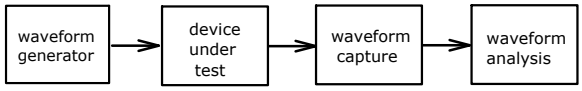
Generating Test Signals

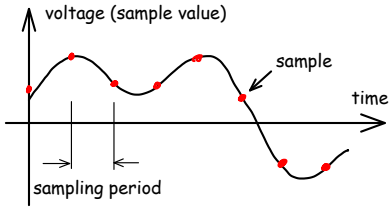
Introduction

One way to test a channel or communication system is to apply a known waveform as the input and analyze the output:

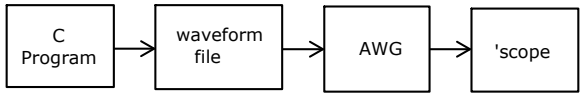


This approach is useful when you need to test a device or system for which there is no specialized test equipment. In this lab you will use an Arbitrary Waveform Generator (AWG) to generate a test waveform.

You will write a C program that computes and writes the sample values of the waveform to a file. The sample values are integers representing the voltages of the waveform at equally-spaced intervals of time:



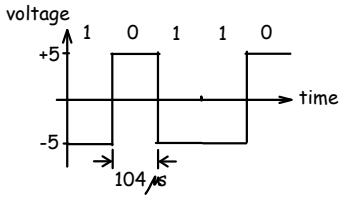
You will then copy this file to the AWG which will generate an analog waveform corresponding to the samples in the file. Finally, you will measure and record this analog waveform on an oscilloscope.



Analog Waveform Specification

The analog waveform output by the AWG should consist of a voltage that can be either +5 V or -5 V and is held steady for intervals of 104 μs. Each interval is used to transmit one bit of data. To transmit a '1' bit the voltage should have should have a voltage of -5 V and for a '0' it should have a voltage of +5 V.

Here's an example of the waveform corresponding to the sequence of bits 1, 0, 1, 1, 0:

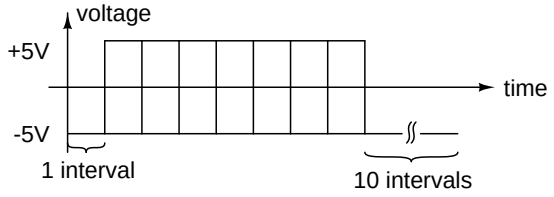


Your waveform must encode a 7-bit binary number that is the sum of all the digits of your student ID. For example, if your ID number is A00123456 the number you would output is $1+2+3+4+5+6 = 21$ (hex 0x15, binary 0010101). This number may not match that of others doing the lab.

The bits of the number should be output in *least significant bit first* (little-endian) bit order. For the value above, it will begin with $101\cdots$, *not* $001\cdots$.

Note that both the bit order and the signal polarity are the opposite of what you were probably expecting.

In addition, one positive voltage interval (equivalent to a '0' bit) should be added before the data bits and ten negative voltage intervals (equivalent to ten '1' bits) should be added after the data bits:



Generating the Sampled Waveform

The sample values you write to the file should have values of 16384 (0x3fff) for +5 V and 0 (0x00000) for -5 V (see Appendix A).

The AWG sampling rate will be set to a frequency that is 6 times the bit rate. This means you will have to write 6 samples for each bit.

Your C program should generate the sample values required to reproduce your specific analog waveform.

Note that your program does not generate the waveform in real time. The waveform samples are loaded into the AWG and will be configured to output

the samples at the appropriate sample rate and voltages.

The pseudo-code shown in Listings 1 and 2 might help if you aren't sure how to structure your program.

```
open the output file

write a '0' bit

for each bit in your number (bit 0...6)
    if that bit is '1'
       write a '1' bit
    else
       write a '0' bit
end

do 10 times:
   write a '1' bit
```

Listing 1: Pseudo-code (possibly incomplete).

```
for each sample (sample 0...5)
   if the bit is '1'
       write 0x0000 (as two bytes)
   else
       write 0x3fff
   end
end
```

Listing 2: Pseudo-code for a function to write a bit.

Your program will probably make use of the following C functions which are declared in the `<stdio.h>` header file:

- `fopen()` - to open a file
- `putc()` - to write a byte to the file

You will probably need to read the C library documentation for these functions. Open a file in "write binary" (`"wb"`) mode, with a file name extension of `.RAF` (e.g. `"waveform.raf"`). For example:

```
#include <stdio.h>
   // ...
   FILE *f ;
   // ...
   f = fopen("waveform.raf","wb") ;
   // ...
   putc(0xff,f) ;
   // ...
```

You can use bitwise logical C operators to extract the values of individual bits from an integer. For example, to test if the value of the *i*'th bit of the integer `n` is non-zero (i.e. 1) we can use the expression: `(n & (1<<i))`.

You must write the sample values to the `.RAF` file in little-endian byte order. For example to write the 16-bit value `0x3fff` you should use `putc(0xff,f); putc(0x3f,f);` where `f` is the pointer returned by `fopen()`.

To avoid duplicating code in your program you may want to use one or more functions. For example, you might want to use a function that writes the samples required for one bit as shown in the pseudo-code above.

Procedure

The lab PCs should have the tcc and Pelles C compilers installed. The instructions below are for using the Notepad++ editor and tcc (tiny C compiler). These are small free programs you can run on any Windows PC.

Use a text editor such as Notepad or Notepad++ to create and edit a C-language program file. When working in the lab, it is recommended that you save files on a flash or network drive so that you don't lose your work if the PC reboots.

Start a command prompt (also known as a command interpreter or "shell") (`All Programs -> Accessories-> Command Prompt`). The command interpreter will execute the commands you type (after you press Enter).

Type the command `h:` to change to the drive where your files are stored (assuming they are in the 'H' drive). Use the command `cd` *foldername* to Change Directory to the folder (directory) where your C file is stored. For example, `cd "Courses/ELEX 3525/lab1"`. Avoid using spaces in file or folder names. If the file or folder names contain special characters or spaces you must use quotes as shown above.

Type the command:

`tcc -run` *filename*`.c`

to compile and run your program using the Tiny C Compiler (`tcc`) where *filename* is the name of your C

file (e.g. `tcc -run wavegen.c`). If there are any error messages, correct the errors in your program and repeat the command.

You can use the arrow keys to repeat (up-arrow) and edit (left- and right-arrow) previous commands. You can use the tab key to auto-complete partial file names.

Once your program has run and created the `.RAF` file you should check that the contents of the file are correct. Run the HexEdit utility and open the `.RAF` file. The program will display the values of the bytes in the file in hexadecimal format. Check that the values and byte order are what you expected.

Take a screen capture that shows the hex value of the first 16 bytes (use `All Programs -> Accessories -> Snipping Tool`) and save it to your `H:` drive for use in your report.

To view the waveform you can use Audacity, an audio waveform editor. Run `All Programs -> Audacity` to start the program. Since your waveform file contains only the sample values and is not in an audio file format, use `File -> Import -> Raw Data` to read the waveform sample values from the file. You will have to specify the file and format. Choose the same format (Signed 16-bit Little-Endian), number of channels (1, Mono) and the sampling rate you assumed when creating the file.

Check the displayed waveform to make sure the waveform shape is correct. Take a screen capture that shows the time scale, the sample rate, sample format and the waveform and save it for use in your report.

Copy your `.RAF` file to your USB flash drive and load it into the AWG using the instructions in Appendix B below.

Connect the 'scope's Channel 1 probe to the alligator clips on the cable connected to the AWG Channel 1 output. Use the oscilloscope to check for a ± 5 V waveform on the AWG output. Capture a sufficiently-long portion of the waveform and adjust the horizontal scale and position to show your complete waveform.

Each time the 'scope is turned on you must select CH1 -> Probe Ratio -> 10X to get correct voltage scaling. Unfortunately, there is no way to make this the default.

Set up the 'scope's decoding feature as follows to check your waveform. Use the "Decode" button on the the 'scope to bring up the decode menu. Select "RS-232" decoding with TX as Channel 1. Set the baud rate appropriately, a threshold voltage of 0V, LSB order, 7 data bits, no check (parity) bit and decimal display format. If you've done everything correctly you should see "your" number displayed.

Have the instructor check that your waveform as displayed on the 'scope is correct to get credit for completing the lab. Capture the 'scope screen to your flash drive by pressing the orange button with the printer icon. Record the displayed file name so you can include the screen capture in your report.

Pre-Lab Assignment

Submit the following to the appropriate drop box before the start of the lab:

- The cover page information as described in the course information handout.
- The sum of the digits in your student number.
- The conversion of this number to bits and voltage levels. Use a table showing the bit number (0, 1, 2, ...), the bit value (0 or 1) and the signal voltage (+5 or -5).
- Compute the sample period (time between samples) and from that the sample rate that you will need to configure into the AWG.
- A drawing of the waveform you expect to see on the 'scope. Show each bit, not necessarily each sample. Label the voltage and time axes.
- A listing of a C program that generates the required waveform.

Remember to save the program on your `H:` drive or bring it to the lab on your flash drive.

Program listings should use a mono-spaced font (e.g. Courier) and single line spacing. A simple way to format listings is to open the file with Notepad++, select all text (Control-A), use Plugins -> NppExport -> Copy RTF to clipboard and then paste (Control-V) the formatted text into a word processor.

Post-Lab Report

Submit a report that includes:

- The cover page information as described in the course information handout.
- The HexEdit, Audacity and 'scope screen captures.

- The C program listing with all errors corrected.

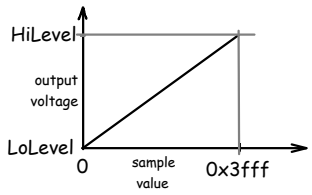
Convert your report to a PDF format file and submit it via the appropriate course web site dropbox.

Appendix A - AWG File Format

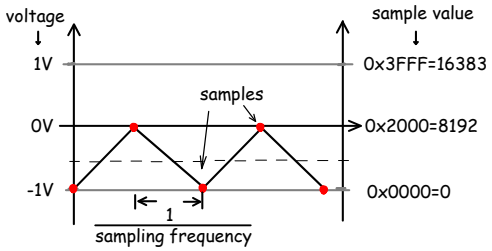
The Rigol DG1000Z AWG in the lab reads files in the `.RAF` (Rigol AWG File) binary file format that is documented on page 2-75 of the user manual.

An `.RAF` file consists of a sequence of 16-bit sample values Each sample value must be an (unsigned) integer between 0 and 16383 (0x3fff = $2^{14} - 1$).

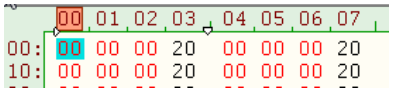
There is a linear relationship between the integer sample values and the output voltage. The value 0 corresponds to the configured Low output voltage level and 16383 corresponds to configured High output voltage level:



For example, if the AWG was configured for a low level of -1 V, a high level of +1 V and the RAF file contained values alternating between 0 and 8192 (halfway between the low and high levels) then the output analog waveform would be a triangle wave with levels of -1V and 0V as shown in the following figure:



The samples values are stored in binary format in *little-endian* byte order. The the contents of the file for the waveform above would be as shown in the following hex dump:



You will have to configure the AWG with the desired High and Low levels as well as the sampling rate as described below.

Appendix B - Configuring The AWG

- Press Utility Set To Default OK to reset the AWG to it's default settings.
- Press Arb to select Arbitrary waveform output.
- Press Arb Mode until SRate (sample rate mode) is selected. Note: to access this and some of the following buttons you may need to press ▽ (gray key on the bottom) to toggle between two sets of menus.
- Plug your USB drive into the USB socket on the front of the AWG. You should see the message USB device detected and the USB icon ( ) will appear on the display.
- Press Select Waveform Stored Wforms.
- Press File Type Arb File
- Press Browser until Dir is selected.
- Use the knob to highlight drive `D:` (the USB drive).
- Press Browser until File is selected.
- Use the knob to highlight your `.RAF` file.
- Press Read and you should see the message Completed! Arb Wave data have been read.
- Press Arb to return to the Arb menu.
- Press Srate and enter the sample rate on the keyboard. Terminate the entry by selecting the appropriate units.
- Press Ampl until HiLevel is highlighted.
- Enter the voltage that should be output for the maximum sample value (0x3ff).
- Press Offset until LoLevel is highlighted.
- Enter the voltage that should be output for the minimum sample value (0x000).
- Press Output1 to turn on the Channel 1 output.