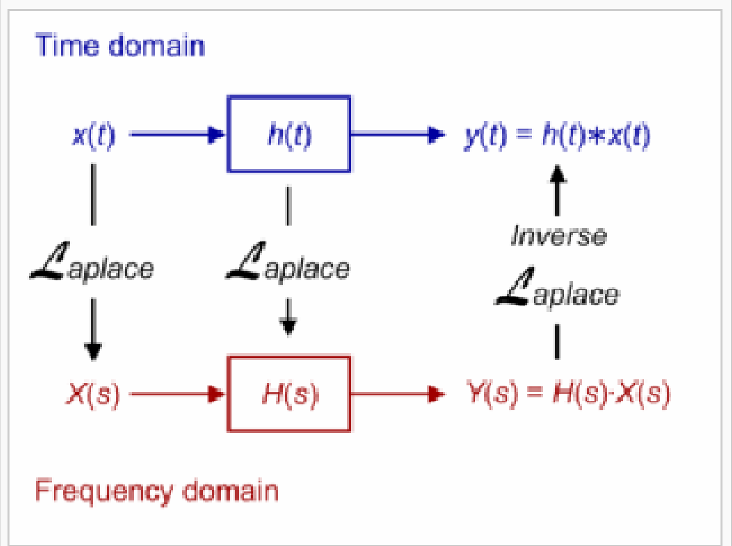
- State fundamental analysis assumptions for serial links
- Propose starting point for serial channel terminology
- Start discussion on common reference terms

Fundamental Assumptions

- SERDES drivers / receivers are linear devices
  - Channels can be treated as linear, time-invariant (LTI) systems
  - Operating parameters may drift over time, but local (billions of bits) conditions are static
- All analysis can be done in either frequency or time domain (or a mixture of the two)
- Data for any channel component can be supplied as either time or frequency domain & converted

LTI Theory

Equivalently, any LTI system can be characterized in the *frequency domain* by the system's transfer function, which is the Laplace transform of the system's impulse response (or Z transform in the case of discrete-time systems). As a result of the properties of these transforms, the output of the system in the frequency domain is the product of the transfer function and the transform of the input. In other words, convolution in the time domain is equivalent to multiplication in the frequency domain.



Relationship between the **time domain** and the **frequency domain**

For all LTI systems, the eigenfunctions, and the basis functions of the transforms, are complex exponentials. This is, if the input to a system is the complex waveform $A\exp(st)$ for some complex amplitude A and complex frequency s, the output will be some complex constant times the input, say $B\exp(st)$ for some new complex amplitude B. The ratio B / A is the transfer function at frequency s.

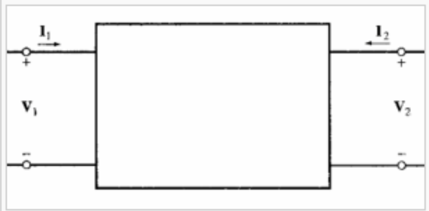
Because sinusoids are a sum of complex exponentials with complex-conjugate frequencies, if the input to the system is a sinusoid, then the output of the system will also be a sinusoid, perhaps with a different amplitude and a different phase, but always with the same frequency.

Network Parameters

Two-port network

From Wikipedia, the free encyclopedia

A **two-port network** (or **four-terminal network**, or **quadripole**) is an electrical circuit or device with two pairs of terminals. Examples include transistors, filters and matching networks. The analysis of two-port networks was pioneered in the 1920s by Franz Breisig, a German mathematician.



Example two-port network

ABCD-parameters

The ABCD-parameters are known variously as chain, cascade, or transmission parameters.

$$\begin{pmatrix} V_2 \\ I_2 \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \begin{pmatrix} V_1 \\ I_1 \end{pmatrix}.$$

where

$$A = \left.\frac{V_2}{V_1}\right|_{I_1=0} \qquad B = \left.\frac{V_2}{I_1}\right|_{V_1=0}$$

$$C = \left.\frac{I_2}{V_1}\right|_{I_1=0} \qquad D = \left.\frac{I_2}{I_1}\right|_{V_1=0}$$

This technique is exactly analogous to the use of ABCD matrices for ray tracing in the science of optics. *See also* ray transfer matrix.

Z-parameters (impedance parameters)

$$\begin{pmatrix} V_1 \\ V_2 \end{pmatrix} = \begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix} \begin{pmatrix} I_1 \\ I_2 \end{pmatrix}.$$

where

$$Z_{11} = \left.\frac{V_1}{I_1}\right|_{I_2=0} \qquad Z_{12} = \left.\frac{V_1}{I_2}\right|_{I_1=0}$$

$$Z_{21} = \left.\frac{V_2}{I_1}\right|_{I_2=0} \qquad Z_{22} = \left.\frac{V_2}{I_2}\right|_{I_1=0}$$

Y-parameters (admittance parameters)

$$\begin{pmatrix} I_1 \\ I_2 \end{pmatrix} = \begin{pmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{pmatrix} \begin{pmatrix} V_1 \\ V_2 \end{pmatrix}.$$

where

$$Y_{11} = \left.\frac{I_1}{V_1}\right|_{V_2=0} \qquad Y_{12} = \left.\frac{I_1}{V_2}\right|_{V_1=0}$$

$$Y_{21} = \left.\frac{I_2}{V_1}\right|_{V_2=0} \qquad Y_{22} = \left.\frac{I_2}{V_2}\right|_{V_1=0}$$

Scattering Parameters

Two-Port Networks

The S-parameter matrix for the 2-port network is probably the most common and it serves as the basic building block for generating the higher order matrices for larger networks. In this case the relationship between the reflected, incident power waves and the S-parameter matrix is given by:

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

Expanding the matrices into equations gives:

$$b_1 = S_{11}a_1 + S_{12}a_2$$

and

$$b_2 = S_{21}a_1 + S_{22}a_2$$

Each equation gives the relationship between the reflected and incident power waves at each of the network ports, 1 and 2, in terms of the network's individual S-parameters, S_{11}, S_{12}, S_{21} and S_{22}. If one considers an incident power wave at port 1 (a_1) there may result from it waves exiting from either port 1 itself (b_1) or port 2 (b_2). However if, according to the definition of S-parameters, port 2 is terminated in a load identical to the system impedance (Z_0) then, by the maximum power transfer theorem, b_2 will be totally absorbed making a_2 equal to zero. Therefore

$$S_{11} = \frac{b_1}{a_1} = \frac{V_1^-}{V_1^+} \text{ and } S_{21} = \frac{b_2}{a_1} = \frac{V_2^-}{V_1^+}$$

Similarly, if port 1 is terminated in the system impedance then a_1 becomes zero, giving

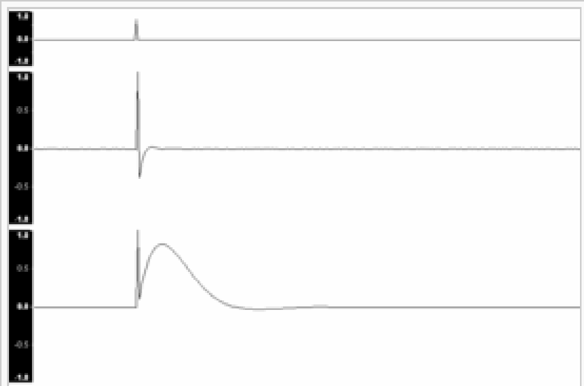
$$S_{12} = \frac{b_1}{a_2} = \frac{V_1^-}{V_2^+} \text{ and } S_{22} = \frac{b_2}{a_2} = \frac{V_2^-}{V_2^+}$$

Each 2-port S-parameter has the following generic descriptions:

- S_{11} is the input port voltage reflection coefficient
- S_{12} is the reverse voltage gain
- S_{21} is the forward voltage gain
- S_{22} is the output port voltage reflection coefficient

Impulse Response

In simple terms, the **impulse response** of a system is its output when presented with a very brief signal, an impulse. While an impulse is a difficult concept to imagine, and an impossible thing in reality, it represents the limit case of a pulse made infinitely short in time *while* maintaining its area or integral (thus giving an infinitely high peak). While this is impossible in any real system, it is a useful concept as an idealization.

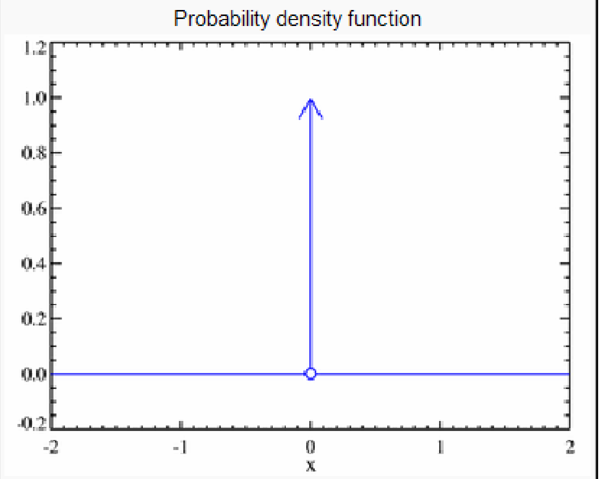


The Impulse response from a simple audio system. Showing the original impulse, with high frequencies boosted, then with low frequencies boosted.

Dirac's Delta Function

The **Dirac delta** or **Dirac's delta**, often referred to as the unit impulse function and introduced by the British theoretical physicist Paul Dirac, can usually be informally thought of as a function δ(*x*) that has the value of infinity for *x* = 0, the value zero elsewhere. The integral from minus infinity to plus infinity is 1. The discrete analog of the delta "function" is the Kronecker delta which is sometimes known as a delta function. It is also often referred to as the discrete unit impulse function. Note that the Dirac delta is not a function, but a distribution that is also a measure.

Dirac delta function



Schematic representation of the Dirac delta function for $x_0 = 0$. A line with an arrow is usually used to schematically represent the Dirac delta function. The height of the arrow is usually used to specify the value of any multiplicative constant, which will give the area under the function. The other convention is to write the area next to the arrowhead.

Pulse Response

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pulse response | Search

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We will be offering a definition for pulse response as part of this effort

Transfer Function

The transfer function is commonly used in the analysis of single-input single-output analog electronic circuits, for instance. It is mainly used in signal processing, communication theory, and control theory. The term is often used exclusively to refer to linear, time-invariant systems (LTI), as covered in this article. Most real systems have non-linear input/output characteristics, but many systems, when operated within nominal parameters (not "over-driven") have behavior that is close enough to linear that LTI system theory is an acceptable representation of the input/output behavior.

In its simplest form for continuous-time input signal $x(t)$ and output $y(t)$, the transfer function is the linear mapping of the Laplace transform of the input, $X(s)$, to the output $Y(s)$:

$$Y(s) = H(s)\,X(s)$$

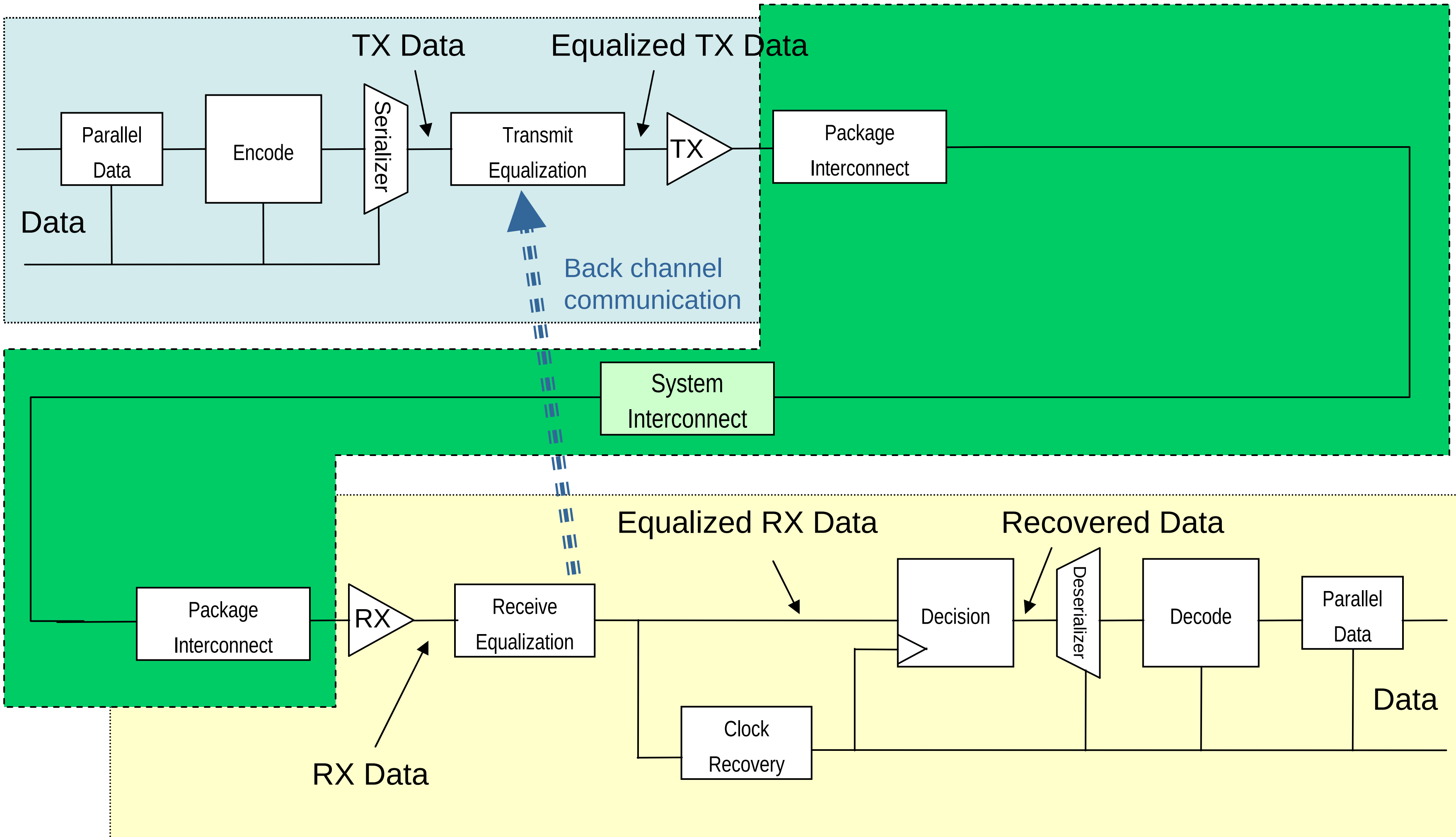
or

$$H(s) = \frac{Y(s)}{X(s)}$$

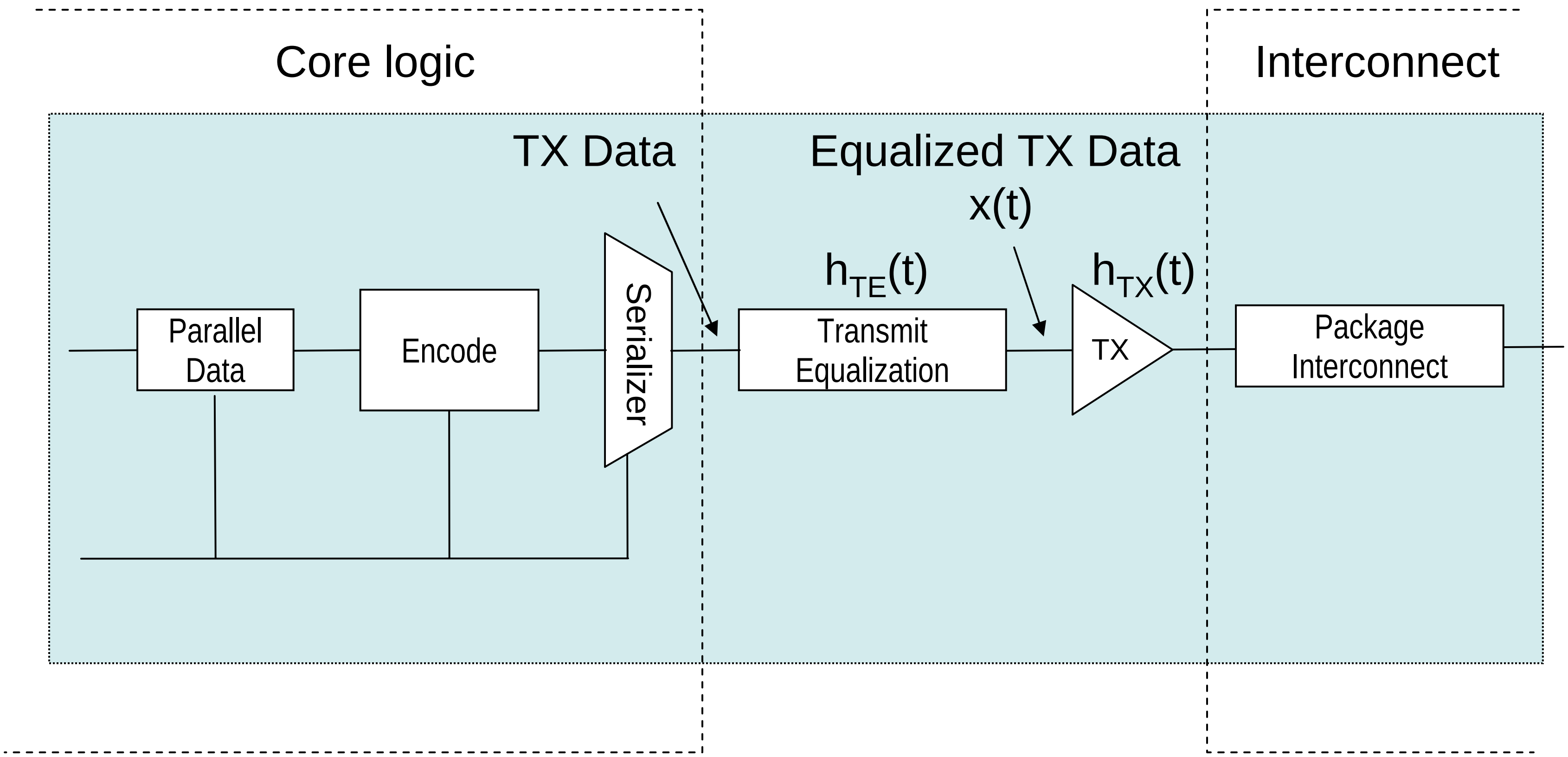
where $H(s)$ is the transfer function of the LTI system.

In discrete-time systems, the function is similarly written as $H(z) = \frac{Y(z)}{X(z)}$ (see Z transform).

End to End High Speed Channel

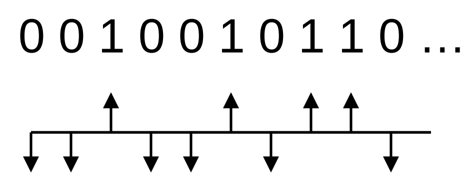


SERDES Driver Model

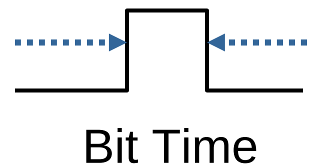


Driver Terminology

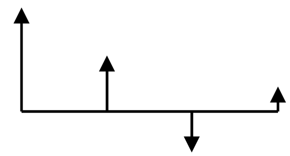
- Bit stream b(t)
  - Sum of delta functions



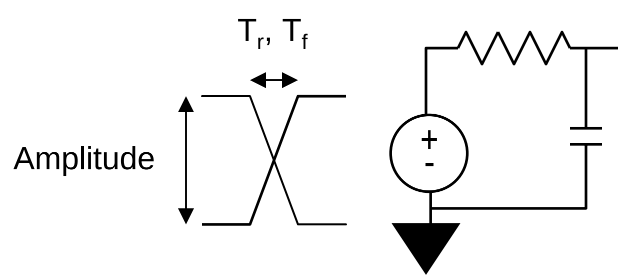
- Data symbol p(t)
  - Single bit width pulse



- Transmitter equalization $h_{TE}(t)$
  - Sum of weighted delta functions
    - Coefficients & delays

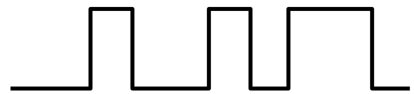


- Transmitter characteristic $h_{TX}(t)$
  - Rise/fall time
  - Voltage swing
  - Drive impedance
  - Capacitance

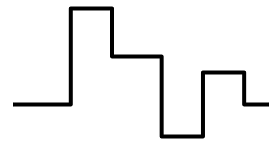


Driver Math

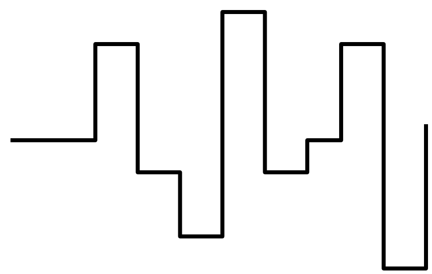
- TX data
  $= b(t) \otimes p(t)$



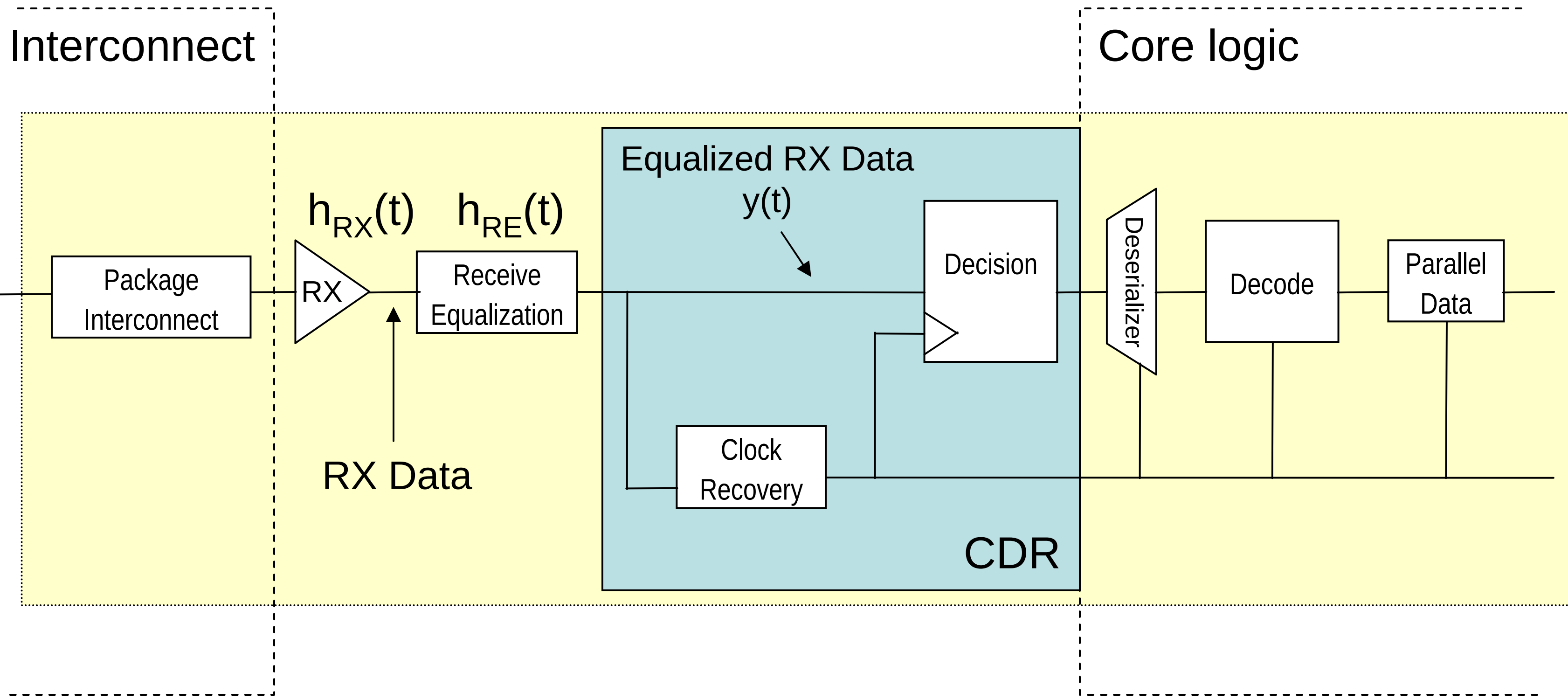
- Equalized TX data symbol
  $= p(t) \otimes h_{TE}(t)$



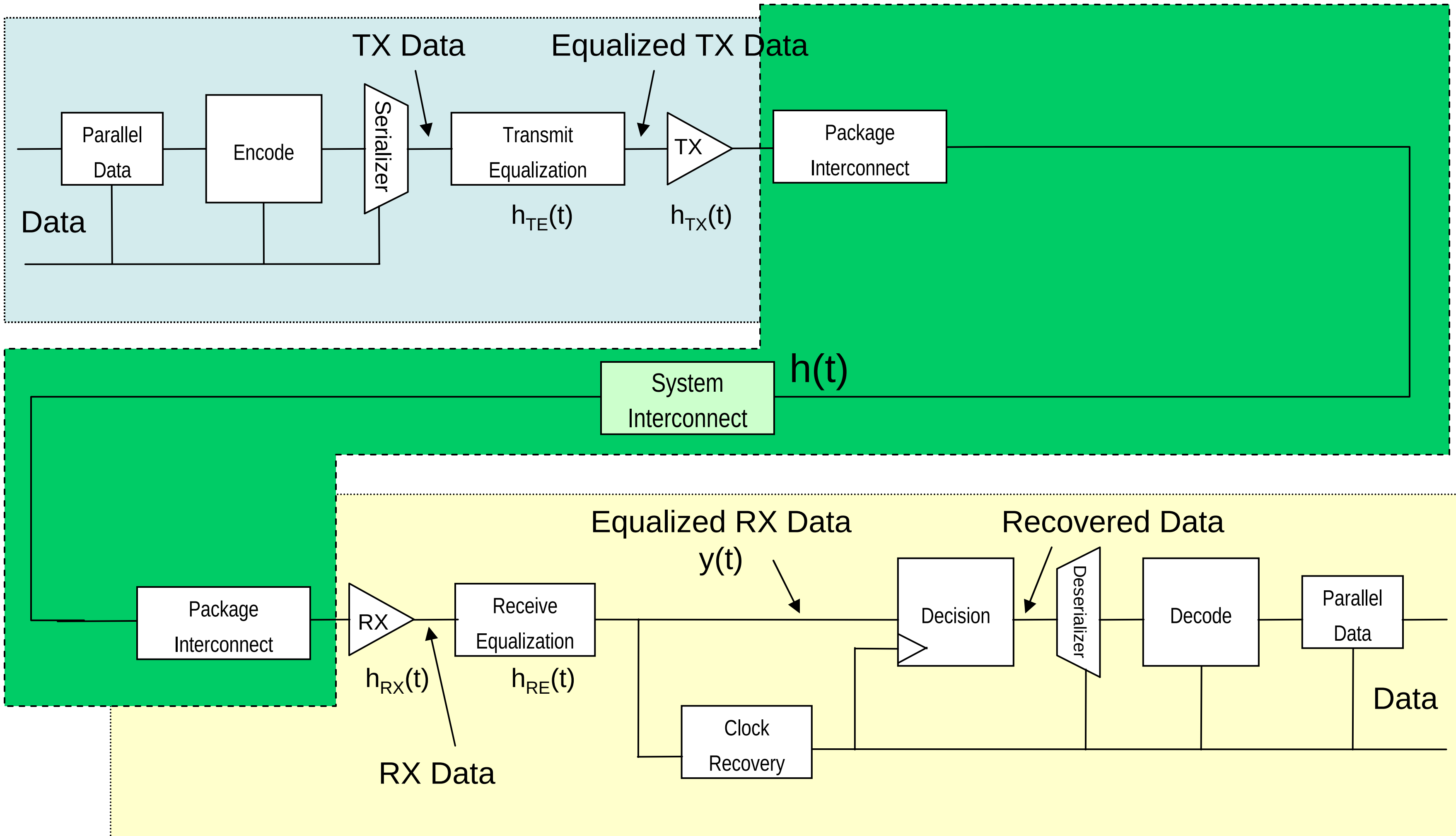
- Equalized TX data
  $= b(t) \otimes p(t) \otimes h_{TE}(t)$



SERDES Receiver Model



End to End High Speed Channel



Channel Math

- Channel impulse response
  $= h_{TX}(t) \otimes h(t) \otimes h_{RX}(t)$

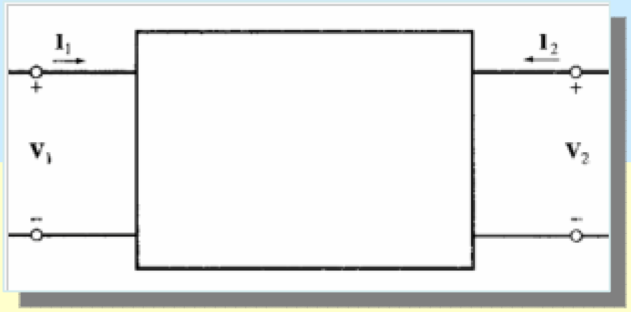
- Channel pulse response
  $= h_{TX}(t) \otimes h(t) \otimes h_{RX}(t) \otimes p(t)$

- Equalized channel pulse response
  $= h_{TE}(t) \otimes h_{TX}(t) \otimes h(t) \otimes h_{RX}(t) \otimes h_{RE}(t) \otimes p(t)$

- Equalized RX data: $y(t)$
  $= h_{TE}(t) \otimes h_{TX}(t) \otimes h(t) \otimes h_{RX}(t) \otimes h_{RE}(t) \otimes p(t) \otimes b(t)$

Domain Conversions

	Input	Network Characteristic	Output
Time Domain	x(t)	Impulse Response h(t)	$y(t) = x(t) \otimes h(t)$
Frequency Domain	X(s)	Transfer Function H(s)	$Y(s) = X(s) * H(s)$



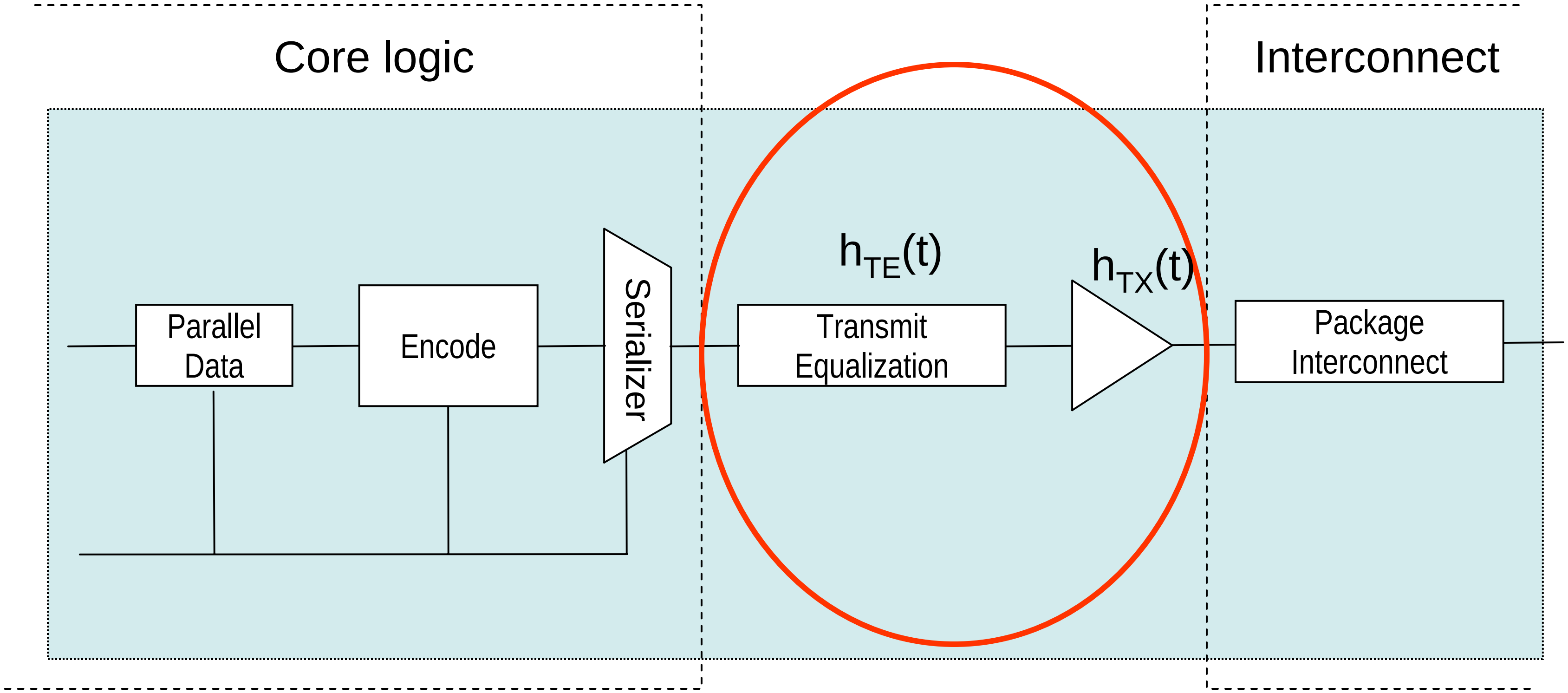
Bi-Lingual Channel Math

- Channel impulse response
  $= h_{tx}(t) \otimes h(t) \otimes h_{rx}(t)$ [Time Domain]
  $= H_{TX}(s) * H(s) * H_{RX}(s)$ [Freq. Domain]

- Channel pulse response
  $= h_{tx}(t) \otimes h(t) \otimes h_{rx}(t) \otimes p(t)$ [Time Domain]
  $= H_{T}(s) * H(s) * H_{R}(s) * P(s)$ [Freq. Domain]

- Equalized RX Data
  $= h_{TE}(t) \otimes h_{TX}(t) \otimes h(t) \otimes h_{RX}(t) \otimes h_{RE}(t) \otimes p(t) \otimes b(t)$ [Time Domain]
  $= H_{TE}(s) * H_{TX}(s) * H(s) * H_{RX}(s) * H_{RE}(s) * P(s) * B(s)$ [Freq. Domain]

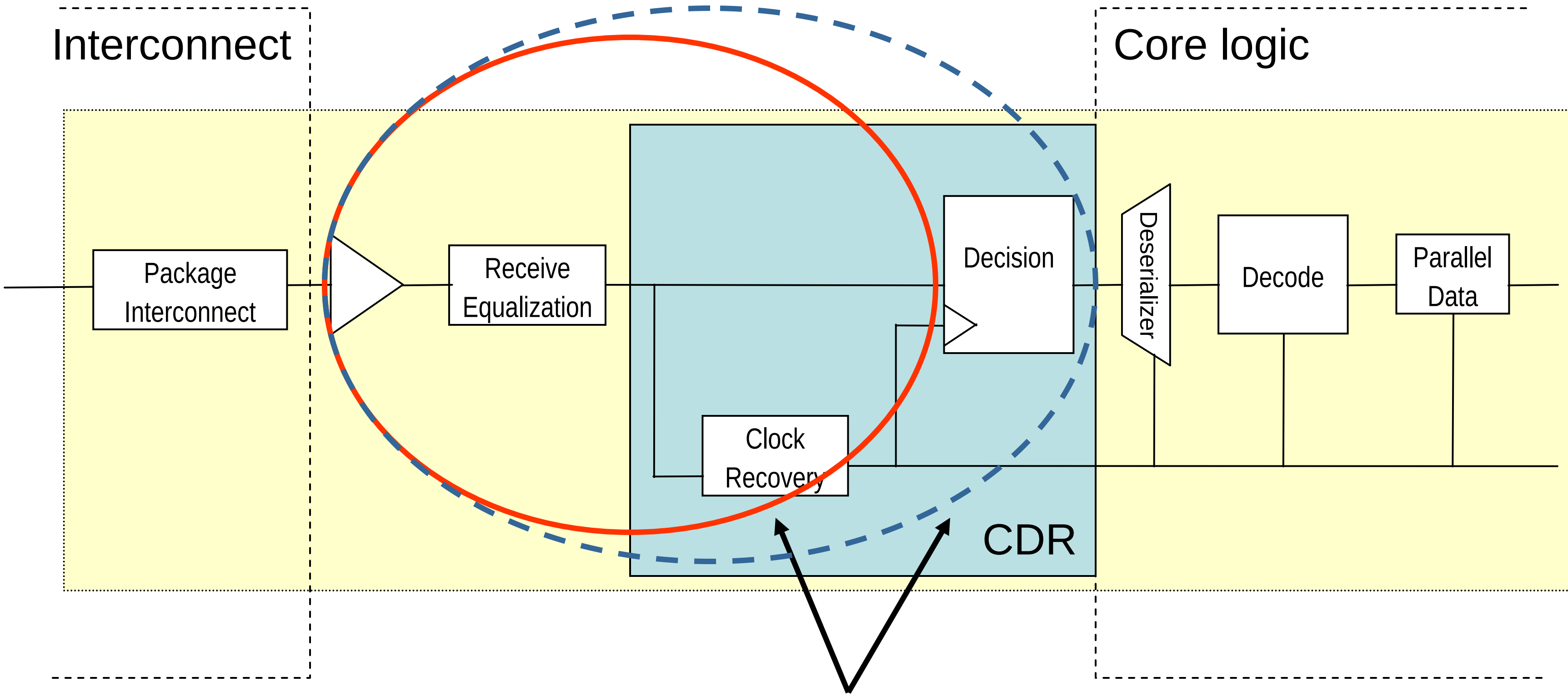
Modeling SERDES Drivers



Do we need more than:

taps, coefficients, amplitude, rise/fall time, impedance, C_Comp?

Modeling SERDES Receivers



Where should the model boundary be?
What data should be returned?
What return data should be standardized?

Discussion Points

- Is a TX API needed at this time?
- Is a single receiver model useful?
- What standard data should a receiver model return?
- How should interaction between TX and RX equalization be handled?