Session: 1532

Remote Monitoring and Control of GPIB-based Electronic Experiment

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I. Introduction

This work presents a novel approach in the implementation of a remote laboratory for an electronic experiment using LabVIEW's remote panel technology. In the past, a number of remote labs have been tried and tested[1,2,3,4]. However, a very limited number of electronic experiments have been attempted. To our knowledge, with the exception of some simple experiments related to basic circuit analysis[5], there is no work presented on remote experiments involving advanced electronic laboratory assignments.

This paper describes a typical electronic experiment, which can be monitored and controlled remotely. The experiment selected is a common-emitter (C-E) type bipolar junction transistor (BJT) amplifier. It is one of the electronic labs taken by most electrical engineering students typically in their junior year. With an adequate provision of GPIB-compatible instruments, the proposed prototype can be applied to virtually any advanced electronics laboratory activity.

With the server computer and experimental set up located in separate project room, the experiment was tested on a network of computers at a remote electronic laboratory. In addition, it was also tested outside the school network, such as in a home setting and at a remote university. Currently, LabVIEW comes with only one license by default. Therefore, only one client computer can monitor and run it at any time. Additional licenses such as 5, 20, or 50 can be purchased from National Instruments (the company that developed LabVIEW), which will allow multiple clients to view the experiment simultaneously.

II. Brief Theoretical Background

The primary purpose of this experiment is to demonstrate to the students that a small voltage signal (46mV$_{rms}$) can be amplified using a properly biased BJT transistor. Also, the students will learn how changes in emitter resistor (R_E) value affect the output voltage and consequently, its gain. Moreover, they will be able to observe how this situation is overcome by applying a bypass capacitor across the R_E. Biased circuitry is used to assure that the transistor operates in the active region. The design of the amplifier circuit is adopted from the electronic laboratory book[6]. The values of the resistors, R_E (emitter resistor) and R_C (collector resistor), were calculated and chosen in such a way that the direct current (DC) operating point known as quiescent (Q) point will lie in the middle of the load line. Having a Q point located in the middle of the load line is critical because under this condition, the amplified voltage signal will have no clipping (i.e. no distortion), even if the waveform engages in maximum positive and negative swings. The voltage gain (A_V) of the C-E amplifier (under no load) can be expressed as follows:

$$A_V = \frac{R_C}{(R_E + r_e)} \qquad (1)$$

where r_e = dynamic resistance, and the dynamic resistance can be calculated as

$$r_e = \frac{V_T(mV)}{I_{EQ}(mA)} \qquad (2)$$

where I_{EQ} = emitter current at Q point,

$$V_T = \frac{(\mathrm{kT})}{\mathrm{q}}$$

with k = Boltzmann's constant: 1.38 E $^{-23}$ joules/Kelvin,
T = absolute temperature in degree Kelvin,
q = electron charge: 1.6 E $^{-19}$ joules/ Volt,
and at room temperature,

$$V_T = 26 \text{ mV}$$

For R_E = 1kΩ and R_C = 3k Ω (the values provided in our reference lab book[6]), the corresponding gain will be as indicated below.

$$A_V = \frac{3\mathrm{k}}{(\ 1\mathrm{k} + \mathrm{r_e}\ )}$$

R_E provides the stability for the gain but it reduces the level of gain as indicated in equation (1). In addition, depending on the value of R_E, the position of quiescent (Q) point can be altered. (Note: The larger the value of R_E, the smaller the gain since R_E is located at the denominator of the gain equation.) This condition can be corrected by using a bypass capacitor for R_E. The purpose of using a bypass capacitor is that, under an alternating current

(AC) condition, it will act as a short circuit. Consequently, R_E value in the gain equation (1) becomes zero under an AC condition when it is bypassed by a large capacitor (100uF). Under direct current (DC) condition, the capacitor will act as an open circuit. Thus, the new gain under AC condition will reflect the following:

$$A_V = \frac{-R_C}{r_e} \qquad (3)$$

Therefore, the use of a bypass capacitor will significantly increase the gain since the value of r_e is relatively small, as we will show in the experimental results section.

Since the purpose of this paper is to demonstrate the realization of the remote lab for a typical electronic experiment, detailed theoretical aspects behind the experiment, including formula derivation of different equations have been omitted. If interested, more information regarding this can be found in any electronic textbook. (The authors recommend the textbook[7] adopted at the University of District of Columbia.)

III. Experimental Set Up

The experiment is carried out using a single experimental set up connected to GPIB-based programmable instruments (such as a digital multimeter, a current source, a digital oscilloscope). The users (students and faculty) can run the experiment virtually anywhere in the world, provided that their computers have Internet access, and they have downloaded LabVIEW runtime engine available in the public domain. As an initial attempt to demonstrate the capability of remote lab for remotely running an electronic experiment, a relatively simple experiment was selected.

A few modifications of the original amplifier circuit were made to verify the effect of changes in the value of the R_E on the voltage gain and also the influence of the bypass capacitor on the gain. A switching circuitry which will allow us to connect different values of the R_E (with or without bypass capacitor) is added to the existing amplifier circuit. The schematic of the overall circuit is shown in the following.

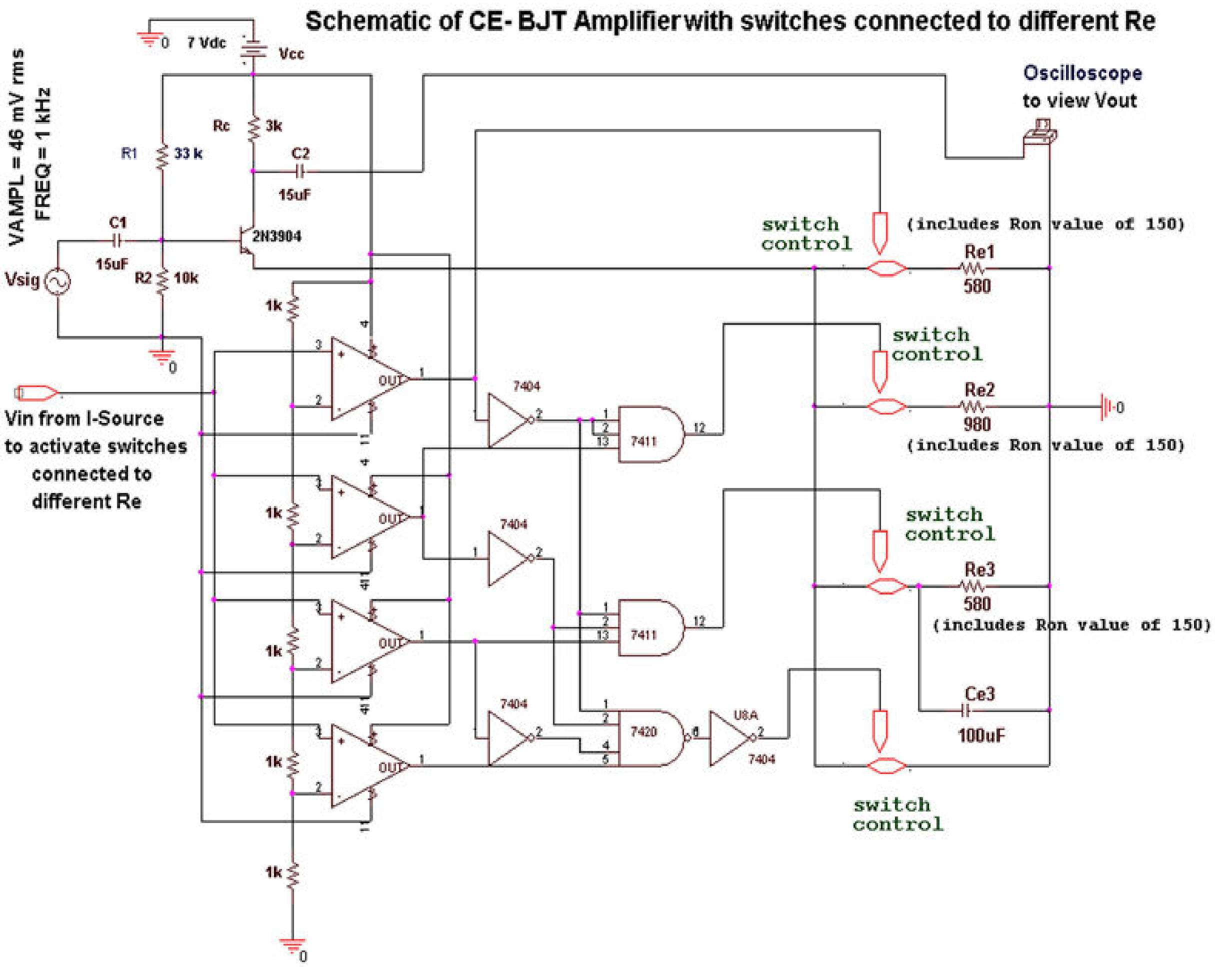
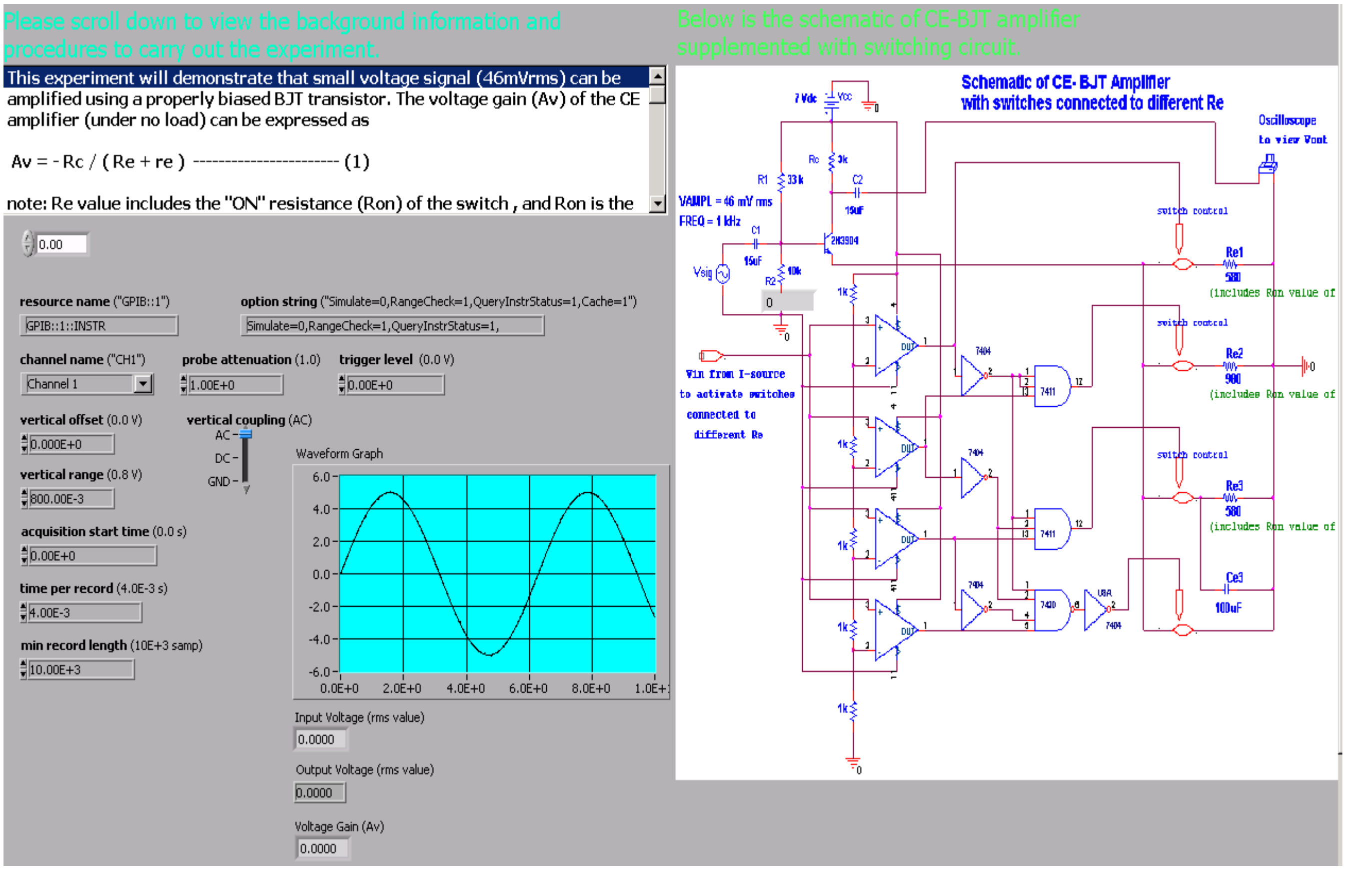


Figure 1. Schematic of CE-BJT amplifier supplemented with switching circuit

The following is a brief explanation of the structural function of the switching circuit. The voltage comparators have been connected in such a way that their outputs become high when their input voltage is higher than their individual reference voltage level. The ladder type of resistors was used to divide a supply voltage (7V) into individual reference voltages. All resistors have the same value (1kΩ) so that the difference between each reference voltage will be similar (i.e. $\Delta V = \frac{7V}{5} = 1.4V$). In other words, the highest reference voltage is about 5.6V (i.e. 7V - 1.4V), the second highest would be about 4.2V (i.e. 5.4V - 1.4V), and the third would be around 2.8V (i.e. 4.2V - 1.4V), and so on. The outputs of voltage comparators are, either directly or indirectly, connected to the control of the switches (i.e. transmission gates), so that when these outputs become high, the switches will be turned on, thereby connecting the different values of R_E to the amplifier circuit. We have used the current source to supply the input voltage to the comparator.

Using LabVIEW 6.1 professional development system, we have programmed the current source in such a way that the user can enter a certain range of current values from the front panel to connect to the selected value of R_E. Other logic gates such as AND gates and inverters are also utilized. Their role is to ensure that even though more than one of the voltage comparator outputs may be high at a particular input voltage level, only one switch control will be activated (i.e. become high) resulting in only one switch to be turned on. As a result, only one R_E will be connected to the amplifier circuit at any time.

Below is the front panel of the VI (Virtual Instrument) that will perform the experiment. The dialog box located in the upper left corner of the panel provides "background information and procedures to carry out the experiment" as indicated on top of the dialog box. Immediately below the dialog box is the control button through which a user can enter different current values in order to connect to desired R_E. Below the control button are parameters that the user needs to enter before capturing the output waveform. Below the waveform graph are three indicators displaying numerical values of "input voltage (V_{rms})", "output voltage (V_{rms})", and "voltage gain (A_V)". The right side of the panel illustrates the schematic of the overall circuitry, which is shown more clearly in figure 1.



Please scroll down to view the background information and procedures to carry out the experiment.

This experiment will demonstrate that small voltage signal (46mVrms) can be amplified using a properly biased BJT transistor. The voltage gain (Av) of the CE amplifier (under no load) can be expressed as

Av = - Rc / (Re + re) ---------------------- (1)

note: Re value includes the "ON" resistance (Ron) of the switch , and Ron is the

0.00

resource name ("GPIB::1"): GPIB::1::INSTR

option string ("Simulate=0,RangeCheck=1,QueryInstrStatus=1,Cache=1"): Simulate=0,RangeCheck=1,QueryInstrStatus=1,

channel name ("CH1"): Channel 1

probe attenuation (1.0): 1.00E+0

trigger level (0.0 V): 0.00E+0

vertical offset (0.0 V): 0.000E+0

vertical coupling (AC): AC

vertical range (0.8 V): 800.00E-3

acquisition start time (0.0 s): 0.00E+0

time per record (4.0E-3 s): 4.00E-3

min record length (10E+3 samp): 10.00E+3

Input Voltage (rms value): 0.0000

Output Voltage (rms value): 0.0000

Voltage Gain (Av): 0.0000

Below is the schematic of CE-BJT amplifier supplemented with switching circuit.

Figure 2. Front Panel of the VI

Also, with LabVIEW's G programming and the GPIB commands from the manual of the scope, the oscilloscope was programmed to "autoset" after the instrument driver captures the waveform. (The instrument driver was developed by National Instruments and is available on the company web site, http://www.ni.com.) After each autoset, the scope was also programmed to automatically change its settings for “amplitude per division” and “time per division” to a certain value so that a clear and visible shape of the waveform will be acquired without manual adjustment of vertical and horizontal scales. GPIB-compatible DMM (digital multimeter) was also used to read the input voltage signal from the function generator and feed that value into the instrument driver. Some modifications of the instrument driver were made so that voltage gain could be calculated. The convenience of this automated experiment is that the drivers of most of the well-known GPIB-compatible instruments have already been developed by National Instruments so that the user of the instrument does not have to spend an ample amount of time trying to learn how to write codes to communicate with the instrument through a computer. In fact, the majority of drivers for all popular instruments are available in the public domain at the National Instruments web site.

It is important to mention the effect of the switch’s “ON” resistance (R_{on}) on the R_E value. R_{on} is the resistance of the switch when it is turned on. Its value varies with the temperature as well as the amount of voltage supply to the switch. According to the DC electrical characteristics table provided in the data sheet from National Semiconductor (manufacturer of CD4066BC, the quad bilateral switch we used for this experiment), at room temperature range, R_{on} is about 270Ω when the voltage supply is 5V. When the voltage supply is doubled (i.e. 10V), R_{on} decreases to 120Ω. Since our supply voltage is 7V, which is about halfway between 5V and 10V, the value of R_{on} was approximately 150Ω. This R_{on} value coupled with the value of R_E results in the effective R'_{E} value becoming slightly larger than its original value. For instance, the value provided for R_E in the laboratory book is 1kΩ. To attain this value, we have chosen 830Ω for R_E so that the resultant value will be about 1kΩ (i.e. 830 + 150 ≈ 1kΩ). R_{on} value (150Ω) will also be added to other resistor values making the individual resultant R'_{E} value moderately higher than their existing value. The following is the complete information inside the dialog box.

Information inside the Dialogue Box

This experiment will demonstrate that small voltage signal (46mV$_{rms}$) can be amplified using a properly biased BJT transistor. The voltage gain (A_V) of the C-E amplifier (under no load) can be expressed as

$$A_V = -\frac{R_C}{(R_E + r_e)} \qquad (1)$$

note: R_E value includes the "ON" resistance (R_{on}) of the switch , and R_{on} is the internal resistance of the switch. The AC dynamic resistance (r_e) can be found as

$$r_e = \frac{\mathrm{V_T(mV)}}{\mathrm{I}_{CQ}\ \mathrm{(mA)}} = \frac{\mathrm{26mV}}{\mathrm{I}_{CQ}\mathrm{(mA)}} \qquad (2)$$

Though R_E provides the stability for the gain, it reduces the level of gain as indicated in equation (1).

This condition can be corrected by using a bypass capacitor (C_E). Under AC condition, C_E will act as a short circuit. Thus, the new gain will become

$$R_E = \frac{-\mathrm{R_C}}{(\mathrm{r_e} + \mathrm{R_{on}})} \qquad (3)$$

Given that R_C = 3kOhm and if measured "I_{CQ}" for R_E = 580 Ohm is 1.38mA,

1) Calculate "r_e" and "A_V" accordingly using (2) and (1).

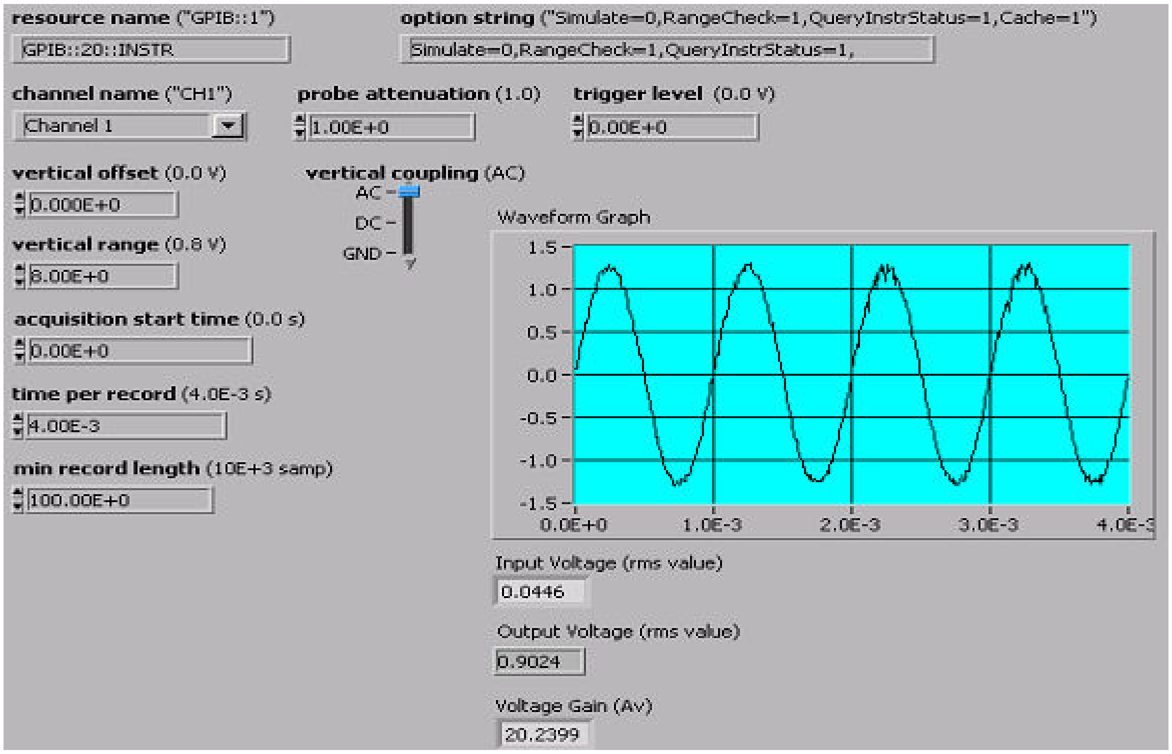
2) Repeat the same procedure for measured I_{CQ} = 0.964mA,

which

3) Record and compare these "A_V" values with the experimental results obtained after running the experiment.

note: The following control button is for Input I (mA)
to create different levels of V_{in},
which operate switches connected to different R_E.
Using different R_E, we can observe how changes in R_E value affect Output Voltage, and consequently, its gain (i.e. A_V).
Also same value of R_E (i.e. 580 Ohm) is used with and without the Bypass Capacitor (100uF) to demonstrate the influence of Bypass Capacitor (C_E) on A_V.
To choose R_E = 580 Ohm with Bypass Capacitor, enter I for ($30 < I < 40$)
To choose R_E = 980 Ohm with no Capacitor, enter I for ($45 < I < 55$)
To choose R_E = 580 Ohm with no Capacitor, enter I for ($60 < I < 80$)
Please note that each R_E value includes the "Ron" of the switch.
Right below the control button are the options that user needs to enter.

Before running the experiment,
1) Type "20" for "resource name" which is the GPIB address of the Oscilloscope.
2) Select channel "1" from the pull-down menu since it is the one connected to the output of the amplifier.
3) Type "4V" for the "vertical range" which is the range of the output voltage displayed on the waveform graph.
4) The default "acquisition start time" of zero second should be unchanged.
5) Since the frequency of V_{in} is 1kHz, choose the period which is higher than 1ms. Default value 0f "4ms" is acceptable.
6) Type "10" for "min record length" so that the driver will capture 10 samples of output waveform.
7) "probe attenuation" and "trigger level" should be remained at default values.
8) "vertical coupling" should be selected for "AC" since the input signal is a sine wave.



resource name ("GPIB::1"): GPIB::20::INSTR

option string ("Simulate=0,RangeCheck=1,QueryInstrStatus=1,Cache=1"): Simulate=0,RangeCheck=1,QueryInstrStatus=1,

channel name ("CH1"): Channel 1

probe attenuation (1.0): 1.00E+0

trigger level (0.0 V): 0.00E+0

vertical offset (0.0 V): 0.000E+0

vertical coupling (AC): AC

vertical range (0.8 V): 8.00E+0

acquisition start time (0.0 s): 0.00E+0

time per record (4.0E-3 s): 4.00E-3

min record length (10E+3 samp): 100.00E+0

Input Voltage (rms value): 0.0446

Output Voltage (rms value): 0.9024

Voltage Gain (Av): 20.2399

Figure 3. Part of the Front Panel capturing the Output Waveform when R_E = 430 Ω with C_E = 100uF

IV. Experimental Results

Before we display the results from the experiment, let us compare the theoretically calculated values with actual experimental results. Any discrepancy between theoretical and calculated value will be discussed for possible reasons.

For $R_E = 430\Omega$, the measured value of I_{CQ} under DC (direct current) condition is

$$I_{CQ} = 1.38\text{mA}$$

Thus, from equation (2),

$$re = \frac{26\text{ mV}}{1.38\text{ mA}}$$

$$= 18.84\ \Omega$$

Finally, we can calculate the voltage gain using $R_E = 430\ \Omega$ (no bypass capacitor, C_E) from equation (1) as follows;

$$A_V = \frac{-R_C}{(R'_E + r_e)} \qquad (\text{note: } R'_E = R_E + R_{on})$$

$$= \frac{-3k}{(430 + 150 + 18.84)}$$

$$= \frac{-3k}{598.84}$$

$$= -5.01$$

For $R_E = 830\ \Omega$, the measured $I_{CQ} = 0.964\text{mA}$

Thus, from equation (2),

$$r_e = \frac{26\text{mV}}{0.964\ \text{mA}}$$

$$= 26.97\ \Omega$$

We can calculate the voltage gain using $R_E = 830\ \Omega$ (no bypass capacitor, C_E) from equation (1) as follows;

$$A_V = \frac{-R_C}{(R'_E + r_e)} \qquad (\text{note: } R'_E = R_E + R_{on})$$

$$= \frac{-3k}{(830 + 150 + 26.97)}$$

$$= \frac{-3k}{1006.97}$$

$$= -2.98$$

Finally, we can calculate the voltage gain using $R_E = 430\ \Omega$ (with bypass capacitor, C_E) from equation (3) as follows;

$$A_V = \frac{-R_C}{(r_e + R_{on})}$$

$$= \frac{-3k}{(18.84 + 150)}$$

$$= \frac{-3k}{168.84}$$

$$= -17.77$$

The experimental values are displayed in the following table.

Emitter Resistor (R_E)	Input Voltage (V_{rms})	Output Voltage (V_{rms})	Voltage Gain (A_V)
R_E = 810 Ω (no C_E)	0.0461	0.1396	3.0297
R_E = 430 Ω (no C_E)	0.0459	0.2335	5.0917
R_E = 430 Ω (with C_E = 100uF)	0.0446	0.9024	20.2399

Table1. Results of Output Voltages for different values of R_E (with or without C_E)

There are several facets of the experiment that require discussion. First, we observe that the actual voltage gains are somewhat higher than the calculated values. This discrepancy may be due primarily to the approximation of R_{on}, since the data sheet does not provide its value when the voltage supply is 7V. Also, we have made an estimation for the device temperature when the experiment was carried out. (i.e. we simply assumed that the device temperature would be about 25 degree Celsius during the experimental process).

V. Remote Panel Set Up

There are several steps for setting up and implementing the remote panel. These are briefly mentioned below.

A. Enabling remote panels

Before a given VI (Virtual Instrument) is transformed into a remote laboratory, the VI must be loaded into LabVIEW memory. Using the “Web Publishing Tool” option, “Document Title” and “VI name” text fields can be loaded. These text fields are used to customize the web page created with the publishing tool.

Selecting the “Start Web Server” button will activate the built-in LabVIEW web server. After activating the web server, the actual HTML (Hyper Text Markup Language) document should be created. This can be accomplished by saving the “Document Title.htm” into the LabVIEW file folder called “www.” Finally, the URL (Universal Resource Locator) of saved the VI will be created. The VI that will carry out the experiment is now available for users who are distantly located.

B. Client operation

Before a user can operate the remote front panel of the VI running the experiment, the LabVIEW run-time engine needs to be installed on the client's computer. Initially, the client's connection will automatically be in a monitor mode. If the experiment is currently being controlled by another client, the user will be able to observe the experimental events carried out by the current controller. After control is requested, there will be the appearance of one of two possible messages. One possible message is that control will be granted to the user. The alternative message will be the indication that control is currently granted to another user. In the event that control is given to another client, the server will notify the controlling client that the control time has now become limited. Application control will be automatically transferred to the next requesting client as soon as the timeout occurs or the controlling client relinquishes control.

C. Application Administration

Among others, several critical network functions are administered by the following facilities available in the LabVIEW 6.1 remote panel package.

(i) *Remote Panel Connection manager*: This facility basically monitors and controls the network traffic of all clients' connections and displays a graph of all visible VIs. It also shows a list of clients who were not able to access the server due to the excess number of connections beyond the maximum allowed number of clients under the license.

(ii) *NI License Manager*: This tool can upgrade the maximum possible number of clients who can observe and control the remote front panel. LabVIEW 6.1 has a default license that will permit the monitoring and control of one client. In case additional licenses for multiple users have been purchased, NI License Manager will be used to install and configure new licenses.

(iii) *Web Server Configuration*: With this, the server can specify which port to be used for HTTP (Hyper Text Transfer Protocol). Also, it can set the timeout (i.e. duration allowed) for individual remote clients as well as other important server functions.

D. Application Security

The tool called "Browser access" will allow the server to protect it from unwelcome users who may try to monitor or even run the experiment. After inserting the computer name or IP (Internet Protocol) address of a welcome user under the "Browser Access" list, the server can decide whether that particular client should be permitted to monitor only, or both monitor and control. Then, the server can be set up accordingly, thereby further enhancing the security protection from intruders.

Additional information dealing with the remote panel can be found in the National Instruments web site.

VI. Conclusion

The remote experiment has been successfully performed numerous times and has consistently produced results which are as reliable as those obtained in the local lab. Finally, we have concluded that this remote lab can replace the conventional lab in terms of application functionality, concepts acquired through the lab, etc. With some visual aids such as the web camera, the level of understanding and appreciation by the remote user can be further enhanced. However, visual aids are not considered to be essential in this particular experiment since the user can observe the output waveform through the instrument driver. With the provision of additional GPIB-compatible DMMs, we can easily evaluate the input and output impedances of the circuit.

Other academic institutions, particularly those offering distance-learning programs, can emulate this approach. In the past, these programs were usually limited to non-experimental type classes. By incorporating this approach, the concept of distance learning can be upgraded to a higher level, allowing universities to offer lab-based study courses at the convenience of students. The authors of this paper envision that the trend of remotely controllable labs in general and the LabVIEW's remote panel approach in particular, will be progressively implemented in many distance-learning higher institutions in the near future.

In fact, remote labs can offer numerous benefits to institutions, which are not involved with distance learning. Although the authors did not attempt to make a thorough financial analysis, it is possible that the remote lab can offer significant cost reduction among other benefits. This is primarily due to factors such as the need of fewer experimental instruments to accommodate large numbers of students, and the limited need of lab instructors. Even after considering the additional expenses associated with the relatively higher price of GPIB-based programmable instruments compared to their non-programmable counterparts, and expenses related to the purchase of additional licenses for multiple viewers, etc, we believe that this approach will reduce overall expenses.

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Bibliographies

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