Automated Frequency Response Measurement

Introduction

Many instruments can be controlled remotely by computer software. This allows many test and measurement tasks to be automated.

In this lab you will write a program that uses the lab's AWG, oscilloscope and DMM to measure the transfer function of a channel.

Before doing the lab you'll also need to unpack a DMM, set it up on your bench and record it's serial number. You will also need to install drivers for the DMM's USB interface.

Control Interfaces

You will connect the lab PC to the three instruments through their USB ports. The AWG and 'scope also have Ethernet interfaces. Older instruments often have an instrumentation-specific parallel bus variously known as IEEE-488, GPIB or HPIB

The computer acts as the interface master and sends commands to the instrument. The instrument acts on each command and, if necessary, sends back a response after the command has been carried out.

SCPI

SCPI (Standard Commands for Programmable Instruments, often pronounced "skippy") is a standard for these instrument commands. The SCPI standard defines different commands for each class of instrument (meters, oscilloscopes, power supplies, etc). However, a particular model may not support all of the commands. Each instrument's manual describes the specific commands that are supported. The programmer's guides for the AWG, 'scope and DMM are available on the course web site – but do not print them out, they total nearly a thousand pages!

Useful SCPI Commands

SCPI commands that all instruments recognize and that you may find useful for this lab include:

*rst sets the device to default values[1]

*idn? retrieves a device's identification string to check that you're connected to the right device

Rigol DS2074 DSO

The lab 'scope is a Rigol DS2074 Digital Storage Oscilloscope (DSO). Some its SCPI commands that you may find useful for this lab include:

:channel<n>:probe 10 - tells the instrument that channel <n> is using a 10x probe (where <n> is 1 or 2)

:channel<n>:coupling AC - sets channel <n> to AC-coupled input

:channel<n>:offset 0 - sets the vertical display offset for channel <n> to zero

:channel<n>:scale <scale> - sets the vertical scale on channel <n> to <scale> volts/division

:timebase:scale: <scale> - sets the horizontal sweep to <scale> seconds/division

:measure - to enable and return measurement results (frequency, phase, RMS voltage). For example:

:meas:freq? chan1 - frequency of Channel 1

:meas:vrms? chan1 - rms voltage of Channel 1

:meas:vrms? chan2 - rms voltage of Channel 2

:meas:fph? chan1,chan2 - phase difference (in degrees) between Channels 1 and 2

Note that the 'scope may indicate that the input signal level is out of range or that there was an error in the SCPI command by returning an impossibly large value (e.g. 9.9E37).

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[1] While the instrument is being reset it may not respond to SCPI commands. Allow a few seconds after sending the reset before sending another command.

Rigol DG1000Z AWG

Some of the AWG's SCPI commands that you may find useful for this lab include:

:output\<n\> on sets output \<n\> (default 1) on.

:source\<n\>:apply:sin \<f\>,\<a\> configure source \<n\> (default 1) to generate a sine wave of frequency \<f\> (Hz) and amplitude \<a\> (Vpp).

B&K 2831E DMM

Chapter 5 of the DMM manual describes the available commands. Some of the DMM's SCPI commands that you may find useful for this lab include:

:function voltage:ac sets the DMM to measure AC voltage

:fetch? reports the most recent measured value

VISA

VISA (Virtual Instrument System Architecture) is an application programming interface (API) that helps you to write programs to control instruments. VISA is a cross-platform multi-interface API that allows the same program to be used on computers with different operating systems (Windows, Unix and OS-X) and different interfaces (USB, Ethernet, GPIB, and others). VISA defines different APIs for different programming languages. We will use the C API.

Several test equipment manufacturers[2] provide free VISA software. For this lab we will use the Keysight (formerly Agilent) VISA software[3]. The VISA API is defined by the `visa.h` and `visatypes.h` include files. The `visa64.lib` library contains the API functions that need to be linked into your program by the compiler. Keysight include several utilities, described below, for troubleshooting.

The VISA API function arguments and return values are described in the VISA API Reference. The NI-VISA and Agilent VISA User's Manuals explain in detail how to use these functions. All three are available on the course web site.

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[2]Suppliers of the most popular VISA software are NI - National Instruments and Keysight (formerly Agilent, formerly HP).

[3]NI VISA software supports multiple operating systems but is only free if you have purchased NI products.

Although the instrument and VISA manuals make for exciting reading, you will probably not have time to go through them from cover to cover. But you should understand where to find specific information, such as the description of a VISA function or SCPI command, and be able to quickly look it up by scanning the table of contents, index or by searching for strings within a document.

Useful VISA Functions

You will probably find the following VISA functions useful for completing this lab:

viOpenDefault - to initialize the VISA system

ViOpen - open a communication link to an instrument

viPrintf - send a SCPI command to an instrument

viScanf - read a response and extract one or more values

viQueryf - combines the two previous functions

viClose - close opened resources

Procedure

Install DMM

You may have to unpack and install the DMM.

Unpack the instrument and check the contents against the included packing ("Contents") list in section 1.2 of the DMM manual. If there are any missing items, note this down and inform the instructor.

Remove the old function generator and its power cord, place it on the table at the front of the lab and set up the DMM in its place. Put the DMM manual and all accessories except for the probes in the zip-lock bag and place it on the front table as well.

Record the DMM's serial number (printed on a label on the back of the instrument) and include it in your report.

On a new instrument you will need to disable the DMM's command echo from the front panel[4]: press ⎡Shift⎤ then ⎡Esc⎤; press ⎡▷⎤ until you see `C:SYS MEU`;

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[4]If you don't change this setting the VISA software will not recognize responses from the DMM.

press $\boxed{\triangledown}$ then $\boxed{\triangleright}$ until you see 4:RETURN; press $\boxed{\triangledown}$ then $\boxed{\triangleright}$ until you see OFF. Press $\boxed{\text{Auto}}$ to save the new setting and then $\boxed{\text{Shift}}$ and $\boxed{\text{Esc}}$.

You will need to install the USB drivers for the DMM. Download the zip file from the course web site to the D: drive, unzip the file and run the CP210xVCPInstaller_x64.exe installer.

Connect a USB cable from the USB connector on the back of the DMM to a free USB port on the back of the PC.
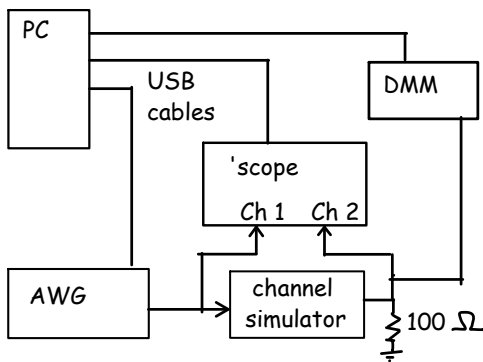
Verify that the driver has been installed and the DMM is connected by running Device Manager and checking under "Ports (COM & LPT)" for the CP210x driver as shown below. Note the COM port that was assigned (e.g. COM5).
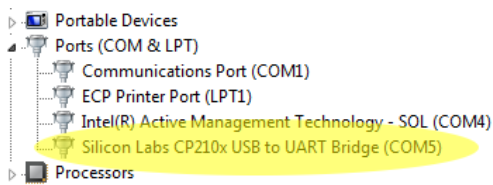
Unfortunately, you will need to reinstall the driver each time the computer reboots.

Connect Equipment

The following diagram shows the measurement setup:

As shown in the photo below, the AWG and the Channel 1 probes should be connected to the channel simulator[5] terminals marked IN and GND and the 100 Ω resistor, the Channel 2 probe and the DMM probes to the terminals marked OUT and GND. All

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[5]The simulator is a four-section lumped-element approximation of the distributed RGLC model of a transmission line.

the switches on the channel simulator should in the down position.

The USB ports on the back of the 'scope, AWG and DMM should already be connected to USB ports on the back of the PC.
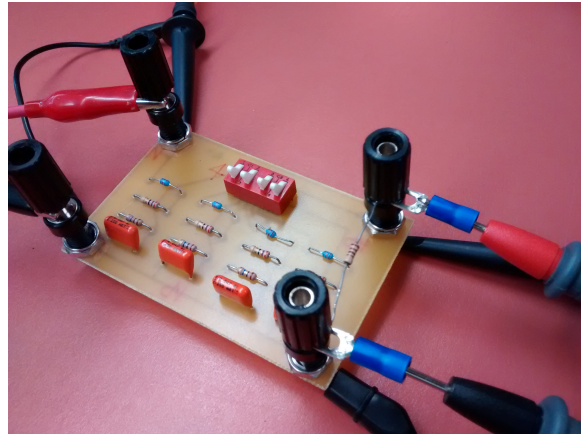
Configure DMM in VISA Library

The DMM's USB interface emulates a serial port and serial ports do not identify the type of device so you will need to add the virtual COM port assigned to the DMM as a VISA instrument.

Run Keysight Connection Expert and under Manual Configuration / Add New Instruments/Interfaces select the appropriate Serial Instrument (e.g. if the DMM is on COM5 use "Serial instrument on ASRL5"). Make sure the serial interface parameters are as shown below (9600,N,8,1) and that the "Auto-Identify This Instrument" option is selected. Click on Accept to make the change.
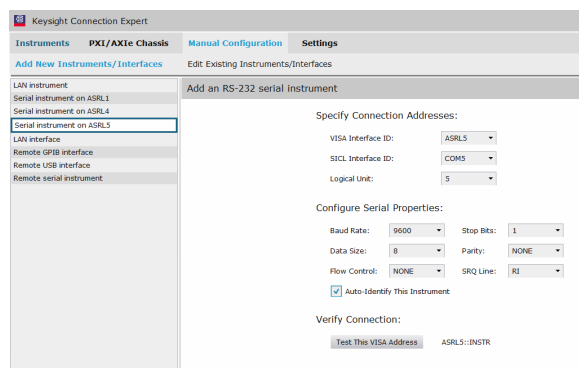

Assign VISA Aliases

Each instrument can be addressed by a VISA device address or name. The Connection Expert soft-

ware can show you the VISA addresses of connected devices. You can also assign aliases to the instruments so that the software does not need to be modified when instruments are changed. Under Settings / Aliases click on "Add New VISA Alias," enter the alias and select the instrument address. Use the aliases you used in your software.
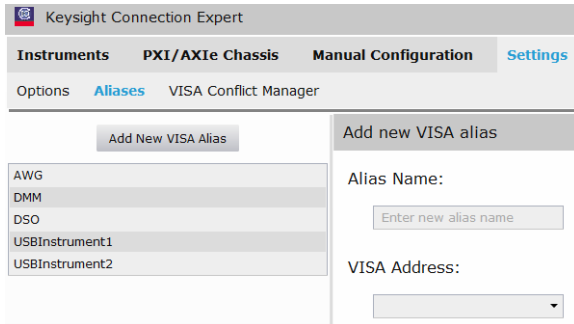
After you are done you should have three instruments, each with the correct alias:
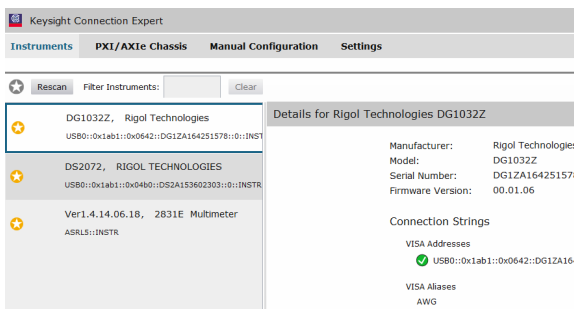
You may need to repeat the DMM and VISA configuration each time the computer reboots.

Write and Compile Software

A sample C program is provided on the course web site to get you started with this lab. The program includes some, but not all, of the functionality required. You will need to enhance it so that your C program will do the following:

- open the VISA default resource manager and the three instruments

- check that the correct instruments have been connected by issuing a '*IDN?' command and printing the result to `stdout`

- send commands to configure the instruments: The 'scope should be set for the probes being used, AC coupling and zero vertical offsets. The Channel 1 (channel input) vertical scaling should be set so the waveform takes 6 divisons vertically[6]. The AWG channel 1 output should be enabled. The DMM should be set to measure AC voltage.

- do the following repeatedly (in a loop) over a frequency range of 100 Hz to 100 kHz[7] in 10 steps per decade:

  – set the AWG frequency and an output level of 5 Vpp

  – read the DMM AC voltage (the channel output voltage)

  – use the measured DMM voltage to compute and set the 'scope's Channel 2 voltage scaling that results in the signal taking up 6 divisions vertically

  – use the known frequency to compute and set the 'scope's horizontal scale to display two cycles of the sine wave

  – read the channel input, channel output and phase difference from the 'scope

  – print the frequency, output voltage and phase shift, separated by commas, to both standard output (`stdout`) and standard error (`stderr`)

You may need to insert delays (e.g. by using the `Sleep()` function) after changing instrument settings.

Use an editor such as Notepad++ to edit your C program. Open a "command prompt" window and change to your working directory. Download the `build.bat` batch file from the course web site. This script will run the Pelles C compiler[8] and linker with the appropriate options[9]. Supply the base name of the C file as an argument to the script (i.e. use the command `build lab6`).

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[6]Note that the scale values can be set to arbitrary values – they don't need to be usual powers of 10 times 1, 2 or 5.

[7]The DMM upper frequency limit is 100 kHz.

[8]`tcc` can't link to the VISA libraries.

[9]Assuming the compiler and VISA libraries were installed in their default locations

Each line output by your program should have three values (frequency, ratio of output to input voltage and phase difference) separated by commas. This is called CSV (comma separated values) format and can be read by spreadsheet software.

Measurement Procedure

Run your program with the standard output redirected to a file. For example:

```
lab6 >results1.csv
```

Monitor the output of your program and resolve any problems.

Data Analysis

Open the `.csv` file with a spreadsheet and *immediately save it in a spreadsheet format*[10]. Add a column that computes the gain of the channel in dB. Add a chart (graph) that shows both the gain and the phase of channel as a function of frequency. Use an XY graph showing smoothed lines with logarithmic axis for frequency. Use two axes (gain on left, phase on the right). Label the graph and the axes. Your graph (but not necessarily the data) should look as follows:
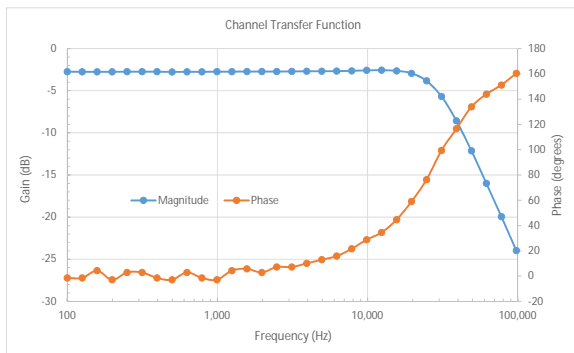

Remember to save your C code and measurements on your network or flash drive.

Hints

A methodical approach will help you complete this lab on time. The following approach is recommended:

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[10] Formulas and charts cannot be saved in `.csv` files, if you skip this step you will lose all your analysis!

- use the **Keysight Connection Expert** utility to check that the instruments are connected and have been assigned the correct aliases.

- use the **Interactive IO** utility (click on Instruments / "Send Commands To This Instrument") to issue SCPI commands manually and make sure the instruments respond as expected
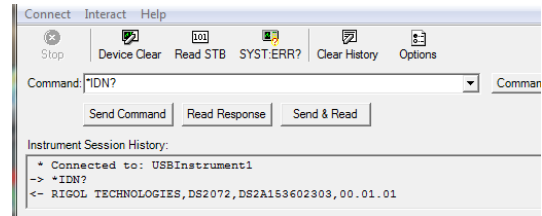
- comment out untested portions of your program using #ifdef/#endif and use the **IO Monitor** utility ('IO' status bar icon > Utilities > IO Monitor) to test a simple version of your program. Gradually add functionality, checking for correct operation after each addition.

Pre-Lab Tasks

Write a C program that meets the requirements described above. You can start from the example given or write your own. You will not be able to test your code without an instrument but you can download the `visa.h` and `visatype.h` files and compile your program with any C compiler to check for syntax errors. For example, if the visa include files are in the current directory, the tcc command: `tcc -c -I. lab6.c` will compile your code and report any syntax errors.

Submit a listing of your code as a PDF file to the dropbox on the course web site before the lab.

Report

Submit the following two files to the dropbox on the course web site:

1. a report in PDF format containing the usual identification information, the DMM serial number, a listing of your (working) C code, the graph of the channel amplitude and phase responses formatted

as described above, and the answers to the following questions:

(a) is this a low-pass, high-pass or bandpass channel?

(b) what are the -3, -6 and -10 dB bandwidths?

(c) how quickly does the channel "roll-off" with frequency, in units of dB per octave?

2. your spreadsheet in Microsoft Excel format (.xls or equivalent) containing the captured data and your chart (graph)

To answer some of the questions above you will want to use the measured data rather than the above graph or change the axis ranges.