Hands-On Experimentation using Digilent Analog Discovery 2
Complete analog & digital circuits in or out of the lab

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Primary HW resources:

- Two-channel scope (1MΩ, ±25V, differential, 14-bit, 100MS/s, 30MHz+ with the BNC Adapter)
- Two-channel AWG (±5V, 14-bit, 100MS/s, 12MHz+ with the BNC Adapter)
- Stereo audio amplifier to drive external headphones with AWG signals
- 16-ch digital logic analyzer/pattern generator/static IO (3.3V CMOS, 100MS/s)
- Two input/output digital triggers for linking multiple instruments (3.3V CMOS)
- Two programmable power supplies (0...+5V, 0...-5V):
  - 250mW max for each supply or 500mW total when powered through USB
  - 2.1W max for each supply when powered by an auxiliary supply
  - 700mA maximum current for each supply

HW resources re-usage (by WaveForms):

- Single channel voltmeter (AC, DC, ±25V)
- Network analyzer – Bode, Nyquist, Nichols diagrams of a circuit; 1Hz to 10MHz
- Spectrum Analyzer – spectrum and measurements (noise, SFDR, SNR, THD, etc.)
- Digital Bus Analyzers (SPI, I²C, UART, Parallel)
Waveforms 2015

Cross platform
- Windows
- Linux
- OS

Supports Digilent instrumentation HW
- Electronics Explorer
- Analog Discovery
- Analog Discovery 2
- Digital Discovery

Programmer support
- SDK
- LabVIEW support

Optimal use of HW resources
## Waveforms 2015

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</tbody>
</table>
LED I/V characteristics

Scope, Channel 2
- Offset: 0V
- Range: 1V/div
- Invisible

Scope, Math 1
- Mode: Custom
- C2/100
- Units: A
- Offset: 0A
- Range: 5mA/div

Scope, Trigger
- Mode: Auto
- Source: Channel 1
- Cond: Rising
- Level: 0V

Scope, Time Base
- Position: 0s
- Base: 0.5ms/div

Scope, Channel 1
- Offset: 0V
- Range: 1V/div

AWG, channel 1
- Mode: Simple
- Shape: Triangle
- Frequency: 1kHz
- Amplitude: 5V
- Offset: 0V
- Symmetry 50%

Diagram of LED circuit:
- W1
- R1 100
- LED1
- GND

Diagram showing connections:
- 1+
- 1-
- 2+
- 2-
LED I/V characteristics

View/Add X/Y
- X: Channel1
- Y: Math1
LED I/V characteristics

More easy experiments...

• Change stimulus shape to sinus
  – Does the X/Y view change? Why?

• Change stimulus shape to rectangle

• Play with frequency
  – you might first want to set the Min/Max limits for Frequency to 100mHz/1kHz.
  – Understand the human eye limitation in stimulus pulse frequency
  – Understand the basics of multiplexed LEDs display

• Play with symmetry (0 to 100%).
  – Understand PWM modulation of LEDs equivalent luminous intensity.
Transistor characteristics

BC546 / BC547 / BC548 / BC549 / BC550
NPN Epitaxial Silicon Transistor

![Graph showing collector characteristics](image)

- $I_B = 50 \mu A$
- $I_B = 100 \mu A$
- $I_B = 150 \mu A$
- $I_B = 200 \mu A$
- $I_B = 250 \mu A$
- $I_B = 300 \mu A$
- $I_B = 350 \mu A$
- $I_B = 400 \mu A$

$V_{CE}$, COLLECTOR-EMITTER VOLTAGE


November 2014
Transistor characteristics

AWG, channel 1
- Mode: Simple
- Shape: Triangle
- Frequency: 50Hz
- Amplitude: 2.5V
- Offset: 2.5V
- Phase: 270°

AWG, channel 2
- Mode: Custom
- Edit/Values: 0, 1, 2, ..., 9
- Normalize

Diagram:
- W1
- T1
- R1 1k
- R2 100
- 1+
- 1-
- 2+
- 2-
- W2

Diagram of a transistor circuit with resistors R1 and R2 and a transistor T1.
Transistor characteristics

**AWG, channel 1**
- Mode: Simple
- Shape: Triangle
- Frequency: 50Hz
- Amplitude: 2.5V
- Offset: 2.5V
- Phase: 270°

**AWG, channel 2**
- Mode: Custom
- Frequency: 10Hz
- Amplitude: 1V
- Offset: 1.6V
- Phase: 0°

**Scope, Channel 1**
- Offset: -2.5V
- Range: 500mV/div

**Scope, Channel 2**
- Offset: -2.5V
- Range: 500mV/div

**Scope, Trigger**
- Mode: Auto
- Source: Channel 2
- Cond: Falling
- Level: 4.9V

**Scope, Time Base**
- Position: 40ms
- Base: 10ms/div

**Scope, Math 1**
- Add Ch/Simple
- C1/100
- Settings: Offset as divisions
- Settings: Units = A
- Offset: -5div
- Range: 3mA/div

**AWG, Synchronized**

![Circuit Diagram]
Transistor characteristics $I_C(V_{CE})$; $I_B$ parameter

Scope
- View
- Add X/Y
- X: C2
- Y: M1
Transistor characteristics; $I_B$ values

Scope, Channel 1
- Offset: -5div
- Range: 200mV/div

Scope, Math 1
- Add Ch/Custom
- C1/10000
- Range: 20uA/div

Scope
- View
- Add X/Y
- X: C2
- Y: M1

DIAGRAM: A circuit diagram showing a transistor (T1), two resistors (R1 10k, R2 100), a ground (GND), and two sources (W1 and W2) with corresponding terminals (1+, 2+ for W1, 1-, 2- for W2).
**RC Low Pass Filter**

**Time domain - step response**

**AWG, channel 1**
- Mode: Simple
- Shape: Square
- Frequency: 50Hz
- Amplitude: 2.5V
- Offset: 2.5V

**Scope, Channel 1**
- Offset: -2V
- Range: 1V/div

**Scope, Channel 2**
- Offset: -2V
- Range: 1V/div

**Scope, Trigger**
- Mode: Auto
- Source: Channel 1
- Cond: Falling
- Level: 2V

**Scope, Time Base**
- Position: 2ms
- Base: 500us/div
RC Low Pass Filter
Time domain - step response

$T = RC = 100\,\mu s$
RC Low Pass Filter
Time domain - sinus response
RC Low Pass Filter
Time domain - sinus response

\[ x(t) = V_{in}(t) = A_{in} \sin(2\pi ft) \]
\[ y(t) = V_C(t) = A_C \sin(2\pi ft + \varphi) \]
\[ y(0) = V_C(0) = A_C \sin(\varphi) \]
\[ \varphi = \arcsin\left(\frac{y(0)}{A_C}\right) = \arcsin\left(\frac{2y(0)}{2A_C}\right) \]
RC Low Pass Filter
Frequency domain – Bode, Nyquist, Nichols diagrams
Audio - Wavegen - modulation, sweep

- Attach an audio headset to the Analog Discovery 2.
- AWG channel 1 in the right speaker, channel 2 in the left speaker.
- Control the amplitude for convenient audio volume.
When importing a stereo .wav file, select a different file channel for each AWG channel. Keep the file sampling rate for correct audition, or change it for effects.
Audio - Wavegen - Custom

Generate AWG buffer data:
- Equations
- Functions
- Sample values
- Files
- Modifiers
- Mouse draw

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ROM Logic
DIO pin block diagram

- system clock
- Prescaler
- n-bit Counter
- MUX1
- Algorithmic generator
- MUX2
- Pattern Memory
- OB
- DIO x
- n-bit input bus
- IB
ROM Logic
Synchronized combinatorial circuit

Pattern Memory

DIO y → IB → Output Logic (comb) → Output Register (synchronous) → OB → DIO z

system clock → Prescaler

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ROM Logic
Mealy State Machine

Pattern Memory

- Output Logic (comb)
- Output Register (synchronous)
- Next State Logic (comb)
- State Register (synchronous)

Inputs
- system clock
- Prescaler

Current state

Outputs
- OB
- DIO x
- DIO y
- DIO z

- IB
b. Use 0, 1 or X (don’t care) in the input pane.
c. An n-bit expanded Truth Table has $2^n$ lines. A line with k X values is the collapsed version of $2^k$ expanded lines.
d. All possible input cases need to be covered.
e. The table lines are “sequential”, i.e. a line can override lines above it in the table.
ROM Logic
Example – 3bit AND gate (sync); static verification
ROM Logic
Example – 3bit AND gate (sync); dynamic verification
Adding stimuli and clock reference in the Pattern Generator

Stimulus for the AND gate
ROM Logic reference Clock
ROM Logic
Example – 3bit AND gate (sync); dynamic verification
Observing output (DIO3) on the Logic Analyzer

DIO3 output synchronized on the 5MHz ROM logic clk (falling edge)
ROM Logic
Example – 8bit binary counter with CE

f. If a signal is used in both input and output panes, it is a State Variable; the input pane shows its value in the Current State and the output pane indicates its value in the Next State.

g. The same functional block might be split in multiple ROM logic objects, to optimize the Truth Table(s).
g. 1, 0, “SignalName” or “/SignalName” in the output pane (“/” for logical NOT).

h. A yellow background of a cell indicates a syntax error.

Remember:

C. An n-bit expanded Truth Table has $2^n$ lines. A line with $k$ X values is the collapsed version of $2^k$ expanded lines.
ROM Logic
Example – 8bit binary counter with CE; verification
ROM Logic Example – PWM modulator – constant sample

Workspace/Open/(No)/PdmPwm5bit2M200k.dwf3work

\[ f_{\text{carrier}} = \frac{f_{\text{cnt}}}{2^n} \]

\[ DF = \frac{\text{sample}}{2^n} \]
ROM Logic
Example – PWM modulator

Edit ROM Logic

Name: PWM Comparator

Properties

Frequency: 2 MHz

Inputs:
Name | DIO
--- | ---
c4 | DIO 9

c3 | DIO 8

c2 | DIO 7

c1 | DIO 6

c0 | DIO 5

s4 | DIO 4

s3 | DIO 3

s2 | DIO 2

s1 | DIO 1

s0 | DIO 0

Outputs:
Name | DIO
--- | ---
CY | DIO 10

Truth table

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<thead>
<tr>
<th>c4</th>
<th>c3</th>
<th>c2</th>
<th>c1</th>
<th>c0</th>
<th>s4</th>
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Default line
LSB compare
MSB compare

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RC Low Pass Filter
With the PWM/PDM Modulator

Scope, Trigger
• Mode: Auto
• Source: Channel 2
• Cond: Rising
• Level: 1.7V

Scope, Time Base
• Position: 0
• Base: 100us/div

Scope, Ch 1 and Ch 2
• Offset: -1.5V
• Range: 500mV/div

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ROM Logic
Example – PWM modulator – variable sample

Workspace/Open/(No)/PdmPwm5bit2M200k.dwf3work

\[ f_{\text{carrier}} = \frac{f_{\text{cnt}}}{2^n} \]

\[ DF = \frac{\text{sample}}{2^n} \]
ROM Logic
Example – PWM modulator – variable sample (sinus)

Building a sinus sample string

\[ \text{sample}_i = 16 + \text{int}\left(15 \times \sin\left(\frac{2 \cdot \pi \cdot i}{100}\right)\right) \in [1 \ldots 31] \]

\[ f_{\text{modulator}} = \frac{f_{\text{sample}}}{100} = \frac{200 \text{KHz}}{100} = 2 \text{kHz} \]

Copy 100 cells of “samples” into Sample column

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ROM Logic
Example – PWM modulator – variable sample (sinus)
ROM Logic
PDM modulator – constant sample

\[
\text{sample} \in [0 \ ... \ 2^n - 1]
\]

\[
DF_{\text{avg}} = \frac{\text{int}(M \cdot \text{sample})}{M}
\]

\[
f_{\text{carrier}} \in \left(0, \frac{f_{\text{cnt}}}{2^n} \ ... \ \frac{f_{\text{cnt}}}{2}\right)
\]

\[
\begin{cases}
\text{sample} = 0 \\
DF_{\text{avg}} = 0 \\
f_{\text{carrier}} = 0
\end{cases}
\]

\[
\begin{cases}
\text{sample} = 1 \\
DF_{\text{avg}} = \frac{1}{2^n} \\
f_{\text{carrier}} = \frac{f_{\text{cnt}}}{2^n}
\end{cases}
\]

\[
\begin{cases}
\text{sample} = \frac{2^n}{2} \\
DF_{\text{avg}} = \frac{1}{2} \\
f_{\text{carrier}} = \frac{f_{\text{cnt}}}{2}
\end{cases}
\]

\[
\begin{cases}
\text{sample} = 2^n - 1 \\
DF_{\text{avg}} = \frac{2^n - 1}{2^n} \\
f_{\text{carrier}} = \frac{f_{\text{cnt}}}{2^n}
\end{cases}
\]
ROM Logic - PDM modulator

Workspace/Open/(No)/PdmPwm5bit2M200k.dwf3work

Addition truth table: 5bit+5bit=Carry&5bit
1024 lines copied from xcel file
(RomLogicTruthTables – PDM)
ROM Logic
Example – PDM modulator – variable sample (sinus)
ROM Logic
Example – PDM modulator – variable sample (sinus)

Compare spectrum and measurements between PWM and PDM

[Image of a graph showing comparison between PWM and PDM]

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