Lab Assignment # 6

Automatic Measurement and Data Processing
Using Instruments with IEEE488 Interface and Agilent VEE

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Objective

- Measurement of transfer functions of passive networks
- Measurement of transistor characteristics

Equipment

- Agilent 34401A Digital Multimeter
- Agilent 33120A Function Generator
- Agilent 53181A Frequency Counter
- Agilent 54622A Deep Memory Oscilloscope or Agilent 54600B Oscilloscope
- Agilent 4284A RLC Meter
- Agilent E1300A Mainframe with
    - Agilent E1328A 4-Channel D/A Converter
    - Agilent E1326B 5 _ Digit Multimeter or Agilent E1312A 6 _ Digit Multimeter
    - Agilent E1345A 16-Channel Thermocouple Relay Multiplexer or Agilent E1347A 16-Channel Relay Multiplexer
    - Agilent E1340A Arbitrary Function Generator

Laboratory Experiments

1. **Exercises**

1.1. **Transfer functions of passive networks**

Develop a virtual instrument measuring and displaying the transfer function and determining characteristic values of the following passive networks:

1.1.1. Parallel resonant circuit,

1.1.2.   RC low-pass or RC high-pass.

Use Agilent VEE and one of the possible instrumentations (stand-alone or VXI instruments).

1.2. **Transistor characteristics**

Develop a virtual instrument measuring and displaying the characteristics of a bipolar transistor in common-emitter circuit and determining the h_{11e} and h_{21e} parameters at a definite operating point using Agilent VEE and a VXI instrumentation.

2. Theoretical Background

The impedance of a parallel resonant circuit depends on the frequency: it is very small if the frequency goes to zero or to infinity and reaches a real maximum R_{res} at the resonant frequency $f_0 = 1/2\pi\sqrt{LC}$. Using a frequency-dependent voltage divider consisting of a very high resistance $R_s \gg R_{res}$ in series with the resonant circuit the voltage across the resonant circuit is proportional to it's impedance. The graph of the voltage amplitude versus frequency is called resonant curve. This function is to be measured and displayed.

First-order RC high-pass and low-pass are simple examples of four-poles with frequency-dependent transfer functions. The complex voltage transfer function $\underline{g}(\omega)$ of a four-pole is defined by

$$\underline{g}(\omega) = \frac{\overline{U}_{out}}{\overline{U}_{in}} \ ,$$

where $\overline{U}_{out}$ and $\overline{U}_{in}$ are the complex amplitudes of the output and the input voltage, respectively. At the cut-off frequency f_c the magnitude of the transfer function is:

$$g(f_c) = \frac{1}{\sqrt{2}} \ .$$

Because it is necessary to describe the behavior in a very wide amplitude and frequency range, it is usual to plot the logarithm of the magnitude of the transfer function $20 \cdot \lg g(\omega)$ [in decibels] and the phase angle $\varphi_g(\omega)$ versus the logarithm of the frequency; this graph is called BODE diagram.

The bipolar transistor in common-emitter circuit is a standard application for voltage amplification. The operating point is described completely by the four variables U_{CE}, U_{BE}, I_C, I_B , which all depend on one another. The behavior of the transistor can be described completely by the four characteristics
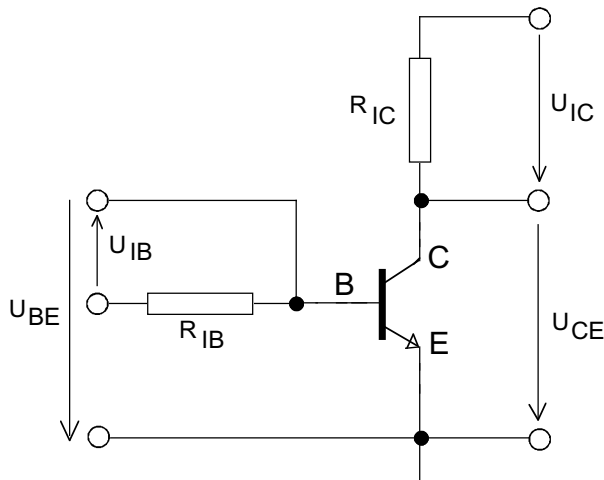

Fig.1: Bipolar transistor in common-emitter circuit (measurement scheme)

$$I_C = f(U_{CE}) \ , U_{BE} = f(U_{CE})$$
at $I_B = const$
and
$$I_C = f(I_B) \ , U_{BE} = f(I_B)$$
at $U_{CE} = const$.

The small signal properties of the transistor in a definite operating point can be described with the h-parameters defined by the slope of the characteristics in this point. Very important values are the input resistance

$$h_{11e} = \left. \frac{\Delta U_{BE}}{\Delta I_B} \right|_{U_{CE}=const}$$

and the current amplification

$$h_{21e} = \left. \frac{\Delta I_C}{\Delta I_B} \right|_{U_{CE}=const} \ .$$

3. Instructions to the Laboratory Exercises

The aim of this laboratory exercises is to learn about
- the application of different stand-alone and VXI instruments in measurement technology,
- remote controlling of instruments using the IEEE488 interface and
- the application of Agilent VEE for data acquisition and processing

(see also: *Remote Control of Instruments Using IEEE488 Interface and Agilent VEE / Lab Assignment #5*).

You are to develop of a virtual instrument, which executes a concrete measurement having a comfortable graphical user interface, which guides the user through the program. There are two instrumentation possibilities: application of stand-alone as well as of VXI instruments. VXI instruments are modular instruments without front panel and control elements usable only with remote control. All instruments are equipped with an IEEE488 interface and fulfil the SCPI standard. For remote control of all instruments Direct-I/O primarily should be used. Select one of the exercises and a suitable instrumentation and consult your selection with the teacher.

After finishing your work demonstrate that your program runs correctly, print out some characteristic results and document your program together with a description.

Exercise 1.1.1.

In this exercise a virtual instrument is to be developed, which
- measures the resonant curve of a parallel resonant circuit,
- displays the resonant curve on the screen, and
- determines the characteristic values resonant frequency f_0, bandwidth B and quality Q of the resonant circuit.

At first measure the values L_p, C_p, R_p of the elements of the resonant circuit using the RLC meter; use a frequency approximately equal to the resonant frequency f_0.

Then start with a very simple program, which only generates and measures an AC voltage with definite amplitude and frequency using a function generator and a multimeter; program a loop changing the frequency step by step and measuring each amplitude, and save all measured data in arrays.

Keep in mind, that there are two possibilities to determine the frequency: from the output of the loop object or from an actual measurement using a frequency counter or a multimeter. Display the graph of the relative amplitude $A_{rel} = U_{max}/U$ versus frequency.

Note: The difference $f_{stop} - f_{start}$ is relatively small, therefore, a linear frequency scaling should be used.

Program user inputs of the following parameters:
- AC voltage amplitude U_s,
- start frequency f_{start},
- stop frequency f_{stop},
- frequency step Δf.

Finally, program the determination of the resonant frequency f_0, bandwidth B and quality Q of the resonant circuit.

Note: After running the program all instruments are in the remote state, and it is impossible to control the instruments using the hardware front-panel. Therefore, at the end of the program reset and switch to local all instruments.

Compare the results of the automatic measurement with those calculated from the measured values L_p, C_p, R_p of the elements.

Exercise 1.1.2.

In this exercise a virtual instrument is to be developed, which
- measures the transfer function of a four-pole,
- displays the transfer function on the screen, and
- determines the cut-off frequency f_c of the used circuit.

At first measure the values R, C or R, L of the elements of the circuit using the RLC meter. Then start with a very simple program, which only generates and measures an AC voltage with definite amplitude and frequency using a function generator and a multimeter. Then program a logarithmic loop changing the frequency and measuring each voltage amplitude, and save all measured data in arrays.

Keep in mind that there are two possibilities to determine the frequency: from the output of the loop object and from an actual measurement using a frequency counter, an oscilloscope or a multimeter.

Note: Using a multimeter only the amplitude of the output voltage and, therefore, the magnitude of the complex transfer function can be measured, but using the oscilloscope the phase angle can be determined also.

Display the graph of the transfer function versus frequency as a BODE diagram..

Program user inputs of the following parameters:
- input voltage amplitude U_{in} ,
- start frequency f_{start} ,
- stop frequency f_{stop} ,
- number of frequency step per decade.

Finally, program the determination of the cut-off frequency f_c of the four-pole.

Note: After running the program all instruments are in the remote state, and it is impossible to control the instruments using the hardware front-panel. Therefore, at the end of the program reset and switch to local all instruments.

Compare the results of the automatic measurement with those calculated from the measured values of the elements of the used four-pole.

Exercise 1.2.

In this exercise a virtual instrument is to be developed, which
- measures the characteristics of a bipolar transistor in common-emitter circuit,
- displays the characteristics on the screen,
- supervises the collector current and stops the actual measurement if the current exceeds a definite limit, and
- determines the h_{11e} and h_{21e} parameters of the transistor in a definite operating point using VXI instruments.

Start with a very simple program, which only generates and measures a DC voltage or a DC current. Then program a loop changing the voltage or current step by step, measuring each outputted value, and save all measured data in arrays.

Keep in mind, that only voltages can be measured because for current measurement it is necessary to change the input connection of the multimeter. For current measurements a current-voltage converter must be used. Use a resistor, measure the voltage across it, and calculate the current.

Keep in mind that for the complete characterization of a transistor, the dependence between the four variables U_{CE}, I_C, U_{BE}, I_B must be determined. Build up the actual measurement circuit (see Fig.1) using a transistor and resistors to convert the collector current I_C as well as the basic current I_B into voltages and connect it with the outputs of the DAC unit and the inputs of the multiplexer. Display the transistor characteristics in all quadrants.

Note: The maximum output current of the DAC is 24mA.

Program a limit supervision of the collector current and a correct reset to zero of the output voltage and output current at the end of the program.

Finally, program the determination of the h-parameters of the transistor in a definite operating point.

Program user input for the following parameters:

- measurement resistors R_{IC} and R_{IB},
- start, stop and step value of the variables U_{CE} and I_B,
- collector current limit $I_{C\,max}$,
- the collector bias current of the operating point $I_{C,B}$.