

A LabVIEW Interface for Transistor Parameter Analysis: An Opportunity to Explore the Utility of Computer Interfaces

Thomas F. Schubert, Jr., Susan M. Lord, Dalia M. Tawy, Sami D. Alsaialy
University of San Diego

ABSTRACT

National Instruments' LabVIEW has become a popular programming environment for data acquisition in academia, industry, and government labs. One of its major advertised advantages lies in creating instrument control interfaces at a user-appropriate level for the task at hand.

At the University of San Diego (USD), the electronics laboratory contains two transistor curve tracers: one simple to use but limited in capability (Tektronix 571) and one more complex both in capability and user interface (Sony/Tektronix 370). Because of the perceived difficulty in using the more complex instrument, students tend to gravitate to the simpler instrument thereby creating a bottleneck in laboratory productivity. In an attempt to alleviate this bottleneck, two USD faculty members decided that LabVIEW could provide a more user-friendly interface for the complex instrument.

During a two-semester long research experience, two electrical engineering seniors at USD developed a LabVIEW interface for a Sony/Tektronix 370 Programmable Curve Tracer and wrote a comprehensive user's manual under the supervision of two electrical engineering faculty members. The interface was designed to approximate the level of user interaction and knowledge required by the department's Tektronix 571 Curve Tracer. Two groups of electrical engineering students, juniors taking a required first-semester electronics course and seniors enrolled in an analog IC design elective, tested the interface the following semester. By having two distinct instruments and using two separate student groups we were able to compare the utility of the new LabVIEW interface to the traditional interface of a more user-friendly instrument for both first time users and seasoned users.

The LabVIEW interface, student response, and comparisons concerning instrument utilization will be discussed in this paper.

INTRODUCTION

All Electrical Engineering programs include significant study of semiconductor electronic devices. Important to that study are the characteristic current-voltage (I-V) relationships and determination of ac model parameters for specific devices. Experimentally, these characteristic curves and parameters are usually determined with a commercial curve tracer. At the University

of San Diego (USD), all Electrical Engineering students learn to experimentally determine semiconductor device parameters in the two laboratory courses that accompany a year-long junior-level electronics course sequence. The electronics laboratory itself contains two transistor curve tracers: one simple to use but limited in capability (Tektronix 571), and one more complex both in capability and user interface (Sony/Tektronix 370). Because of the perceived difficulty in using the more complex instrument and its long learning curve, students have tended to gravitate to the simpler instrument thereby creating a bottleneck in laboratory productivity.



Figure 1: Tektronix 370 Curve Tracer

Student hesitance to use the Tektronix 370 curve tracer is understandable. As seen in Figure 1, the user is expected to choose proper settings for more than thirty controls before testing a device. While the controls provide great flexibility, knowing which are significant to a particular measurement requires some practice and experience. In addition, some controls have settings that are distinctly improper for certain devices under test. For example, the step control abruptly changes from voltage steps (gate-source voltage for a FET) to current steps (base current for a BJT) midway in its range. Although the plots obtained are large and easy to read and use for extrapolation, the axes are not clearly labeled which is problematic for novice users. The unit does provide for storing a limited number of complete control setups in the volatile memory and could provide a cache of model setups. However, in a student laboratory environment, these settings are often inadvertently user altered and can not be considered permanent.

Conversely, the Tektronix 571 user interface consists of ten buttons: four of which control a cursor. On a single screen, the user selects the device type and then chooses, from a fixed set of values for no more than seven control variables before beginning device test. For example, in characterizing a BJT, only the most commonly used plot of collector current versus collector to emitter voltage as a function of base current is available and the user selects values for six control variables. Students usually prefer the limited number of choices. However, the plots obtained from this instrument are small, difficult to read, and of poor quality due to being printed on a dot matrix printer. Students are usually able to obtain sufficient information to continue

with their lab work but some design laboratories would benefit from the superior plots and greater variety of plots obtainable from the more complex instrument.

LabVIEW (**L**aboratory **V**irtual **I**nstrument **E**ngineering **W**orkbench) is a graphical programming language that was developed in 1986 by National Instruments.¹ It has become a vital tool for engineers and scientists in research throughout academia, industry, and government labs. Most significant to this project is its ability to be used to create an instrument control interface at a user-appropriate level. Thus, LabVIEW is an excellent candidate for creating a user-friendly interface for the Tektronix 370. Two USD EE faculty members were motivated to develop such an interface to alleviate the observed laboratory bottleneck and enhance the utilization of the more complex curve tracer. Fortunately, several USD Electrical Engineering students had previously developed expertise in LabVIEW while working on interfacing projects^{2,3}. Two of these students and the two faculty members thus formed a team to develop a LabVIEW interface for the Tektronix 370 curve tracer.

BUILDING THE LABVIEW INTERFACE

The development team decided that the new LabVIEW interface should be designed to approximate the level of user interaction and knowledge required by the department's Tektronix 571 Curve Tracer. The user interaction would be simplified by limiting the number of controls that could be accessed and by limiting the settings of each control. Similarly, the capability would mimic the 571: basic output curves for diodes, BJTs with the emitter common, and FETs with the source common would be the only tests possible through the interface.

The major goals of the interface were:

- Creating a state machine to divide the major program into 5 different sub-programs so that each program is used for a separate device: Diode, npn and pnp BJTs, and n-channel and p-channel FETs.
- Creating a simple user's interface to facilitate the process of entering the inputs and receiving the outputs for each device.
- Plotting diode current vs. voltage.
- Plotting collector current vs. collector-emitter voltage as a function of base current for npn and pnp BJTs.
- Plotting drain current vs. drain-source voltage as a function of gate-source voltage for n-channel and p-channel FETs.
- Transferring all of the output results automatically to an Excel spread sheet at the end of the measurement for printout or further analysis.
- Creating a dialog with the user using pop-up messages to provide instructions, and guarantee satisfaction with the gathered data before ending the program as well as giving the option of repeating the process to gather more accurate data after changing the settings.

Determination of ac parameters at the point of operation was also considered highly desirable. Specifically this included a display of:

- β_F for BJTs
- g_m for FETs

Since these parameters are dependent on the quiescent operating point of the device (Q-point), input of that information was required. It should be noted that the display of g_m for FETs was not available on either curve tracer directly from the instrument (β_F was available only on the 571). Thus the LabVIEW interface for the Tektronix 370 would not only provide the user with more user-friendly interaction but additional capability for the FETs. A comprehensive user's manual for the LabVIEW interface was another significant deliverable.

After setting these design goals, a suitable LabVIEW GPIB driver that could be used as a starting point was downloaded from the National Instruments website (www.ni.com/devzone/idnet/). The project began late in the fall semester of 2002 with projected completion for student usage in fall 2003. The team of students met on a regular basis throughout 2003 with the supervising faculty to review progress. Since the GPIB driver did not fully function with our early-version 370 curve tracer, the student team needed to make some significant modifications to the driver. For example, they corrected the algorithm for choosing the volts/step so that the instrument chose the nearest allowed value to the input value rather than the next largest value. They worked on the development of the LabVIEW front panels in the following order: diode, npn BJT, pnp BJT, n-channel FET, and p-channel FET. Each panel was reviewed for correct functionality and ease of usage by the faculty supervisors and revisions were implemented. Significant effort was placed on ease of operation while minimizing input interaction and keeping an appropriate level of functionality.

The user sees the LabVIEW interface as a series of panels. First is a device selection panel as shown in Figure 2. Here the user indicates which device is to be tested. As an additional aid

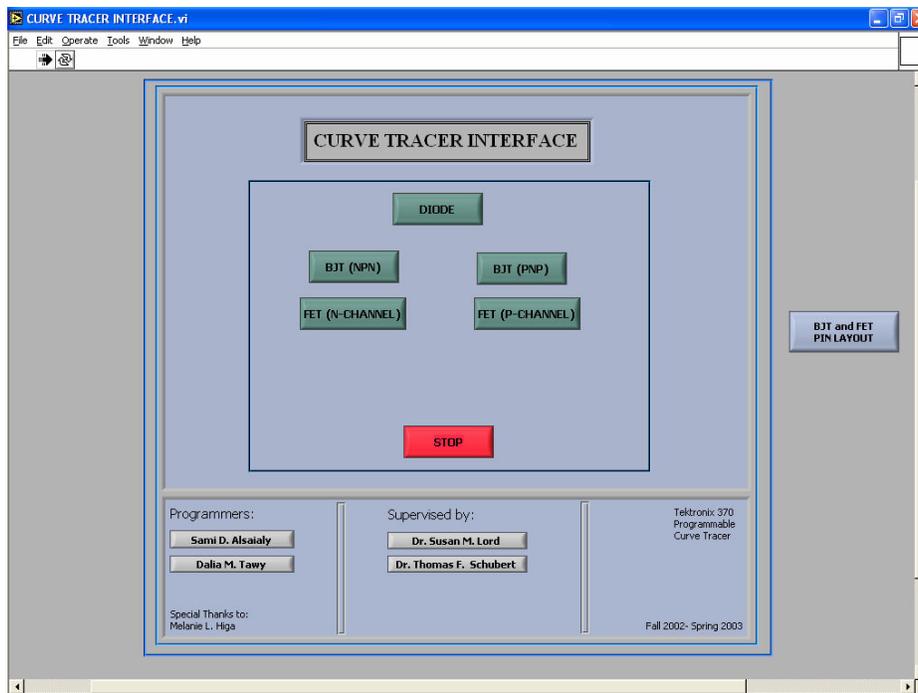


Figure 2: LabVIEW interface for Tektronix 370 device selection panel

to the user is a link to device pin layout diagrams so that the device under test can be properly inserted into the curve tracer. Selection of device leads to a second panel which is unique to the device type under test.

The diode panel, shown in Figure 3, displays the degree of simplification that can be achieved using a LabVIEW interface. The more than thirty controls of the 370 have been reduced to five significant inputs: the vertical and horizontal scales desired, limits on peak voltage and power, and variable control on voltage as a percentage of the peak value. Switches to run the test and to create an Excel spreadsheet complete the front panel. The vertical and horizontal scales are keyed in entries: since not all values can be selected, the LabVIEW interface selects the closest allowable value and displays the actual scale in the lower portion of the panel as a readout. Also displayed is a plot of the current-voltage diode characteristic. The diminished capability encountered by this radical simplification of control is that positive and negative voltages can not be applied in the same test.

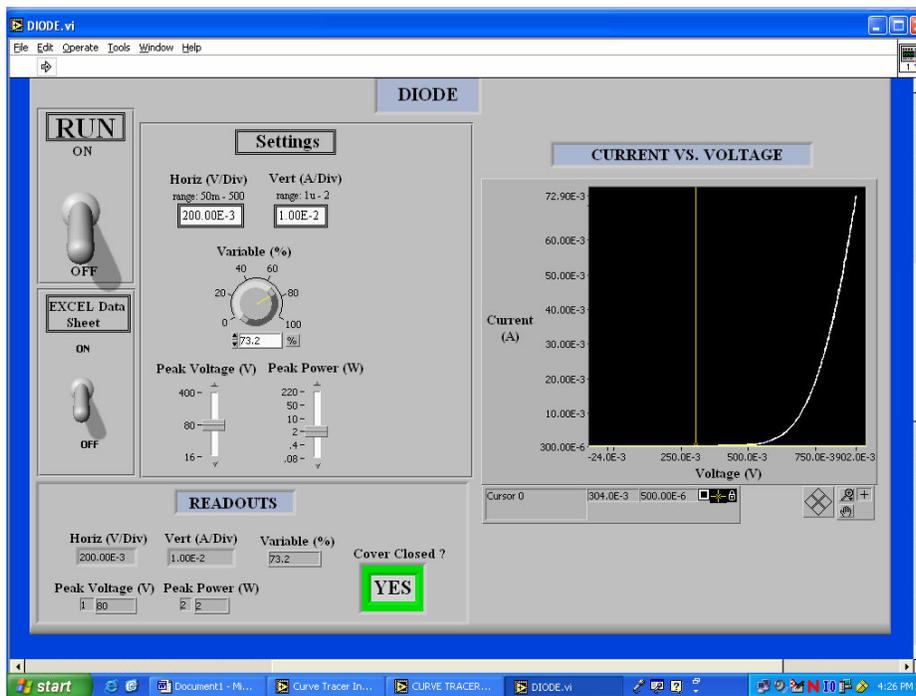


Figure 3: Typical LabVIEW interface panel for Tektronix 370: diode

The front panel for an npn BJT is shown in Figure 4. Here the number of user determined parameters has increased to ten. In addition to the five itemized for the diode, included are: base current step number, size, and offset and the expected Q-point of the BJT for determination of β_F . Once again, the LabVIEW interface selects proper scales based on the user's input values and returns them in the readout section. Similarly, the characteristic plot is displayed. The BJT panel also includes the determination of β_F at the Q-point. The interface compares the user's input values for the Q-point and selects the nearest data points for determination of β_F . If the collected data points do not include the Q-point, the interface increases the number of base

current steps until appropriate data can be collected for computation of β_F – if, at the maximum number of steps, the Q-point is still not within range, an error message is displayed. A similar algorithm is employed for the determination of g_m for FETs where the gate to source voltage is the step parameter that is increased until the Q-point is included in the collected data. Note that the development of the LabVIEW code for the calculation of β_F and g_m was not simple. In fact, the student team considered this to be the most technically challenging and complicated aspect of project.

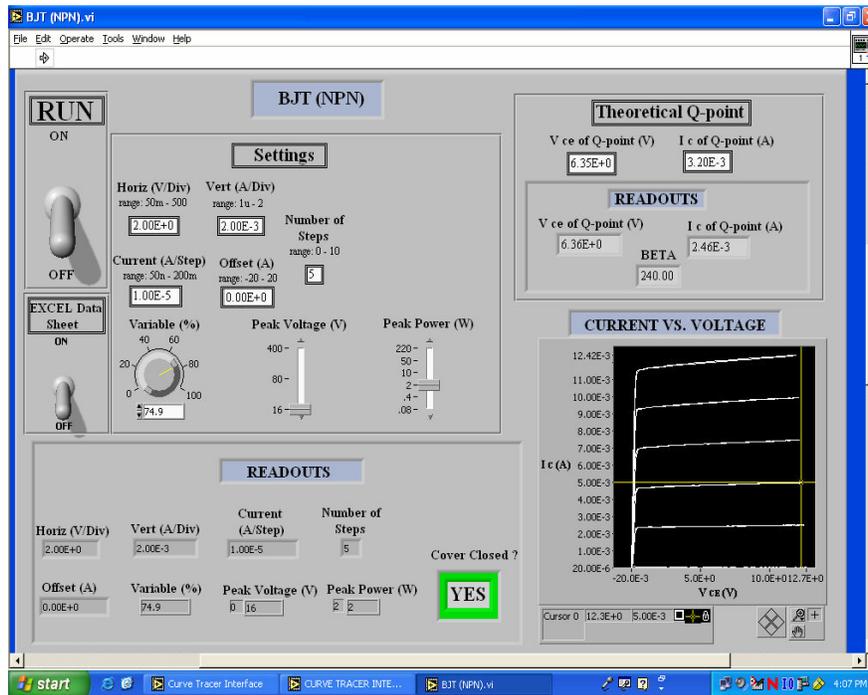


Figure 4: Typical LabVIEW interface panel for Tektronix 370: BJT (NPN)

Integral to this project was the development of a comprehensive user’s manual. This twenty-one page manual gives step-by-step instructions for the testing of each of the five devices. Typical instructions (those for diode test) are shown in Figure 5.

TESTING THE UTILITY OF THE INTERFACE

In the Fall Semester of 2003, seventeen junior electrical engineering majors in the required course, EEE 130 *Electronics I*, and six senior students in the elective course, EEE 194 *Analog IC Design*, tested a prototype version of this LabVIEW interface for the department’s Sony/Tektronix 370 Programmable Curve Tracer. By having two distinct instruments and using two separate student groups we were able to compare the utility of the new LabVIEW interface to the traditional interface of a more user-friendly instrument for both first time users and seasoned users.

Diode Test

1. Check that the values in the “Settings” section match the diode you will be testing, and make any modifications if necessary. The values of the **Horizontal Divisions (V/Div)** and **Vertical Divisions (A/Div)** can be adjusted by typing in the white areas. The **Variable (%)** value can be adjusted by either typing in the white area or rotating the knob using the cursor of the mouse. The values of the **Peak Voltage (V)** and the **Peak Power (W)** can only be adjusted by moving the slide using the mouse. *Note:* All of the settings are originally set by default to match the 1N4148 Diode.
2. If you want to transfer the data that will be collected to an excel spreadsheet, it is preferred that you click on the “EXCEL Data Sheet” switch to turn it to the ON position before running the program. However, this step can be performed at any time while the program is running.
3. Click on the “RUN” switch to turn it to the ON position to initiate the program.
4. Notice that the “READOUTS” section confirms that the values of the “Settings” section have been correctly transferred to the curve tracer. *Note:* The curve tracer can receive only certain specific values, and any entered value will be rounded to the closest available value. In this section, the **Cover Closed?** blank indicator has a grey color before running the program. As soon as the program runs, the boundary color of the indicator and the message on it indicate the status of the door of the curve tracer ((2) in Figure 1). If the cover is closed, the boundary color of the indicator changes to green, the word “YES” appears on the indicator, and the program functions properly. If the cover is open, the boundary color of the indicator changes to red, the word “NO” appears on the indicator, and the pop-up message shown in Figure A2 asks you to close the cover then click “OK”. The message will keep appearing until you close the cover then the program can resume.



Figure A2: “Please close the cover” pop-up message

5. Notice that the Current versus Voltage graph appears on the “CURRENT VS. VOLTAGE” plotting area.
6. The pop-up message shown in Figure A3 will ask you to determine if you are satisfied with the values and the graph;

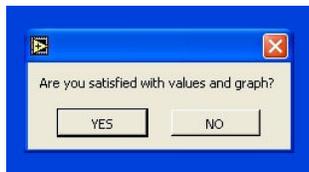


Figure A3: “Are you satisfied with values and graph?” pop up message

- If you click on “YES”, the “DIODE.vi” program will end. The “RUN” switch will turn to the OFF position automatically. If you have selected to transfer the data to excel earlier before or while running the program, an excel spreadsheet will open automatically and show all of the data points that were recorded and graphed by the curve tracer. You can use excel to graph the same VI curve and save it to the excel sheet. Click on the “x” in the top right corner of the front panel of the “DIODE.vi” program to close it. The front panel of the “Curve Tracer Interface.vi” program will appear. You can select to run the program of a different device or of the diode again, or you can end the whole “Curve Tracer Interface.vi” by clicking on the STOP switch then clicking on the “x” in the top right corner of the front panel of the “Curve Interface.vi” program to close it.
- If you click on “NO”,
 - a) The **CLICK AFTER ADJUSTING SETTINGS** switch shown in Figure A4 will appear in the “Settings” section.



Figure A4: “Click after adjusting settings” Switch

- b) The pop-up message shown in Figure A5 will ask you to adjust the values of the settings explained in step 1 and click the switch. While you are adjusting the settings, the program will pause until you click the switch. After clicking the switch, the program will resume and the new values and graph will appear. The pop up message in Figure A3 will appear again. *NOTE:* There is no limit on the number of times you can click on “NO”; the program will keep running until you click on “YES” to indicate you are satisfied with the values and graph.



Figure A5: “Adjust settings, & click switch” pop-up message

Figure 5: Typical user’s manual instructions (diode test)

Other than a short demonstration by the respective course instructors, the student-developed user's manual for the interface was the main guide to usage. Students in each class typically worked in pairs, but each student was responsible for his/her own proficiency in transistor parameter measurement. A Tektronix 571 Curve Tracer was also available for student use for both groups. Student response to the new interface was generally positive as shown on an anonymous survey given at the end of the semester.

The junior students were first-time curve tracer users. During the semester, their usage was regular, but none reported more than ten total usages. When asked, students agreed that a curve tracer is a useful tool (4.0 on a scale of 1-5: "1" indicating "strongly disagree" – "5" indicating "strongly agree"). Since the course is an introductory electronics course, transistor characteristic curves were reported to be somewhat more significant than ac parameter (i.e., β_f and g_m) determination. Data downloaded through the interface was as important to the students as directly-printed hard copy. The students were essentially neutral on the ease of usage of the LabVIEW interface as compared to the 571 Curve Tracer (3.5/5). However, the students did not report significant use of the 571. By the end of the semester, the junior students used the LabVIEW interface almost exclusively.

The senior students were using a curve tracer for the third semester. Five of the six had learned on the 571 with only one reporting significant prior usage of the 370 (manual usage only). All reported more than twenty-five usages and one reported more than fifty-five usages. They found a curve tracer a very useful tool (4.5/5), and were more interested in finding ac parameters than in characteristic plots which is consistent with their more advanced laboratory experiments that involved design. Usage of the data-download capability of the interface was infrequent. These students strongly agreed that the LabVIEW interface was as easy to use as the 571 (4.4/5) and their usage during the semester moved from almost exclusive usage of the 571 to approximately equal usage of the two instruments.

Thus the development of a LabVIEW interface for an older, more complex transistor curve tracer improved its utility in a teaching laboratory situation significantly. Experienced users moved from infrequent usage to usage equivalent to that of a newer, simpler curve tracer. New users seem to prefer using the interface, although that preference may be a function of classroom requirements. When asked the best and worst features of each instrument, complaints centered around the 370's size, age, and the transistor sockets rather than the user interface: only one complaint was received concerning software problems. The ease of use, the LabVIEW interface, and ability to obtain plots and transistor parameters were cited as good features of the 370.

There is still more work that may be done on the LabVIEW interface for the Tektronix 370. Improvements in identifying the instrument settings necessary to differentiate between enhancement and depletion mode FETs could be made. The instructor for the junior electronics course has noted that in addition to ac parameter determination, FET DC parameter (V_p and I_{DSS} for depletion mode or V_T and K for enhancement mode) determination is vital for both theoretical and computer simulation comparisons to experimental data and those parameters should be added to the FET panel displays. Determination of the early voltage, V_A {or

equivalently, h_{oe} (BJT) or r_d (FET)} and the determination of the BJT input characteristic parameters, h_{ie} and h_{re} are also possible additions.

SUMMARY

Under the direction of two electrical engineering faculty, two electrical engineering seniors at the University of San Diego developed a LabVIEW interface for a relatively complex Sony/Tektronix 370 Programmable Curve Tracer and wrote a comprehensive user's manual. The interface was thoroughly tested and compared to a simpler to use but more restricted in capability manually-operated Tektronix 571 curve tracer by two classes of USD students: both novice and experienced users. The results were quite positive with novice users overwhelmingly using the interface and experienced users moving from almost no usage of the 370 to equal usage of the two curve tracers. Thus the LabVIEW interface accomplished the intended goal of increasing utilization of the more complex curve tracer.

ACKNOWLEDGEMENTS:

This project was primarily supported by the USD Department of Engineering through an Engineering Research Grant. The authors thank National Instruments, who provided a full development version of LabVIEW, and their representative, Jose Noguera, who provided valuable programming assistance and general encouragement. Special thanks go to the USD Electrical Engineering students who participated in the testing of this project and the course instructors who guided them.

Bibliography

- [1] Beyon, J. Y., *LabVIEW Programming, Data Acquisition and Analysis*, Prentice Hall PTR (Upper Saddle River, NJ), 2001.
- [2] Higa, M. L, Tawy, D. M, & Lord, S. M., *An Introduction to LabVIEW Exercise for an Electronics Class*, Proceedings of 32nd ASEE/IEEE Frontiers in Education Conference, November 6 - 9, 2002, Boston, MA
- [3] Alsaialy, S. D., Tawy, D. M, & Lord, S. M., *Introduction to LabVIEW Two-Part Exercise*, Proceedings of the 33rd ASEE/IEEE Frontiers in Education Conference, November 2003, Boulder. CO

SAMI D. ALSAIALY

Sami D. Alsaialy received a B.S./B.A. in Electrical Engineering and a minor in Mathematics from the University of San Diego in May 2003. Sami is currently working at Solar Turbines, Inc. with the Technical Information department. His interests include writing code for the control of laboratory testing procedures using LabVIEW software.

DALIA M. TAWY

Dalia M. Tawy received a B.S./B.A. in Electrical Engineering from the University of San Diego in August 2003. She is currently an Associate Design Engineer at the Product Compliance Department at Solar Turbines, Inc. in San Diego. She is a member of IEEE, the Dean's List Organization, and the National Collegiate of Scholars.

SUSAN M. LORD

Susan M. Lord received a B.S. in Electrical Engineering & Materials Science from Cornell University and the M.S. and Ph.D. in EE from Stanford University. Dr. Lord taught at Bucknell University from 1993-1997 and is presently an Associate Professor of Electrical Engineering at the University of San Diego. Her teaching and research interests include electronics, optoelectronics, microwave photonics, materials science, and first year engineering courses.

THOMAS F. SCHUBERT, JR.

Thomas F. Schubert, Jr. received a B.S., M.S. and Ph.D. in Electrical Engineering from the University of California at Irvine. After four years in the aerospace industry, Dr. Schubert taught at Portland State University (1978-80) and the University of Portland (1980-87) and is presently a Professor of Electrical Engineering at the University of San Diego. His teaching interests include analog circuits and electronics, communications, and electromagnetic fields.