Conversion To Logic Levels

Problem: Convert a voltage or other quantity to a logic value.

The electrical characteristics of a 0 and 1 vary with logic family.

(Don’t assume ground is a 0 and 5 V is a 1.)

Will describe (plain) TTL and CMOS.
Plain TTL Logic Levels

Introduction

There are many varieties of TTL. Each has different electrical characteristics.

Material here is for “plain” TTL.
Input to gate is a transistor emitter.

With 0 at input, current will be flowing out of input-transistor emitter.

A 0 is at 0.4 V with current flowing to ground.

This can be provided by a 250 Ω resistor to ground.

With 1 at input, input transistor turned off, no current flows.

A 1 must then be greater than 4.5 V.

This can be provided by a 50 kΩ resistor to $V_{cc}$ or 5 V.
Example

*A circuit having a push button should have a 1 output when the button is pressed and a 0 output at other times.*

The circuit below is all that’s needed.
CMOS circuits use pairs of complementary transistors.

Input is applied to gate of transistors.

Almost no direct current flows through gate.

Input of 0 V for 0 and $V_{DD}$ for 1.
Error

Error is the difference between an ideal (or correct) value and an actual value.

- Several different types of error can be measured.
- An error type can be expressed in several ways.
Expression of Error

Notation

$\mathcal{I}$ denotes an *ideal* value.

$\mathcal{A}$ denotes an *actual* value.

*Absolute error* defined $|\mathcal{I} - \mathcal{A}|$.

*Percent error* defined $100 \frac{|\mathcal{I} - \mathcal{A}|}{\mathcal{I}}$ for $\mathcal{I} \neq 0$.

Consider a transducer designed to measure process variables in the range $\mathcal{I} \in [x_{\text{min}}, x_{\text{max}}]$.

*Percent-full-scale error* defined $100 \frac{|\mathcal{I} - \mathcal{A}|}{x_{\text{max}}}$ for $x_{\text{max}} \neq 0$.

Example: *Mr. A orders the 250 g baked potato he found in the menu. A 271 g baked potato is served. What are the absolute, percent, and percent-full-scale errors?*

$\mathcal{I} = 250$ g, since menu lists ideal quantity.

$\mathcal{A} = 271$ g.

Absolute error is 21 g.

Percent error is 8.4%.

Percent-full-scale error does not apply since no scale has been defined. (Yes, a trick question.)
Types of Error

- **Model Error.**
  Error in transducer model, $H_t$.

- **Repeatability Error.**
  Transducer change from occasion to occasion.

- **Stability Error.**
  Transducer change during use.

- **Calibration Error.**
  Difference between two transducers of same kind.
Model Error

Let $y = H_t(x)$ denote a transducer output, response, and process variable.

The accuracy of $H_t(x)$ depends upon how well the transducer is understood and how complex a transfer function can be tolerated.

For example, the following are all for the same transducer:

Okay: $H_{t1}(x) = R_o(1 + ax)$.

Good: $H_{t2}(x) = R_o(1 + ax + bx^2)$.

Better: $H_{t3}(x) = R_o(1 + ax + bx^2 + cx^3)$.

Best: $H_{t4}(0 \, ^\circ C) = 100 \, \Omega$, $H_{t4}(0.01 \, ^\circ C) = 100.15 \, \Omega$, . . . . (This is sometimes called a lookup table.)

Model error quantifies the accuracy of the transfer function.

<table>
<thead>
<tr>
<th>Definition of Model Error Quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test conditions: a single measurement. Let $H_t(x)$ denote the transducer response, $x$ denote the process-variable value, and $y$ the quantity measured at the transducer outputs.</td>
</tr>
<tr>
<td>Then: Ideal: $I = x$, Actual: $A = H_t^{-1}(y)$.</td>
</tr>
</tbody>
</table>
Model Error Example

What is the absolute model error of a transducer having response \( H_t(x) = (10x^2 - 5) \text{ V} \) under test conditions, with process variable \( x = 2.130 \) and measured transducer output \( y = 34.90 \text{ V} \).

The ideal quantity is \( I = 2.130 \).

\[
H_t^{-1}(y) = \sqrt{\frac{1}{10} \left( \frac{y}{\text{V}} + 5 \right)}.
\]

Based on the transducer \( A = H_t^{-1}(34.9 \text{ V}) = 1.998 \).

The absolute error is then, 0.1325.
Repeatability

Measures how well a transducer performs over time.

Definition of Repeatability Error Quantities

Test conditions:

Let $H_t(x)$ denote the transducer response.

Let $x(t)$ denote the value of the process variable at time $t$.

Two measurements are made, at times $t_1$ and $t_2$, $t_1 < t_2$.

The test is set up so that $x(t_1) = x(t_2) = x$ and $x(t_{1.5}) \neq x$ for some $t_1 < t_{1.5} < t_2$.

Let $y_1$ and $y_2$ denote the quantities read at the transducer outputs at times $t_1$ and $t_2$.

Then: Ideal: $I = H_t^{-1}(y_1)$. Actual: $A = H_t^{-1}(y_2)$. 
Stability

Measures how well the a transducer measures a steady quantity.

Definition of Stability Error Quantities

Test conditions:

Let $H_t(x)$ denote the transducer response.

Let $x(t)$ denote the value of the process variable at time $t$.

Two measurements are made, at times $t_1$ and $t_2$, $t_1 < t_2$.

The test is set up so that $x(t_1) = x(t_2) = x(t_{1.5}) = x$ for all $t_1 < t_{1.5} < t_2$.

Let $y_1$ and $y_2$ denote the quantities read at the transducer outputs at $t_1$ and $t_2$.

Then: Ideal: $I = H_t^{-1}(y_1)$. Actual: $A = H_t^{-1}(y_2)$. 
Calibration

Measures how well two transducers of the same type compare.

Definition of Calibration Error Quantities

Test conditions:

Let $H_t(x)$ denote the transducer response and $x$ denote the value of the process variable.

A measurement is made with each transducer.

Let $y_1$ and $y_2$ be the quantities read at the transducers’ outputs.

Then: Ideal: $I = H_t^{-1}(y_1)$. Actual: $A = H_t^{-1}(y_2)$.
Example

A type of integrated temperature sensor has a response of $H_t(x) = \frac{7x}{K} \mu A$. Tests were performed on two such sensors by exposing the sensors to a known temperature, $x$, and measuring their response, $y$, as follows:

At time $t_1$ sensor A exposed to $x = 295$ K; output $y = 2050 \mu A$.

At time $t_2$ sensor A exposed to $x = 300$ K; output $y = 2085 \mu A$.

At time $t_3$ sensor A exposed to $x = 295$ K; output $y = 2052 \mu A$.

At time $t_4$ sensor A exposed to $x = 295$ K; output $y = 2053 \mu A$.

At time $t_5$ sensor B exposed to $x = 295$ K; output $y = 2040 \mu A$.

Temperature is held constant from $t_3$ to $t_5$. Find model error, repeatability error, stability error, and calibration error.

Inverted Model Function

$$x = H_t^{-1}(y) = y \frac{K}{7 \mu A}.$$  

Model Error

Use measurement at $t_1$.

$T = 295.0$ K and $A = H_t^{-1}(2050 \mu A) = 292.9$ K.

Percent model error: \[
\frac{295.0 \text{ K} - 292.9 \text{ K}}{295.0 \text{ K}} = 0.71\%.
\]

Could have used any time to compute model error.
Repeatability Error

Use measurements at \( t_1 \) and \( t_3 \) (since temperature different at \( t_2 \)).

\[ I = H_t^{-1}(y(t_1)) = H_t^{-1}(2050 \, \mu A) = 292.9 \, K. \]

\[ A = H_t^{-1}(y(t_3)) = H_t^{-1}(2052 \, \mu A) = 293.1 \, K. \]

Percent repeatability error:

\[ \frac{|292.9 \, K - 293.1 \, K|}{292.9 \, K} = 0.06828\%. \]

Note, actual and ideal quantities could be reversed in this example.

Also possible to use \( t_1 \) and \( t_4 \).

Stability Error

Use measurements at \( t_3 \) and \( t_4 \) (since temperature held constant in this time range).

\[ I = H_t^{-1}(y(t_3)) = H_t^{-1}(2052 \, \mu A) = 293.1 \, K. \]

\[ A = H_t^{-1}(y(t_4)) = H_t^{-1}(2053 \, \mu A) = 293.3 \, K. \]

Percent stability error:

\[ \frac{|293.1 \, K - 293.3 \, K|}{293.1 \, K} = 0.06824\%. \]

Calibration Error

Use measurements at \( t_4 \) and \( t_5 \).

\[ I = H_t^{-1}(y(t_4)) = H_t^{-1}(2053 \, \mu A) = 293.3 \, K. \]

\[ A = H_t^{-1}(y(t_5)) = H_t^{-1}(2040 \, \mu A) = 291.4 \, K. \]

Percent calibration error:

\[ \frac{|293.3 \, K - 291.4 \, K|}{293.3 \, K} = 0.6478\%. \]
Miscellany

Typically, error specially defined for each type of transducer.

The definition includes the exact test circuit and test conditions.

Error measures can be applied to conditioning circuits and anything else that transforms a process variable value.