Keysight BenchVue software has revolutionized the ease-of-use of Keysight instruments by doing the behind-the-scenes work for you of automatically locating and connecting to all instruments it can find on LAN, GPIB and USB. It also gives you a simple way to control the instruments and retrieve data, all without writing a single line of code.
Introduction

This application note shows how to make a simple transistor curve tracer using a Keysight B2962A power source along with a Test Flow sequence running in Keysight’s BenchVue software. The B2962A was chosen because of its low current stimulus capabilities, but BenchVue works with hundreds of Keysight instruments. Many other choices are possible depending upon your measurement requirements.

BenchVue Test Flow

BenchVue Test Flow is a flow-chart style sequencer that is included with purchase of any BenchVue app. It allows you to create automated tests without programming, simply by dragging and dropping properties and measurements into a sequence. It’s not like graphical programming, such as Keysight VEE, because you are not interacting with drivers and having to understand all the nuances of the instruments. The hassles of an integrated development environment with a myriad of build options, library references, revision control, and deep programming knowledge are also avoided. With Test Flow, you can focus on your real goal: setting instrument parameters and getting measurement results. Although some programming techniques are part of Test Flow—delays, loops, conditionals, prompts, calls to external programs or scripts, and so on—they are easily dragged and dropped into the sequence as easily as a measurement or an instrument setup. This app note will show how to use these features to characterize transistor performance.
Curve Tracers — the old-fashioned way

Figure 1 shows the typical way this measurement was made in the past:
A transistor’s collector and emitter are connected to the vertical and horizontal scales of a storage type oscilloscope, with a load resistor and an emitter resistor included, limiting the base and collector currents. The base circuit is driven by a voltage source that can be stepped to provide different base currents. The voltage on the emitter is directly proportional to collector current, so it is fed into the vertical channel of the oscilloscope. The collector voltage is a rough approximation of collector-emitter voltage as long as the emitter voltage is not too large. The collector voltage has to be ramped up to create a curve, then back down along a ramp with the same slope so as not to disturb the existing trace. The base current is then changed to a different value and the process is repeated.

![Figure 1. A simplified block diagram of a basic transistor curve tracer.](image)

Curve tracers — the modern way

Now it is possible to do this measurement using a Keysight B2962A power source. See Figure 2. This instrument has two channels, and is capable of low current stimulus in the femtoamp range, and voltage as high as 210 V. In addition, it can measure the current and voltage it is outputting with 6.5 digit accuracy.

![Figure 2. Keysight B2962A power source.](image)
Figure 3 shows an example DUT—a 2N3904 NPN transistor. The base will be driven with channel 1, set up as a current source, and various voltages will be applied to the collector. The resulting collector current will be measured with channel 2. No extra components are needed—just a set of clip leads.

**BenchVue startup**

When BenchVue starts up it automatically discovers the B2962A power source and any other connected instruments and populates the instrument bar at the bottom of the main screen:

To start BenchVue Test Flow, simply click on the Test Flow button at the top of the screen:
This brings up the Test Flow panel on the right side of the screen. See Figure 4. Blocks can be dropped into this panel and will execute from top to bottom when the Start button is pushed.

Figure 4. Starting the Test Flow screen.
Creating a Test Flow Sequence

When the B2962A instrument is launched by double clicking it, its control panel shows up on the left side of the screen as shown in Figure 5. The items that can be dragged into the Test Flow sequence are highlighted with orange rectangles. Some settable properties have already been entered for this example: Both outputs are off and Channel 1 is set up as a current source with a voltage limit of 1 V, since it will drive the base-emitter junction of a bipolar NPN transistor, and thus the voltage is not expected to go above about 0.7 V. The current range is set to 105 µA so that up to 105 µA can be fed into the base. Channel 2, which will be connected between the collector and emitter, is set up as a voltage source, with a current limit of 100 mA. If the transistor has a beta of 200, 100 µA of base current would result in 20 mA of collector current, so the current limit can be set much lower. A 2N3904 transistor has a maximum collector current rating of 200 mA, so any value between 30 mA and 200 mA would work. The voltage range has been set to 21 V so that values from 0-4 V can be applied. (The next range down is 2.1 V.)

Since the Test Flow sequence needs to be able to reset the instrument to the above initial values every time it is loaded and run, simply drag and drop each instrument measurement or property into the sequence one at a time. Here is the result of the first drag and drop operation as it appears in the Test Flow sequence. The number to the left of the title matches the number of the instrument shown at the top.
Since the sequence begins by turning the outputs off, they will be off during the other initialization steps, so before applying stimulus and measuring the response, the outputs need to be turned on. Rather than dragging the on/off button from the app into the Test Flow sequence again, the existing blocks are duplicated by right clicking on a block and selecting “Duplicate this Block,” then dragging it to any point in the sequence:

All the initialization steps to this point are shown in Figure 6.
Figure 6. Initialization steps prior to generating results.
Now the sequence is ready to sweep the base current, so drag the Current Setting property in Channel 1 to the Test Flow pane. When this is done, it defaults to a “Sweep” operation. Enter the appropriate values and change the title that will show up in the plot when the sequence is run:

For each value of base current, the collector voltage must be swept and the voltage and current measured, so drag those properties inside the base current sweep:

The sequence is now ready to run, but it would be a good idea to set the outputs to 0 and turn them off at the end. Repeat the “Duplicate” procedure described earlier (and note that although “0” was entered, the instrument forced the minimum value to be 1 µA and 1 µV):
Before the sequence is run, the chart and table provide a “Preview” mode that shows where settings will be changed at each step. As the sequence executes, the chart and table are populated with measurement data. See Figure 7.

Figure 7. Line chart and table show at a glance what will happen when the sequence is run.
To see a plot of the Collector Voltage versus Collector Current for each value of Base Current, the points for each Base Current sweep need to be grouped together. These are selected via drop-down lists in the X-Y Chart as shown in Figure 8:

![Figure 8. The X-Y Chart can be configured to plot any setting or measurement against any other, and the measurements can be grouped onto one chart. In this case there is only one group —Base Current.](image)

The Test Sequence can now be run by clicking the green Start button. It can be stopped at any time by pressing the red Stop button. It can also be single-stepped by pressing the blue single-step button:
When the sequence is run, the familiar shape of a transistor curve trace takes shape in the chart. You can mouse over the chart even while the sequence is running to see all values at each step. See Figure 9.

Figure 9. Final plot of the collector voltage vs. collector current for five values of base current.

Trace data and screen shots can be exported in Excel, Word, MATLAB and CSV formats. The test sequence can be saved in a BenchVue-specific format for later loading back into BenchVue.
There are other blocks available too. Let’s say that a delay is needed after turning on the power source. The “Delay” or “Wait Until” blocks can be used for this. Or perhaps you want to be notified when the setups are complete and the sweep/measure blocks are ready to execute. The “Prompt” block allows a message to be displayed and requires a “Continue” button to be clicked to resume execution. There are other blocks to allow creation of various kinds of loops, and even to insert low-level instrument-specific commands (SCPI) into the sequence. External programs can also be called. Tool tips appear when the mouse is hovered over the block to help identify which one would be appropriate. See Figure 10.

![BenchVue Test Flow](image)

Figure 10. Other useful blocks can be dragged into the sequence. Hovering over the block shows the tool tips and helps identify what each block does.
Conclusion

What once took expensive, dedicated curve tracer hardware to characterize transistors can now be done with relatively inexpensive and re-usable instrumentation along with Keysight BenchVue software. With BenchVue Test Flow, a tedious repetitive process can now be created quickly without having to write any software, and results can be exported easily for further analysis or documentation. This can dramatically reduce the time and costs of characterizing semiconductor devices.

More information

Learn more about how BenchVue software can simplify your bench tests and download the free trial version today at: www.keysight.com/find/BenchVue

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