Electronic Circuits Laboratory
EE462G
Lab #1

Measuring Capacitance, Oscilloscopes, Function Generators, and Digital Multimeters

Original slides prepared by Kevin D. Donohue (Spring 2007)

Modified by Zhi David Chen (Fall 2018)

Instrumentation

Tektronix MDO3012 Oscilloscope

Oscilloscope

◦ 2 and 4 analog channel models

◦1 GHz, 500 MHz, 350 MHz, 200 MHz, 100 MHz bandwidth models

◦Bandwidth is upgradable (up to 1 GHz)

◦Up to 5 GS/s sample rate

◦ 10 M record length on all channels

◦>280,000 wfm/s maximum waveform capture rate

◦Standard passive voltage probes with 3.9 pF capacitive loading and 1 GHz, 500 MHz, or 250 MHz analog bandwidth

Spectrum Analyzer

◦Frequency range ◦Standard: 9 kHz - oscilloscope bandwidth

◦Optional: 9 kHz - 3 GHz

No LabVIEW to output the data.

Instrumentation

Analog Discovery 2: USB Oscilloscope, Logic Analyzer

•Two-channel USB digital oscilloscope (1MΩ, ±25V, differential, 14-bit, 100MS/s, 30MHz+ bandwidth - with the Analog Discovery BNC Adapter Board)

•Two-channel arbitrary function generator (±5V, 14-bit, 100MS/s, 12MHz+ bandwidth

•16-channel digital logic analyzer (3.3V CMOS and 1.8V or 5V tolerant, 100MS/s)

•Network Analyzer – Bode, Nyquist, Nichols transfer diagrams of a circuit. Range: 1Hz to 10MHz

•Spectrum Analyzer – power spectrum and spectral measurements (noise floor, SFDR, SNR, THD, etc.)

A student, who has it, can use it as a oscilloscope, which can output data.

Instrumentation

BK Precision 4011A Function Generator

- 0.5 Hz to 5 MHz
- Sine, Square, Triangle, Pulse, & Ramp output
- Coarse and Fine tuning
- 4 digit LED display
- Variable duty cycle
- Variable DC offset
- Variable amplitude output plus 20dB attenuator
- 20Vpp output into open circuit (10Vpp into 50 Ωs)

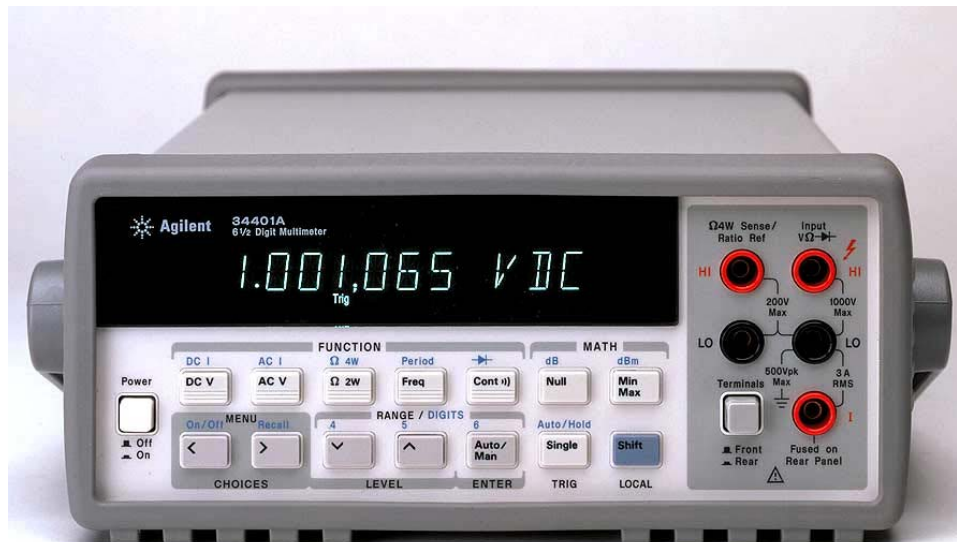# Instrumentation

Agilent 33220A Waveform Generator

- 20 MHz sine and square waveforms

- Ramp, triangle, pulse, noise, and DC waveforms

- 14-bit, 50 MSa/s, 64 K-point arbitrary waveforms

- AM, FM, PM, FSK, and PWM modulation type

- Linear & logarithmic sweeps and burst operation modes

- Graph mode for visual verification of signal settings

- USB, GPIB and LAN interfaces included

- 100 - 240 Vac, -5%, +10%; 50/60Hz operation

Instrumentation

Digital Multimeter Agilent 34401A

- 6½ digit resolution

- DC/AC voltage, DC/AC current, 2- and 4-wire resistance, diode, continuity, frequency, period

- Basic accuracy: 0.0035% DC, 0.06% AC

- 1000 V max voltage input, 3 A max current input

Instrumentation

TENMA DC Power supply 72-6905

• Quad Independent DC Output

• Four LED Display with 3 digits, selectable for two sets output voltage and current display

• Auto series, parallel and tracking operation

• Constant voltage and constant current operation

• Low ripple and noise
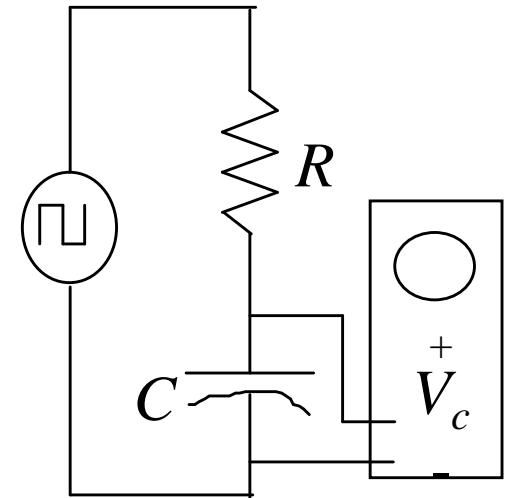
Test Circuit A

Problem:

➢ *C* is unknown, use step response to determine its value with a known resistor value, *R*.

Analysis:

➢ Derive relationship between *C* and step response of amplitude *A* in terms of *R*.

Procedure:

➢ Determined what must be measured to resolve the values for *C* and develop process for measuring these quantities.
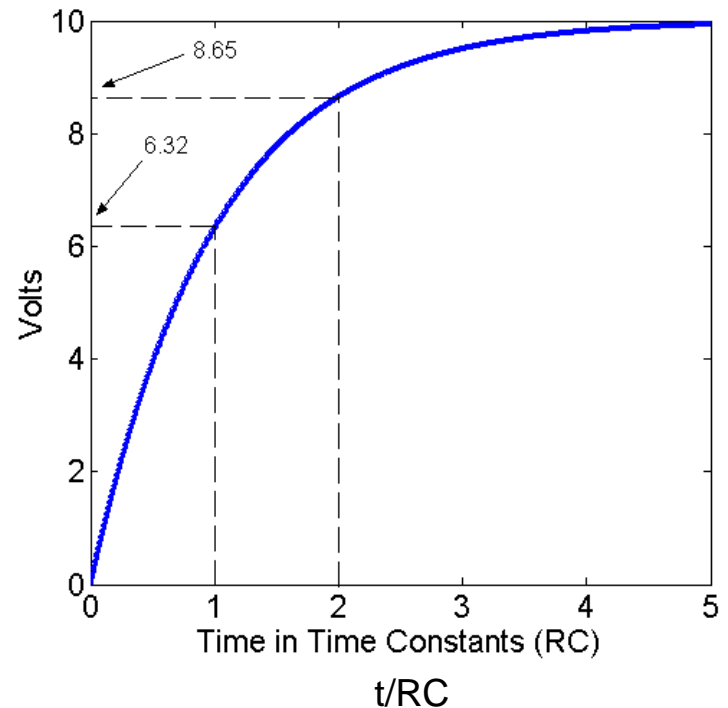
Test Circuit A

Step response:

$$V_c = A\left[1 - \exp\left(\frac{-t}{RC}\right)\right]$$

Procedure issues:

➢ How should a value for R be determined?

➢ At what values of V_c should t be measured?

On the Oscilloscope, at V_c=6.32V find the corresponding time t_1=RC. C=t_1/R

Example curves for A=10 V

t/RC

Test Circuit A

Data Sheet

> Must include sketch of circuit, sketch of waveform from which measurement was made, value of Resistor(s) (measure with DMM), oscilloscope time and voltage measurements, and frequency of square wave(s).

Procedure Description

> Describe test circuit (use a figure with node labels that you can refer to in your discussion !!!!!) and discuss grounding for scope probe and function generator placement.

> Describe how R and square wave frequency were determined. (Use the equation editor to reference formulae used. Avoid long wordy descriptions. Be precise, use equations, and describe all variables in the equation.)

> Describe computations using measured quantities to obtain C value. (Use the equation editor to show the formula used.)

Results Section

> Show measurements from data sheet in tables (paste in waveforms and schematics rather than sketches).

> Present estimated values of C, and summary statistics with confidence intervals.
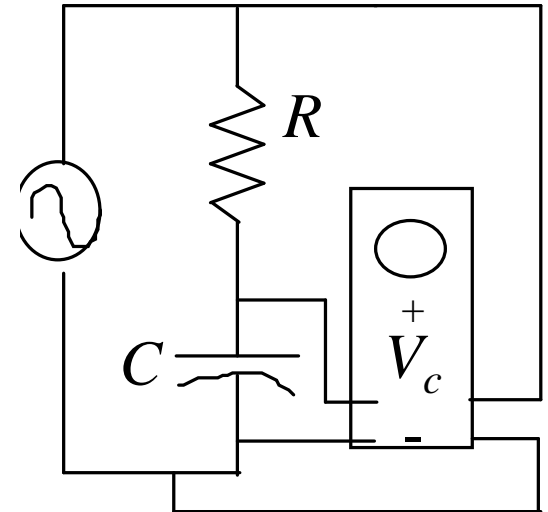
Test Circuit B

Problem:

 ➢ *C* is unknown, use frequency response to determine its value with a known resistor value, *R*.

Analysis:

 ➢ Derive frequency response for output V_c with sinusoidal input from function generator of amplitude *A*.

Procedure:

 ➢ Determined what must be measured to resolve the value of *C*. Use the Tektronix MDO3012 oscilloscope to measure frequency response manually and then curve fit to estimate best-fit value of C.

Alternative Way: Use the Analog Discovery 2 to measure frequency response and then curve fit to estimate best-fit value of C.
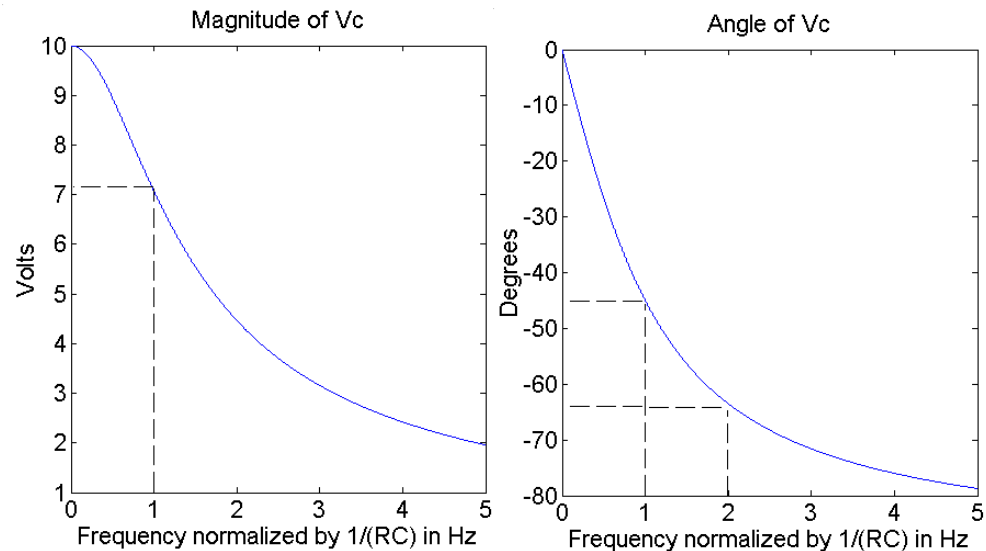
Test Circuit B

Frequency response($\omega=2\pi f$):

$$\hat{V}_c(j\omega) = \frac{A}{1+j\omega CR}, \quad \left|\hat{V}_c(j\omega)\right| = \frac{A}{\sqrt{1+\left(\dfrac{\omega}{1/RC}\right)^2}}, \quad \angle\hat{V}_c(j\omega) = 0 - \tan^{-1}\left(\frac{\omega RC}{1}\right)$$

Procedure issues:

➤ What frequencies should be selected to estimate sample of the frequency response?

➤ How to combine curve fit values from phase and magnitude spectra?

➤ What is a simple way to verify manually the values of C and resulting cut-off frequency?

Example curves for $A=10$ V

Magnitude of Vc — Volts vs Frequency normalized by 1/(RC) in Hz

Angle of Vc — Degrees vs Frequency normalized by 1/(RC) in Hz

Test Circuit B

Data Sheet

➤ Must include sketch of circuit, sketch of sample waveform (i.e. select one close to the cutoff), value of Resistor(s) (Measure with DMM), outputs from LabVIEW program with clearly labeled magnitudes and phases measurement for each tested frequency.

Procedure Description

➤ Describe test circuit (use a figure with node labels that you can refer to in your discussion !!!!!) and discuss grounding for scope probe and function generator placement.

➤ Describe how frequencies for testing the circuit were determined.

➤ Describe curve fit procedure used to estimate the final values of C.

Results Section

➤ Present all direct measurements and each value (show outliers if any and indicate which measurements were not used in the curve fit computation). Present estimates of C with summary statistics with confidence intervals.

Curve Fit in Matlab

- For your experiments you are using a low-pass filter circuit
- Curve fit examples for a high-pass filter fit are provided by class posted mfiles
  - fithpmag.m for magnitude fit
  - fithpang.m for phase fit
- These can be studied and modified for the curve fitting in this lab assignment.

Computing Confidence Intervals

In order to examine measurement variability in a quantitative and consistent manner, the 95% confidence interval can be computed using the estimated mean, variance, and t-statistic table.

For example, you will report your result from multiple measurements with summary statistics such as:

$$\hat{C} = 20.1 \pm 5.6 \mu F$$

where 20.1μ is the average of all your measurements/estimates, and the range from 20.1-5.6=14.5μF to 20.1+5.6=25.7μF is the range in which it is 95% likely the true value exists.

The smaller the range, the **more precise** the measurement.

Confidence Interval Example

Assume you make 6 **independent** measurements of the same quantity:

$$\{x_1, x_2, x_3, \ldots x_6\} = \{3.1713 \quad 2.9503 \quad 3.2883 \quad 2.7991 \quad 3.4143 \quad 3.6871\}$$

The sample mean (average) is obtained by:
$$\bar{x} = \frac{1}{6}\sum_{k=1}^{6} x_k = 3.2184$$

The sample standard deviation:
$$S_x = \sqrt{\frac{1}{6-1}\sum_{k=1}^{6}\left(x_k - \bar{x}\right)^2} = 0.3202$$

6 independent values correspond to 5 degrees of freedom (*N-1*) for the *t*-statistic. Go to table in Lecture 0 notes and find:

$$t_{(97.5,5)} = 2.5706$$

Confidence Interval Example

Now apply formulas:

$$t_v = \frac{\bar{x} - \mu}{S/\sqrt{N}} \qquad \Pr\left[\bar{x} - (t_{.975,5})\frac{S}{\sqrt{N}} < u < \bar{x} + (t_{.975,5})\frac{S}{\sqrt{N}}\right] = 0.95$$

to obtain the symmetric 95% confidence interval number:

$$\Delta = (t_{.975,5})\frac{S}{\sqrt{N}} = 2.5706\frac{0.3202}{\sqrt{6}} = 0.3361$$

Therefore, result can and should be reported as:

$$\hat{x} = 3.2184 \pm 0.3361$$

Final Notes

Data Sheet

➢ Include a labeled drawing of each test circuit so the reported values can easily be identified from your data sheet. Points will be taken off for ambiguity or lack of clarity in reported numbers.

➢ Waveforms should be sketched on your data sheet, however sample waveform should be saved to floppy disk from scope, or you can use the LabVIEW "Show Wave" program or option through the GPIB interface to save image on screen directly to hard drive   (SAVE IN A FORMAT YOU CAN RETRIEVE LATER FOR PRINTING OR ANALYSIS). For multiple measurements made with LabVIEW programs, then can be organized in a labeled table, printed and attach to the datasheet. Clearly label figures and table so it can be determined how they were generated.

Procedure Description

➢ Description should be detailed enough so that the reader can repeat your experiment with similar results.

➢ Clearly indicate, on a circuit drawing, where measurements were made.

➢ Address all questions asked in the lab assignment sheet and lecture.

Final Notes

Presentation of Results

➢ Organize and present data in table and graphs.

➢ Clearly relate results back to the particular procedure from which they were obtained (give procedures descriptive names).

➢ Clearly indicate formula used to process measured data for obtaining final results.

Discussion of Results

➢ Compare the methods used in terms of the relative difficulty of each procedure.

➢ Explain possible sources for variability between the C values determined through each method and discuss relative accuracy of each.

➢ Respond to questions asked in lab assignment/lecture.

Final Notes

Conclusion

> Briefly sum up the results and indicate what was learned through doing this experiment. Address the objectives in the lab assignment.

General

> Number all figures, tables, pages, and equations sequentially (learn how to use equation editors), and avoid first person voice. All graphs axes should be label, all rows and columns of tables should be labeled. Use figure captions and table titles.

Quizzes

> A quiz will cover the lecture material and the pre-lab assignment and solutions that were assigned one week ago. It is open book and you can use class materials on my website. Even it is open book, you still must study the materials.

Hint: Wrote the note that is emphasized by the instructor in the lecture; Study the prelab solutions and examples.

Example: The cable effect in the real world