Lecture 1

The Digital Abstraction

Learning Objectives

- Understand digital encoding of information.
- Appreciate the benefits of digital abstraction.
- Understand why digital circuits must adhere to the static discipline.
- Ability to determine the noise margins of a digital circuit.

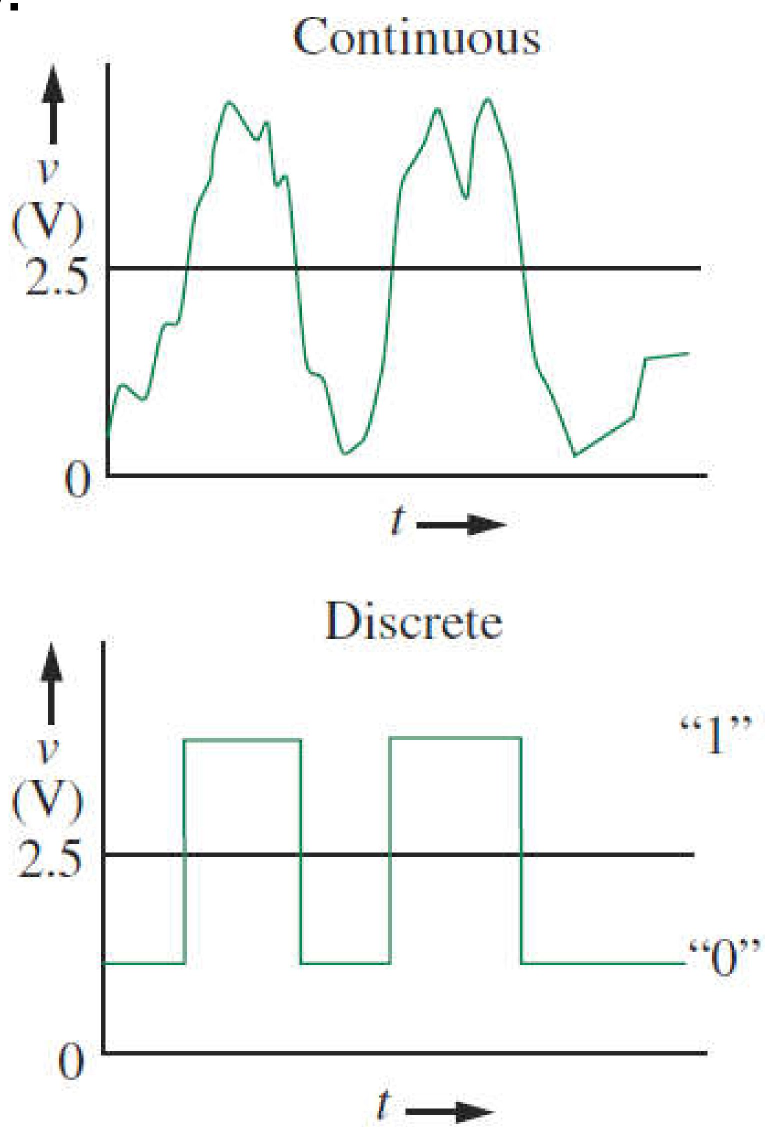
Value Discretization

- Value discretization forms the basis of digital abstraction. The basic idea is to lump signal values that fall within some interval into a single value.

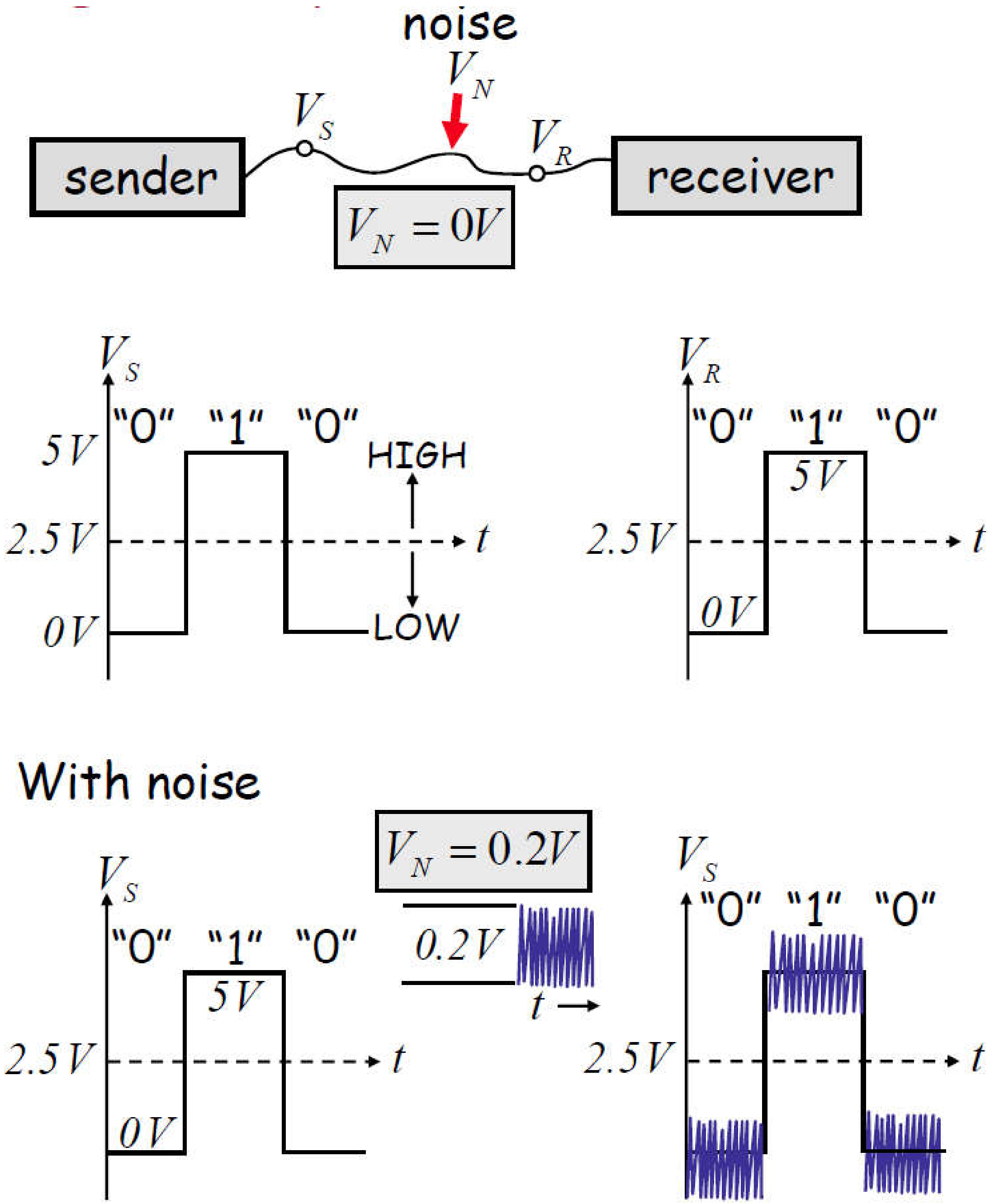
- Example of a voltage signal discretized into two levels.

- In this example, an observed voltage value between 0 volts and 2.5 volts is treated as a "0".

- A value between 2.5 volts and 5 volts is treated as a "1".



Noise Margins



- Better noise immunity requires larger "noise margins"
- For "1":

  noise margin →

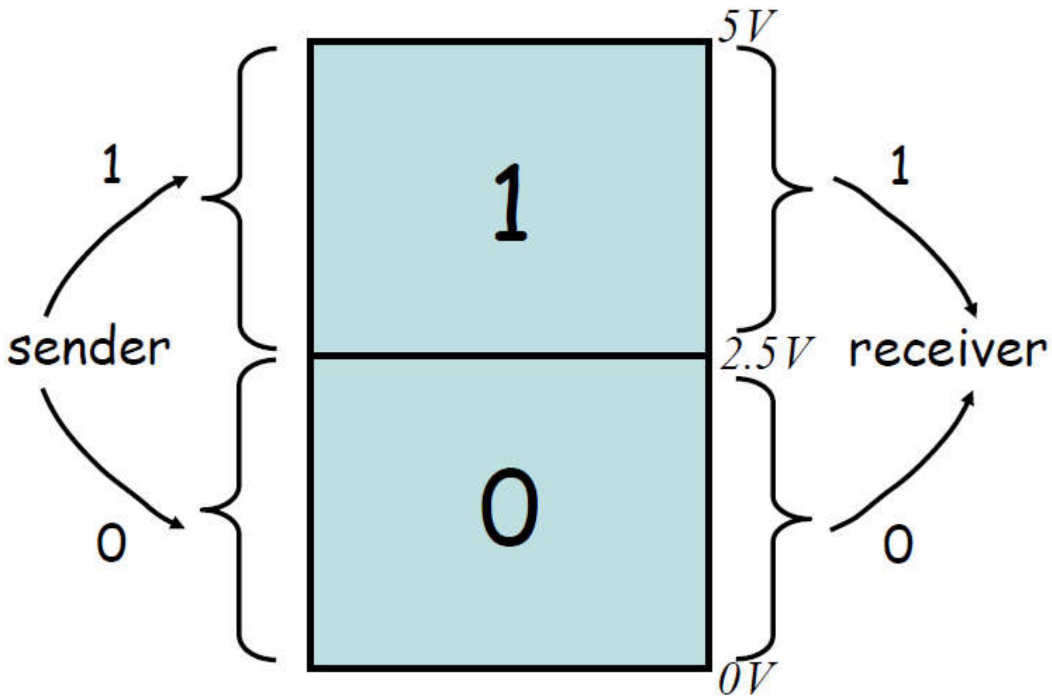
  5V to 2.5V = 2.5V
- For "0":

  noise margin →

  0V to 2.5V = 2.5V

Voltage thresholds and logic values

- Senders and receivers use an agreed-upon mapping between voltage levels and logical signals so that they can communicate with each other.



- There is one problem, however. What does the receiver do if it sees a voltage level of 2.5 V on the wire? Does it interpret this signal value as a logical 0 or as a logical 1?

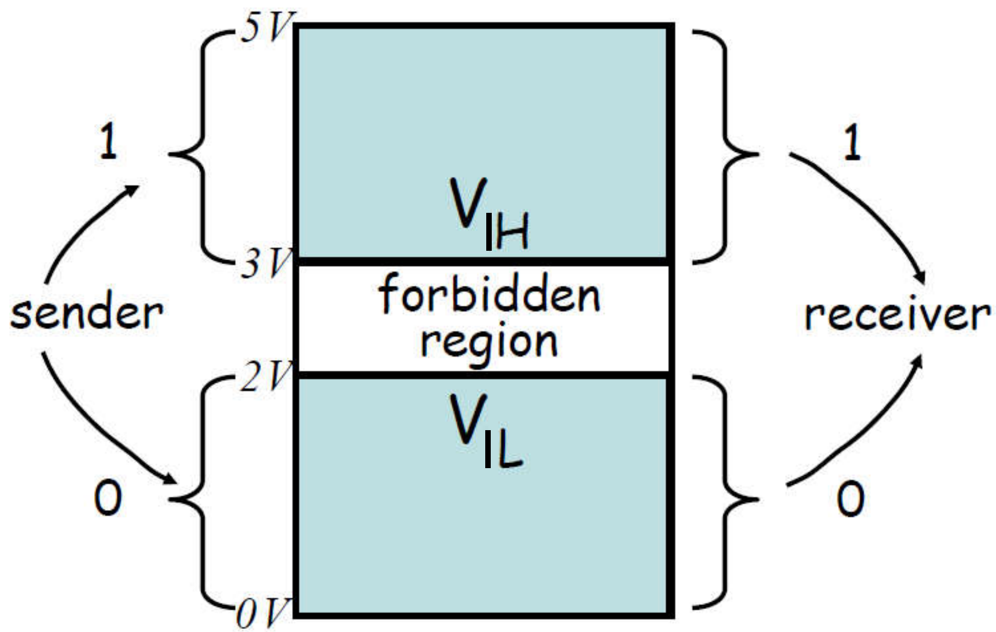
Voltage thresholds and logic values

- To eliminate such confusion, we further prescribe a forbidden region that separates the two valid regions. We further allow the behaviour of the receiving device to be undefined if it sees a voltage in the forbidden region.

- **Key idea**: ***don't allow "0" to be mistaken for a "1" or vice versa.***

- Use the same "uniform representation convention" for every component and wire in our digital system.

- To implement devices with high reliability, we outlaw "close calls" via a representation convention which forbids a range of voltages between "0" and "1".



"1" ➡ V_{IH} → 5V

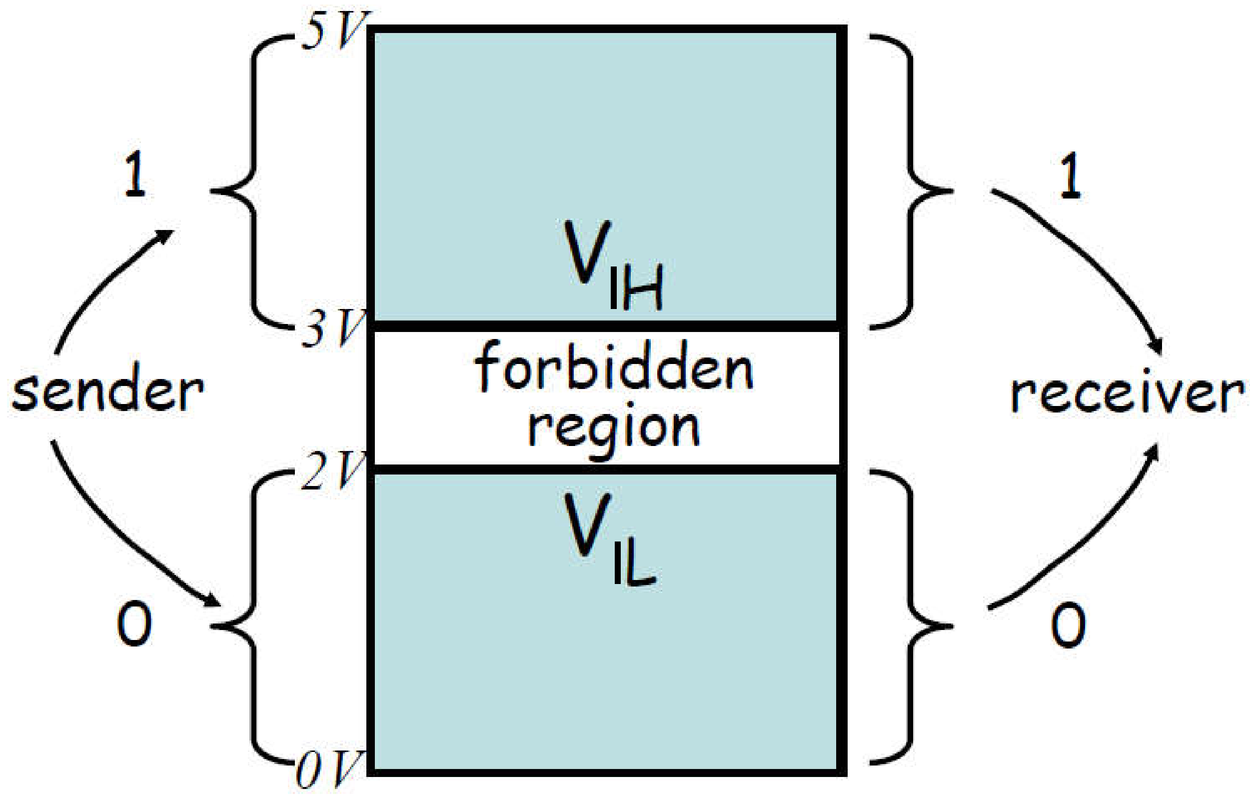
"0" ➡ 0V → V_{IL}

- Forbidden zone avoids mistaking "0" for "1" and vice versa.

- Gives rise to notion of signal VALIDITY : **a voltage in forbidden zone is not a valid voltage!**

Voltage thresholds and logic values

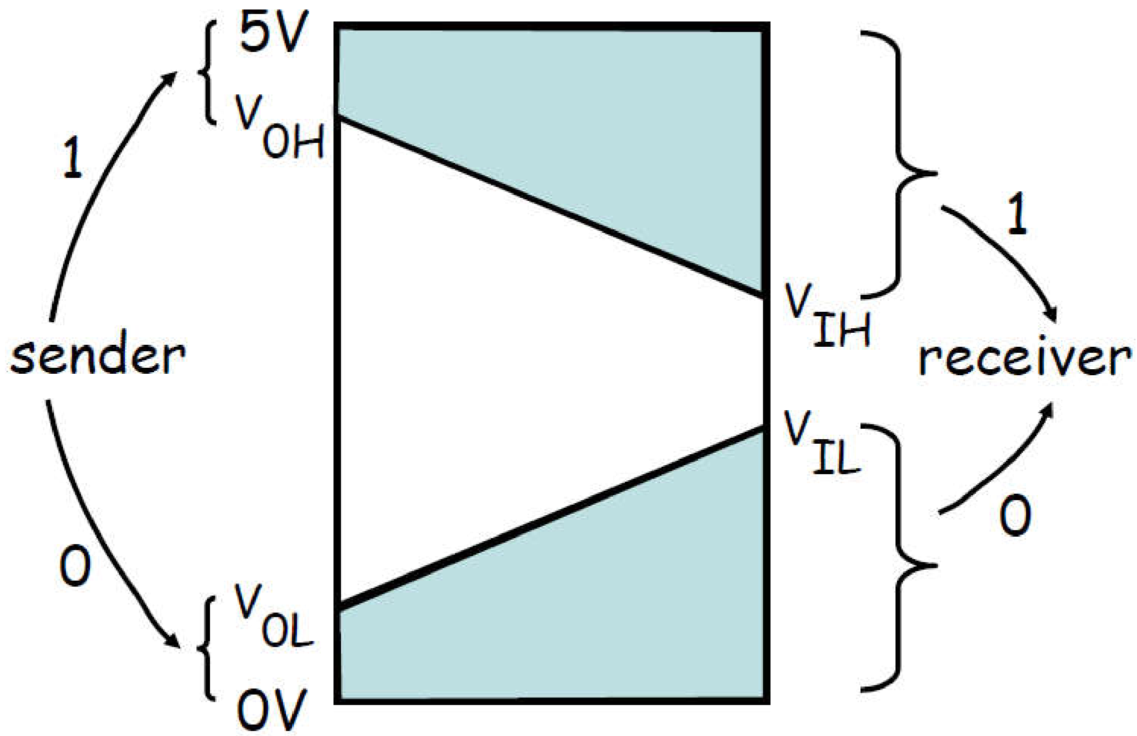
- The largest voltage that a receiver will interpret as a valid logical 0 is termed the low voltage threshold, V_{IL}, and the smallest voltage that a receiver will interpret as a valid logical 1 is termed the high voltage threshold, V_{IH}.
- But where's the noise margin?
- What if the sender sent V_{IH}?



Voltage thresholds and logic values

- Hold the sender to tougher standards by reducing V_{OL} and increasing V_{OH}. The sender is restricted to sending voltages below V_{OL} and above V_{OH}.

- The tighter bounds on the voltage values for a sender compared to those for a receiver result in an asymmetry in input and output voltage thresholds.



Noise Margins

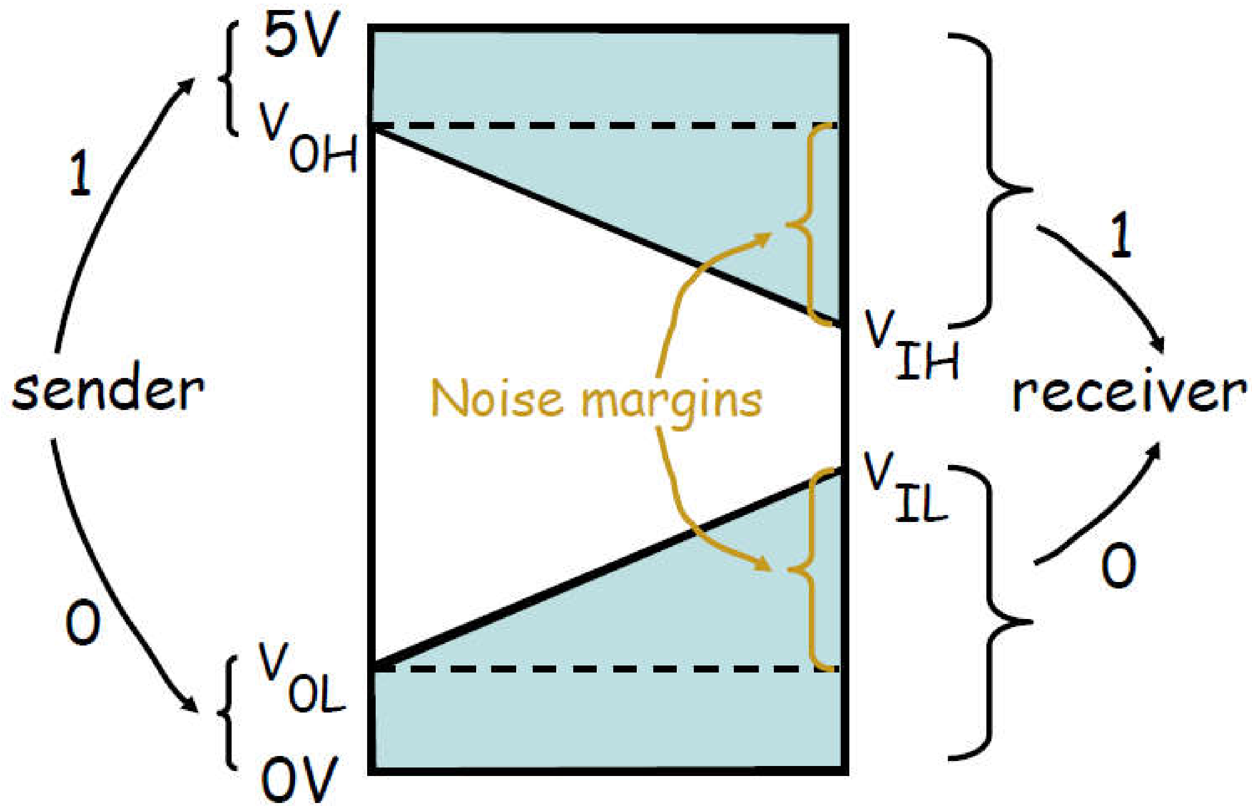
- Noise Margin: The absolute value of the difference between the prescribed output voltage for a given logical value and the corresponding forbidden region voltage threshold for the receiver is called the noise margin for that logical value.

Noise margin for a logical 0

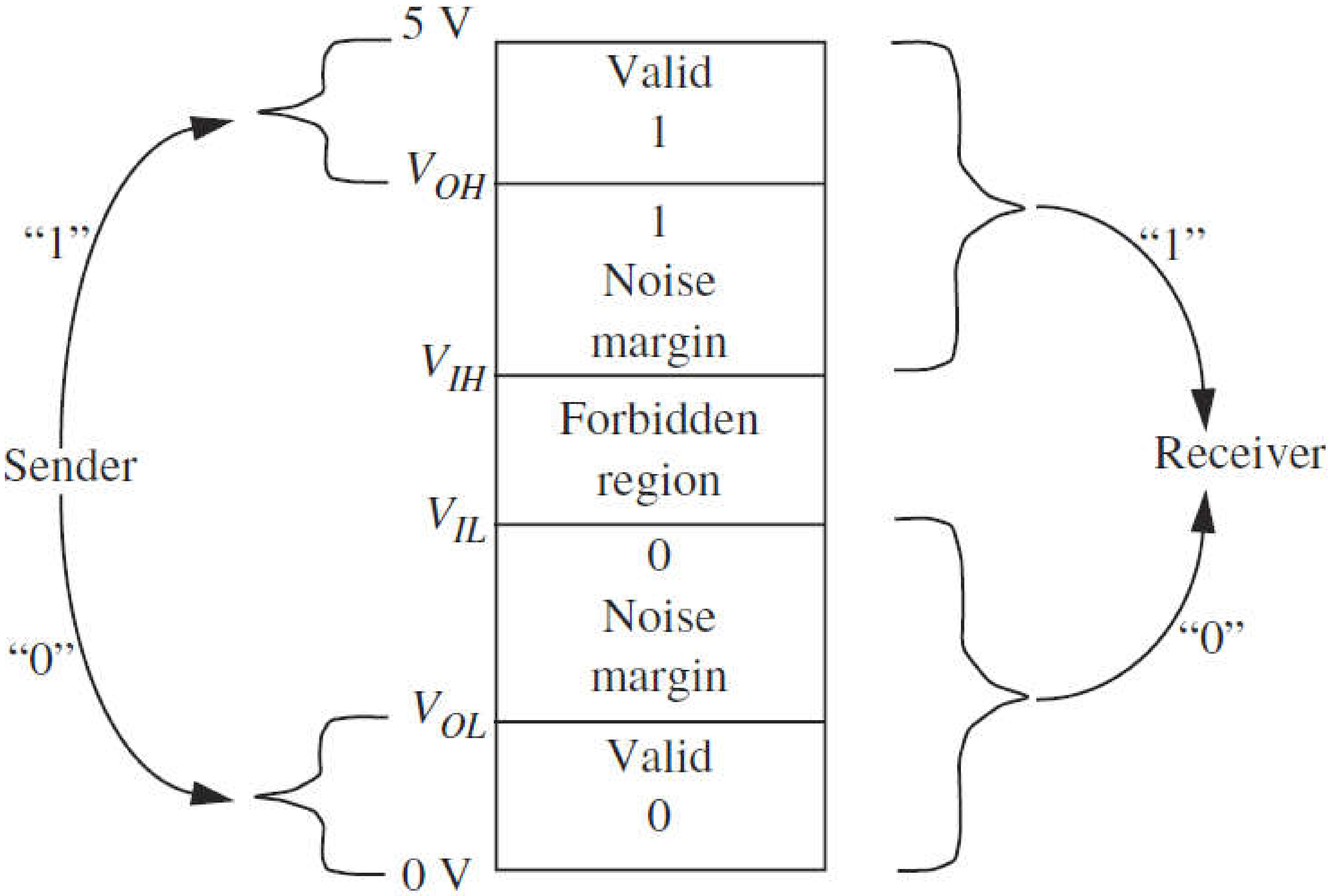
$$NM_L = V_{IL} - V_{OL}$$

Noise margin for a logical 1

$$NM_H = V_{OH} - V_{IH}$$



Noise Margins



Noise Margins

To send a logical 0, the sender must produce an *output* voltage value that is less than V_{OL}. Correspondingly, the receiver must interpret *input* voltages below V_{IL} as a logical 0.

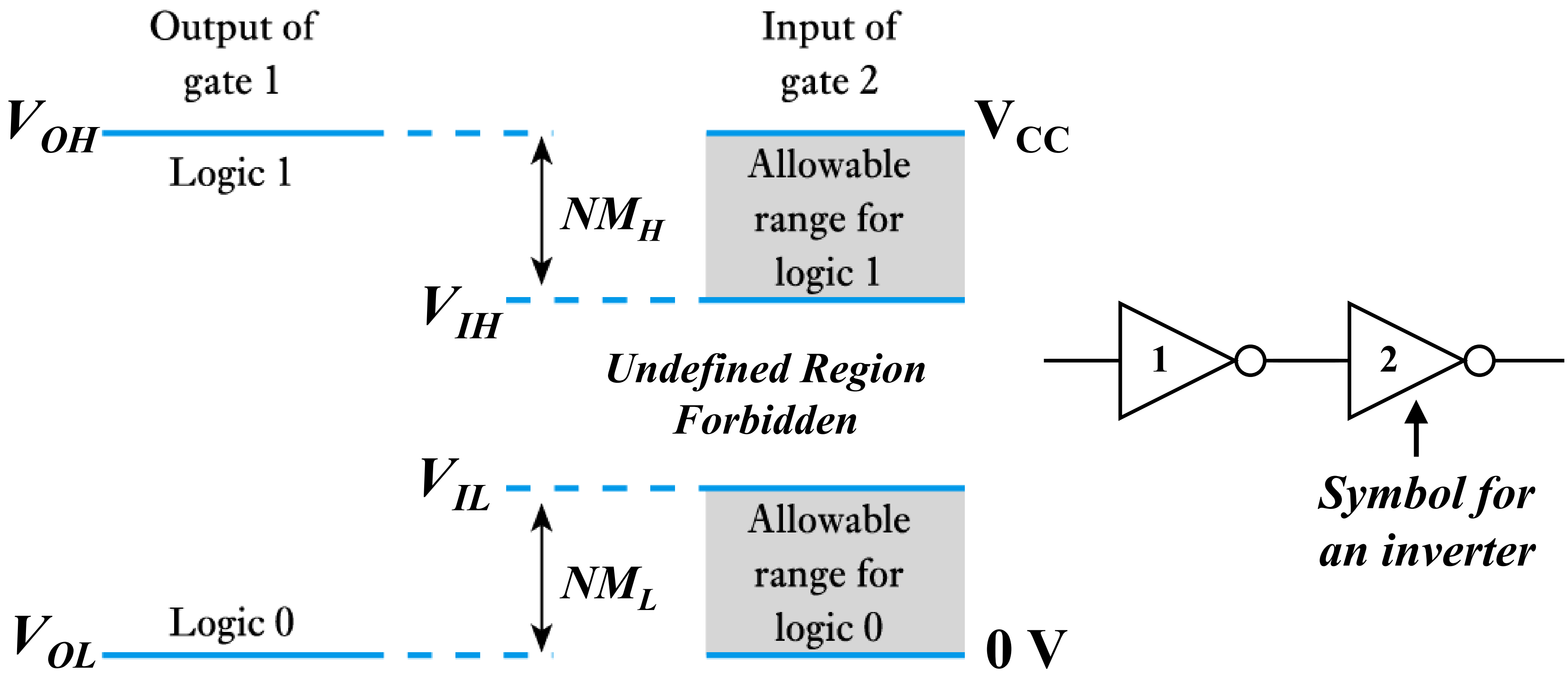
To allow for a reasonable noise margin, V_{IL} must be greater than V_{OL}.

Similarly, to send a logical 1, the sender must produce an *output* voltage value that is greater than V_{OH}. Further, the receiver must interpret voltages above V_{IH} as a logical 1.

To allow for a reasonable noise margin, V_{OH} must greater than V_{IH}. We can define both a noise margin for transmitting logical 1's and for transmitting logical 0's.

Logic Levels and Noise Margins

- The noise margins represent the level of noise that can be sustained when gates are cascaded. The margins should be larger than 0 for a digital circuit to be functional (and by preference as large as possible).

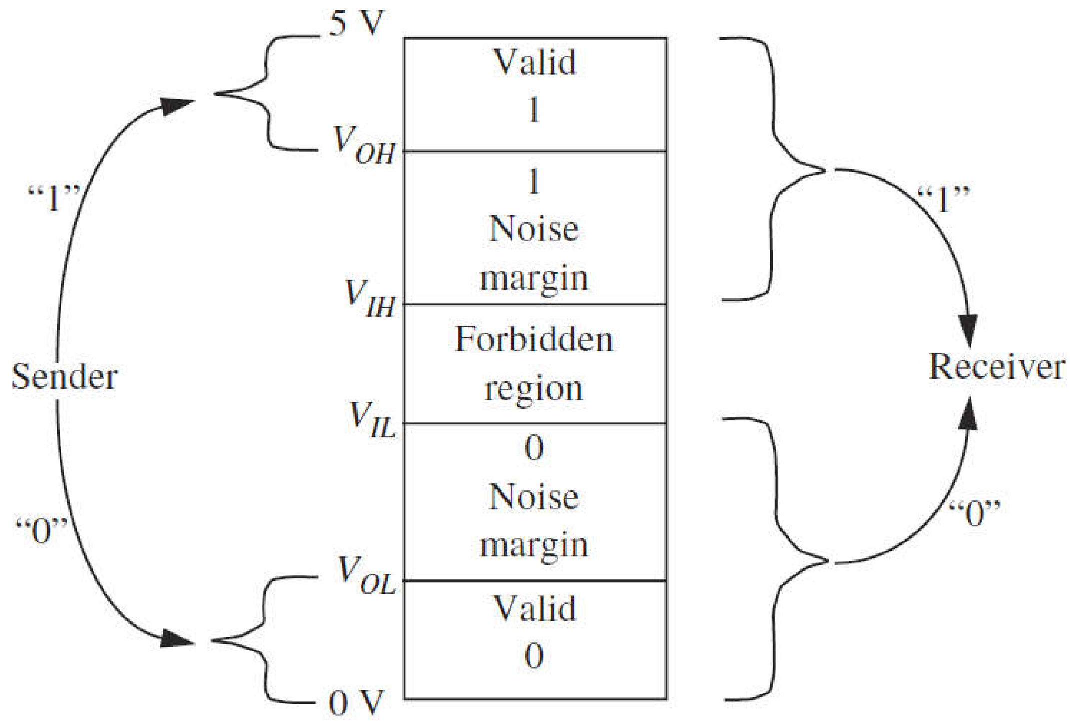


Static Discipline

- Because we require that digital devices built by various manufacturers talk to each other, the devices must adhere to a specification, called **<u>the static discipline</u>** which requires:

  - Devices to interpret correctly voltages that fall within the input thresholds (V_{IL} and V_{IH}).

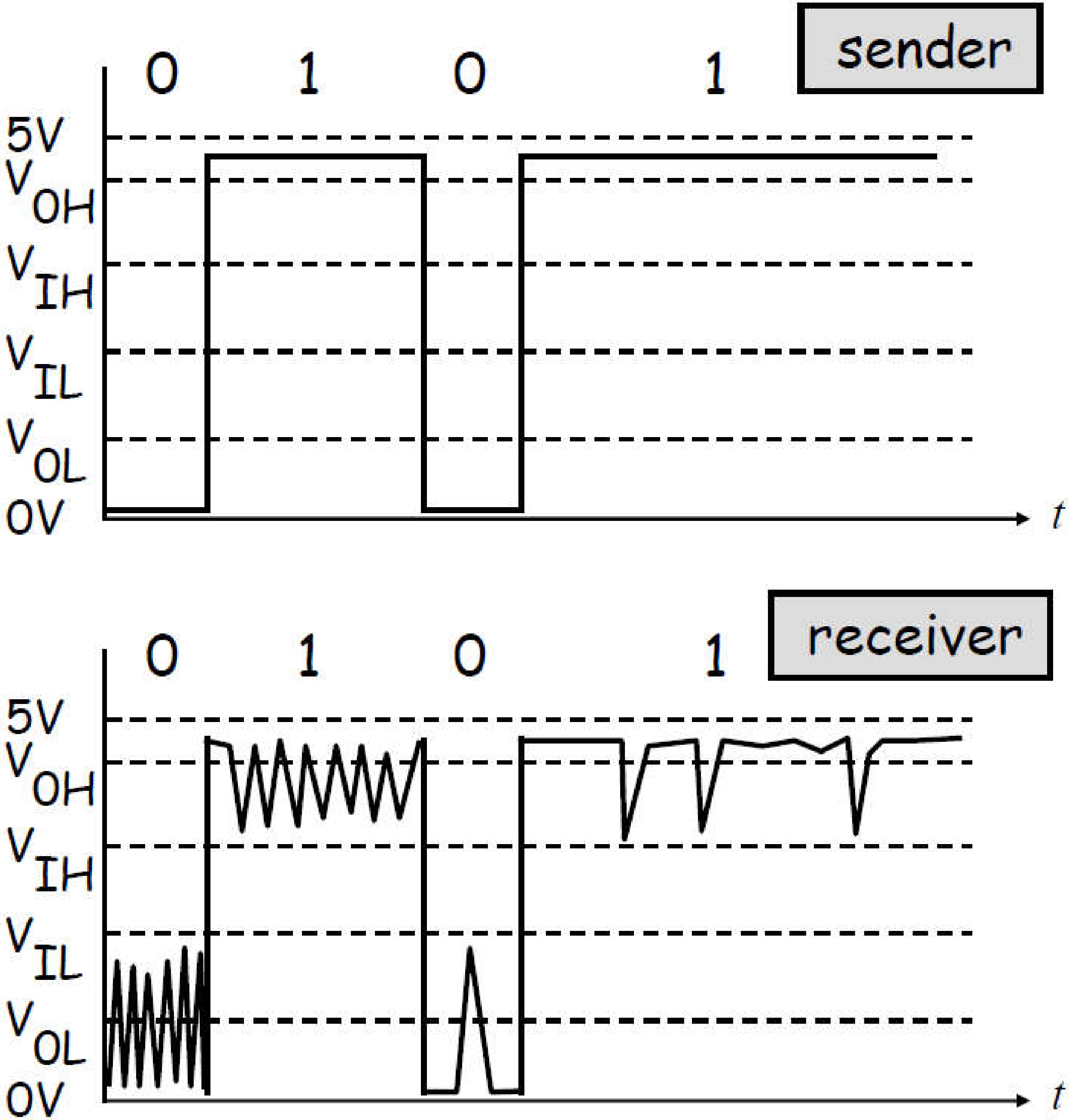
  - As long as valid inputs are provided to the devices, the discipline also requires the devices to produce valid output voltages that satisfy the output thresholds (V_{OL} and V_{OH}).



Static Discipline

- Digital systems follow static discipline:

  - if inputs to the digital system meet valid input thresholds, then the system guarantees its outputs will meet valid output thresholds



Static Discipline

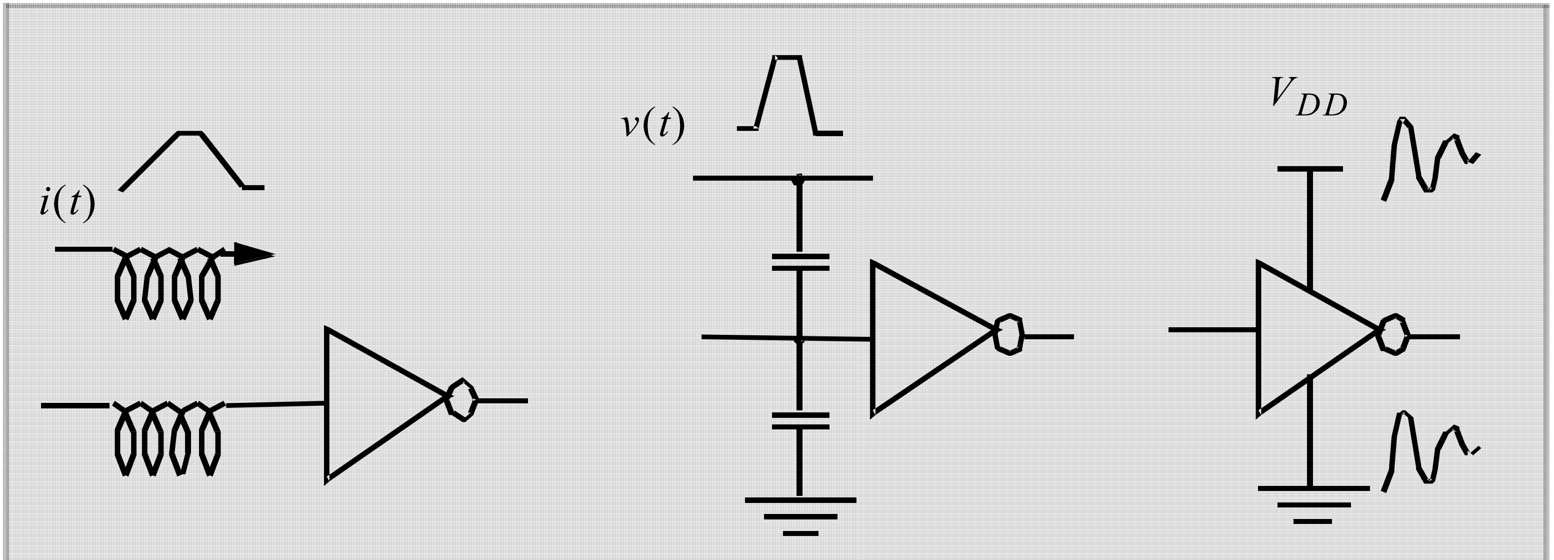
- **Two constraints** to obey static discipline:

  - **Non-zero noise margins: (V_{OL}<V_{IL}≤V_{IH}<V_{OH})**: This ensures non zero noise margins and that the quality of the output signal produced is of better quality than the inputs, thereby avoiding signal degradation as signal is propagated from one stage to the other.

  - **If inputs meet valid input thresholds**, then the system must guarantee **its outputs will meet valid output thresholds: A valid low input** ($V_{in} \leq V_{IL}$) **should always produce a valid output voltage** ($V_{out} \geq V_{OH}$ when output is"1" and $V_{out} \leq V_{OL}$ when output is "0"); and a **valid high input** ($V_{in} \geq V_{IH}$) **should always produce a valid output voltage** ($V_{out} \geq V_{OH}$ when output is"1" and Vout $\leq V_{OL}$ when output is "0").

Digital Abstraction

- Digital signals are **analog** signals and can suffer any of the impairments that analog signals do.
- A touch of reality - Interconnections may introduce significant analog signal impairments that may invalidate the idealisations of digital systems we have assumed in our abstractions (models).

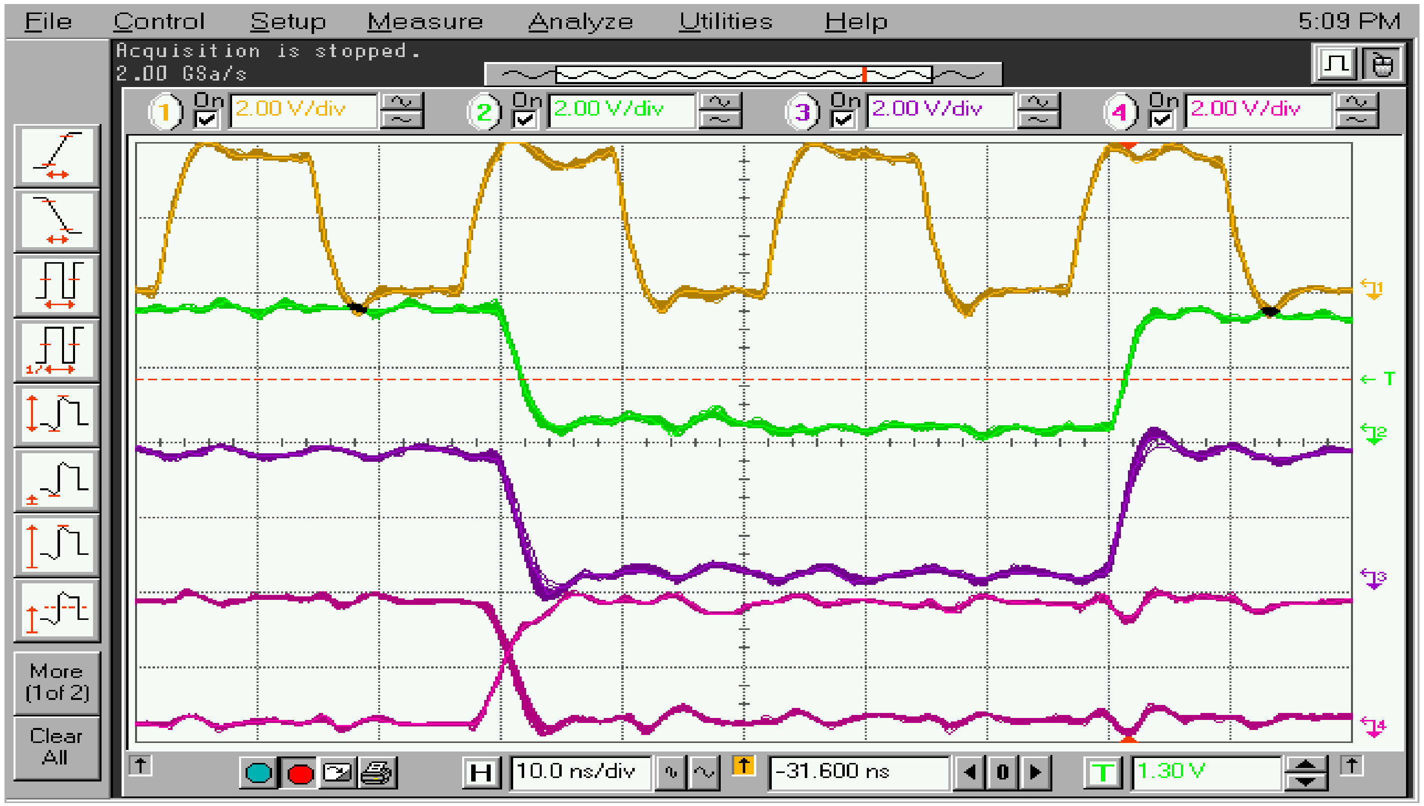


(a) Inductive coupling (b) Capacitive coupling (c) Power and ground noise

Digital Abstraction – Regeneration

Signal **Regeneration**

- The circuit must thus restore marginally valid signals.
- It must accept marginal inputs and provide unquestionable outputs (i.e., to leave room for noise).



Digital Abstraction – Regeneration

Signal **Regeneration**

- A key property of analog signals that **represen**t **digital** signals is that they can be **regenerated** after suffering **bounded degradation** due to
  - **noise**
  - **dispersion**

- **Regeneration** can occur many times without causing errors in the information carried by the signals.

Digital Abstraction – Regeneration

- **Regeneration** can occur due to the input /output characteristics of logic elements and the re-synchronisation in synchronous logic elements such as flip-flops.

- How well signals can be regenerated depends on the **analog characteristics** of the switching devices used to realise the logic family in use and the **analog transmission quality of interconnections**

Digital Abstraction – Summary

- The **digital** (0/1) perspective is ultimately an **ABSTRACTION** of a physical reality that is ***engineered*** to satisfy simple rules (assumption) with some degree of robustness and confidence.
  - Indeed, we can best (and do) describe behavior in statistical terms – e.g. mean time between failure, availability ,... etc. So much for the our intuitive notion of rock solid digital systems !

- The abstractions facilitate design of systems with **reliable and repeatable functionality** by exploiting theories and paradigms that deal with objects represented in terms of collections of elements with <u>**value (0/1**</u>) and systems in which <u>**interconnections do not have any impact**</u> of the values.

Acknowledgments

- Credit is acknowledged where credit is due. Please refer to the full list of references.