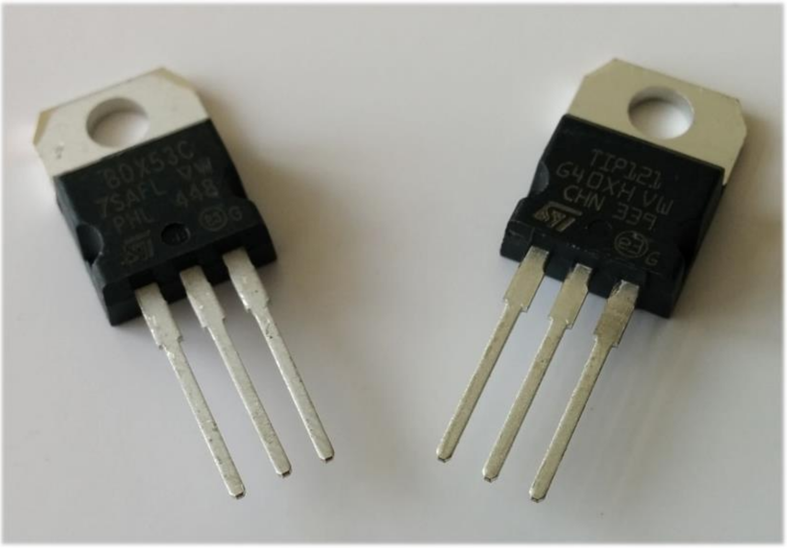
Bode 100 - Application Note

Bipolar Transistor AC Current Gain Measurement



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Contact support@omicron-lab.com for technical support.

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Note: Basic procedures such as setting-up, adjusting and calibrating the Bode 100 are described in the Bode 100 user manual. You can download the Bode 100 user manual at www.omicron-lab.com/bode-100/downloads#3

Note: All measurements in this application note have been performed with the Bode Analyzer Suite V3.0. Use this version or a higher version to perform the measurements shown in this document. You can download the latest version at www.omicron-lab.com/bode-100/downloads

1 Executive Summary

This application note describes how to measure the AC current gain h_{fe}[1] of a bipolar transistor using the Bode 100 vector network analyzer and the PICOTEST J2130A DC Bias Injector.
The DUTs[2] are the bipolar Darlington transistors BDX53C and TIP121.

2 Measurement Task

In order to optimize the frequency response of a specific design that includes bipolar transistors it is of advantage to measure the AC current gain parameter h_{fe} of the used bipolar transistors.
The AC current gain h_{fe} is the quotient of the collector current I_C and the base current I_B depending on the frequency.

$$h_{fe}(f) = \frac{\Delta I_C}{\Delta I_B} \; with \; V_{CE} \; const. \qquad (1)$$

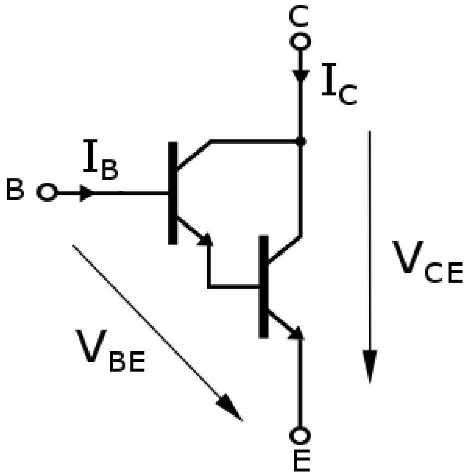

Figure 1: Bipolar Darlington NPN Transistor

To perform this measurement we measure I_B on CH1 and I_C on CH2. A Gain measurement will then deliver the AC current gain $h_{fe}(f)$ over frequency.

[1] h_{fe} refers to the AC current gain and h_{FE} to the DC current gain.
[2] DUT…Device Under Test

3 Measurement Setup

3.1 Measurement Equipment

- Bode 100 vector network analyzer with a computer
- PICOTEST J2130A DC Bias Injector
- 2x Tektronix A6302 current probe
- 2x Tektronix AM503B current probe amplifier.
- Hameg Triple Power Supply HM7042-5
- Maxwell BCAP0310, 310F Super-capacitor
- Fluke 87 Digital multimeter
- BDX53C Darlington transistor
- TIP121 Darlington transistor
- Active heat sink

3.2 Test Objects

Our DUTs are a BDX53C and a TIP121 Darlington transistor. We place the two transistors on an active heat sink, to ensure that the components do not overheat. Both transistor feature a TO220 package.

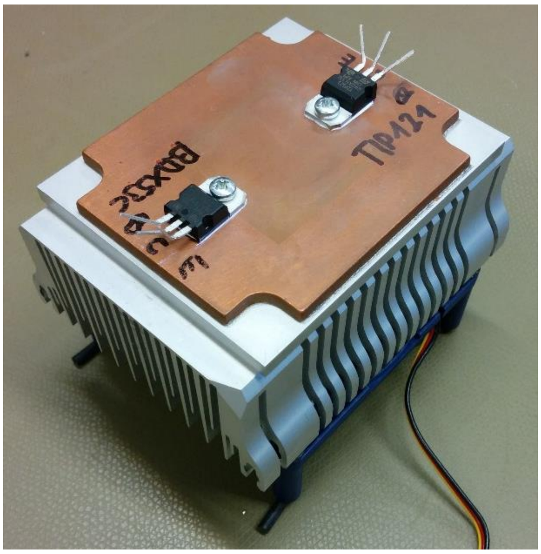

Figure 2: DUTs mounted on active heat sink

From Datasheet:

BDX53C:

- $h_{FE,min} = 750$ at $I_C = 3\ A$ and $V_{CE} = 3\ V$
- $V_{CEmax} = 100\ V$
- $I_{Cmax} = 8\ A$
- $V_{BEmax} = 5\ V$

TIP121:

- $h_{FE,min} = 1000$ at $I_C = 3A$ and $V_{CE} = 3V$
- $V_{CEmax} = 80\ V$
- $I_{Cmax} = 5\ A$
- $V_{BEmax} = 5\ V$

3.3 Measurement Setup

To measure the AC current gain we set up the measurement as shown in the following picture:

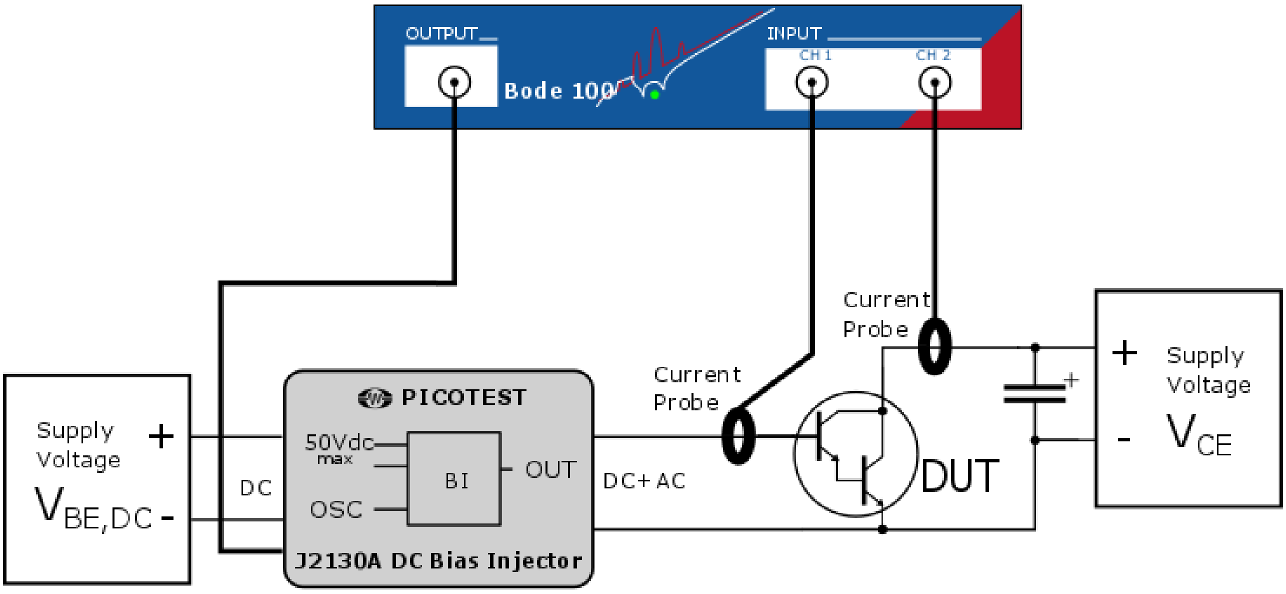

Figure 3: Measurement Setup

With the PICOTEST J2130A DC Bias Injector we bias the base-emitter voltage V_{BE}, to bring the transistor in the forward-active region, where the transistor's behavior is approximately linear. Therefor we set V_{BE} to 1.5 V. The Bode 100 output feeds the OSC input of the bias injector.

The collector voltage V_{CE} is fed by the lab power supply and set to 2.5 V DC. Due to the high frequency of the AC component of I_C we have to support the lab power supply with a capacitor (Maxwell 310 F 2.7V). Otherwise the output impedance of the source would influence the measurement, at higher frequencies. To confirm this approach, we measure the output impedance of the lab power supply according to [1] (OMICRON Lab, 2015).

In the following picture you can see the results of the output impedance measurement.

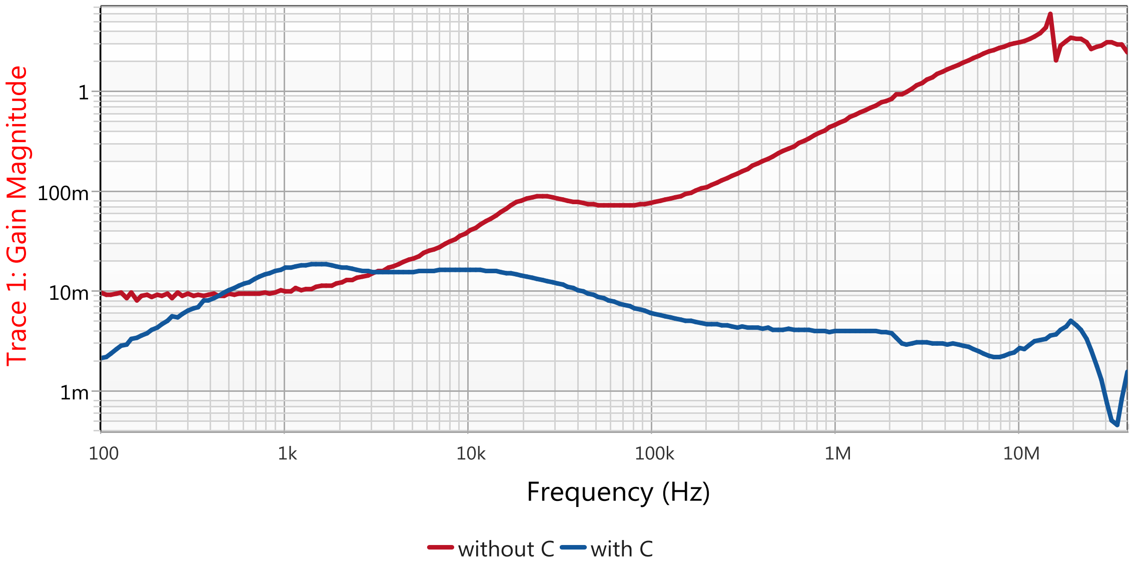

Figure 4: Output impedance of the power lab supply in Ω.

The red line shows the output impedance of the power supply alone. At higher frequencies the output impedance rises ($> 100\ m\Omega$). This will cause a measurement error since the AC current I_C will be limited by the power supply impedance and not the transistor under test. By adding a supporting low-impedance super-cap to the power supply, the output impedance is lowered to $< 20\ m\Omega$ over the entire frequency range and shows now a very good behavior at lower and higher frequencies. Note that the super-cap is mounted directly to the DUT in order to minimize connection inductance.

With the current probe on CH1 we measure the AC base current ΔI_B. The current probe on CH2 measures the collector current ΔI_C.

The following pictures show the h_{fe} measurement setup in detail:

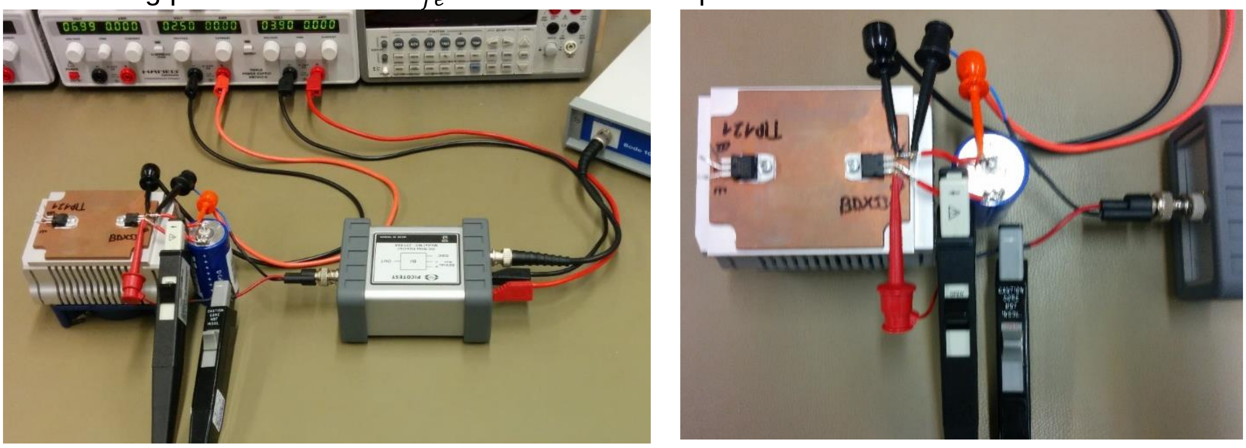

Figure 5: Measurement setup

3.4 Current Probe Amplifiers

We set both current probe amplifiers to the same amplification level, such that the amplification factors cancel each other. The coupling is set to DC to enable low-frequency measurements.

Figure 6: The two current probe amplifiers

3.5 Bode 100 Setup

At first we set the *Gain / Phase* measurement type in the Bode Analyzer Suite:

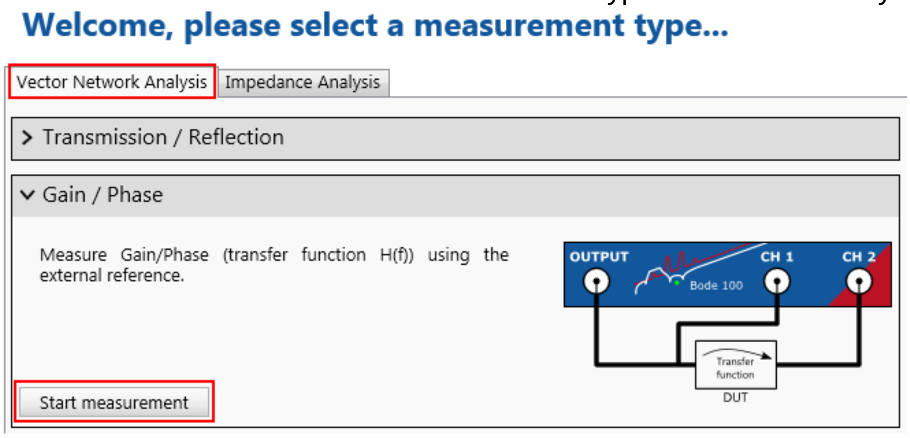

Figure 7: set measurement type Gain / Phase

Then we open the *Hardware Setup* and set channel 1 and 2 to 50 Ω.

Figure 8: open Hardware Setup

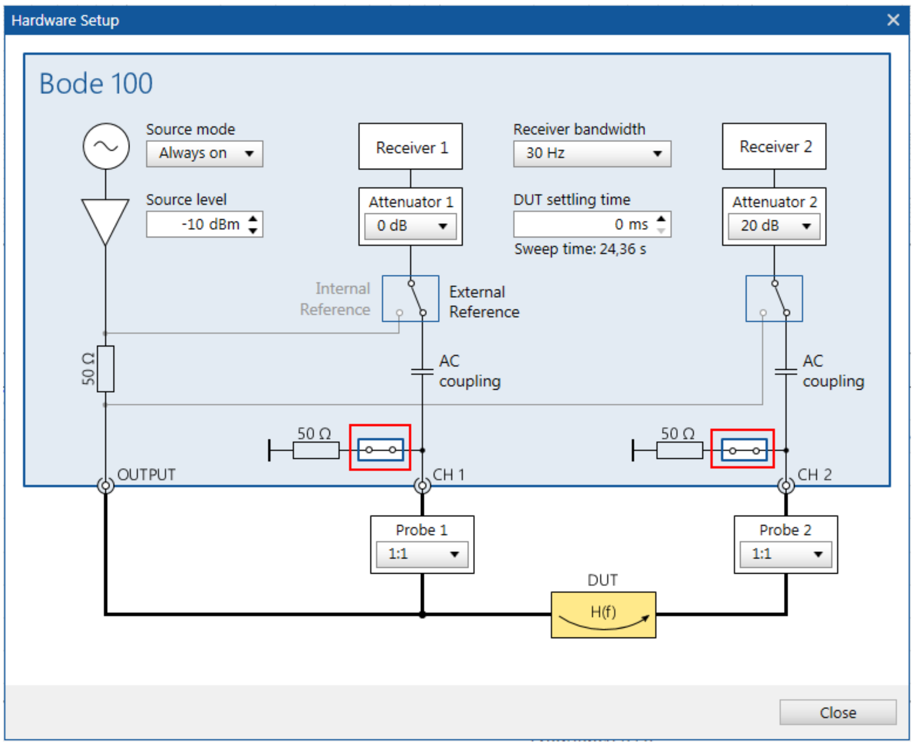

Figure 9: Hardware Setup window

The measurement settings are as follows:

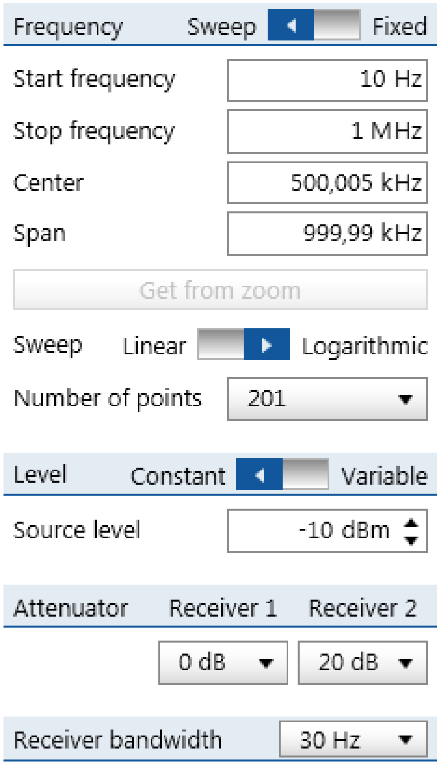

Figure 10: measurement settings

3.6 Calibration

Before we start the measurement we have to calibrate the setup. Therefor we perform a user-range calibration.

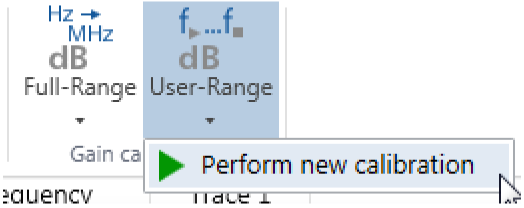

Figure 11: perform user-range calibration

The Thru calibration is started by clicking on the Start button in the calibration window.

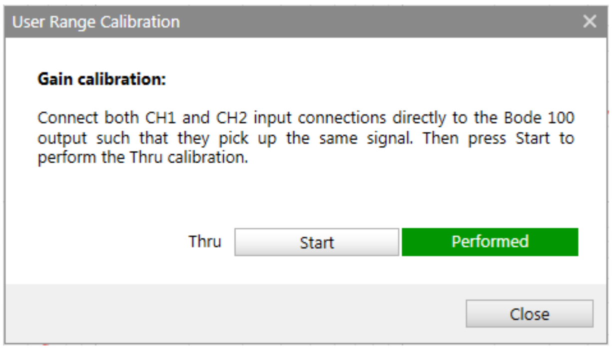

Figure 12: perform Thru-calibration

The following picture shows the calibration setup:

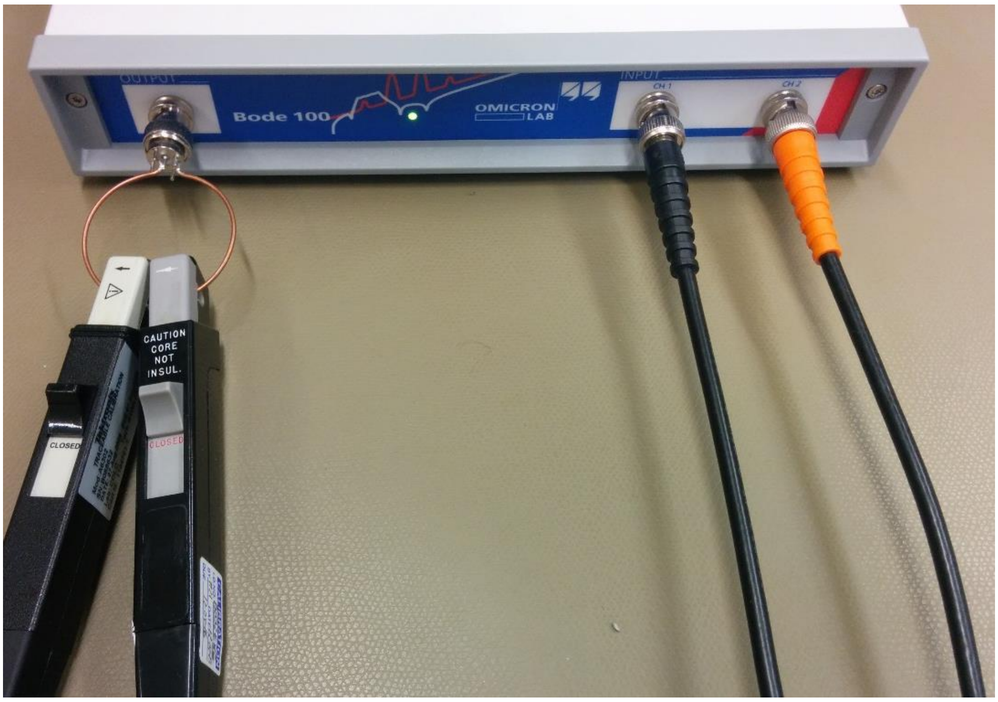

Figure 13: THRU calibration

4 Measurement Results

4.1 BDX53C

At first we measure the BDX53C. With a single measurement, the following result was obtained:

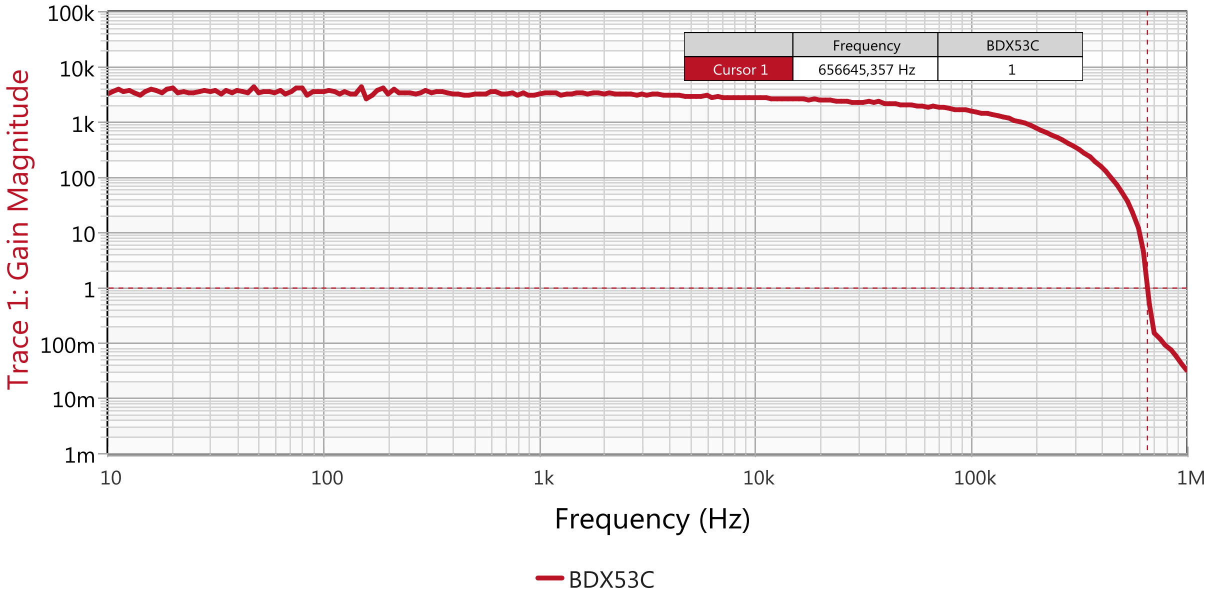

Figure 14: BDX53C, AC current gain, magnitude

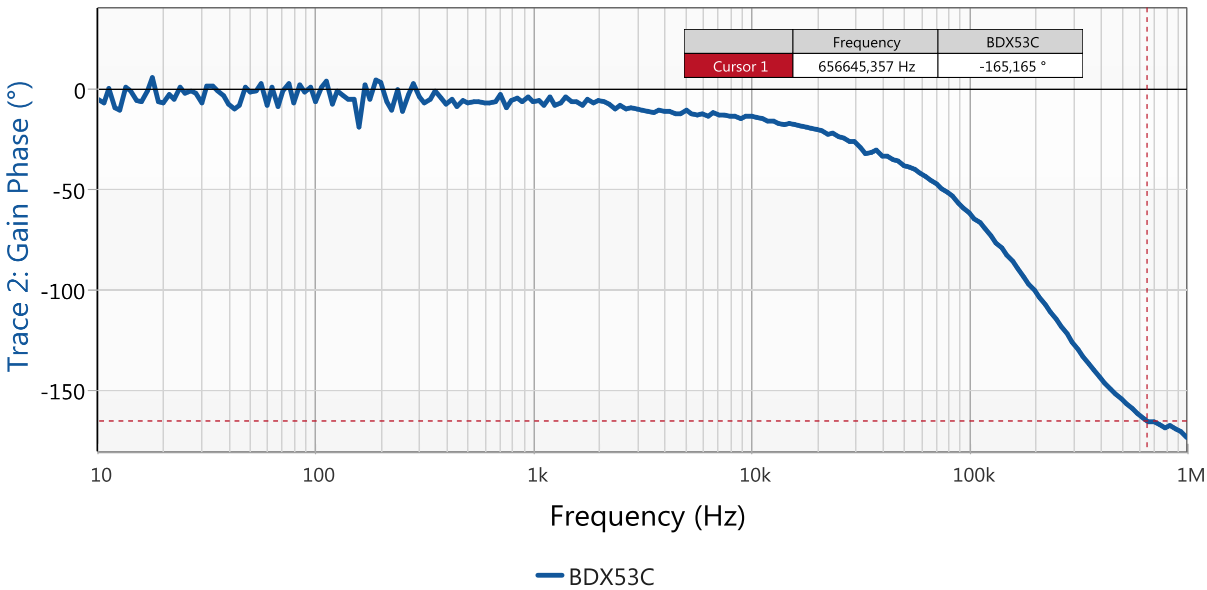

Figure 15: BDX53C, AC current gain, phase

The transistor shows an AC current gain of approximately 3500 and a very linear behavior over frequency. The current gain starts to drop at roughly 100 kHz.
The transit frequency f_T is at $\approx 657\ kHz$. The phase shows the same trend, but drops earlier.

4.2 TIP121

Now we connect the TIP121. A single measurement showed the following curves:

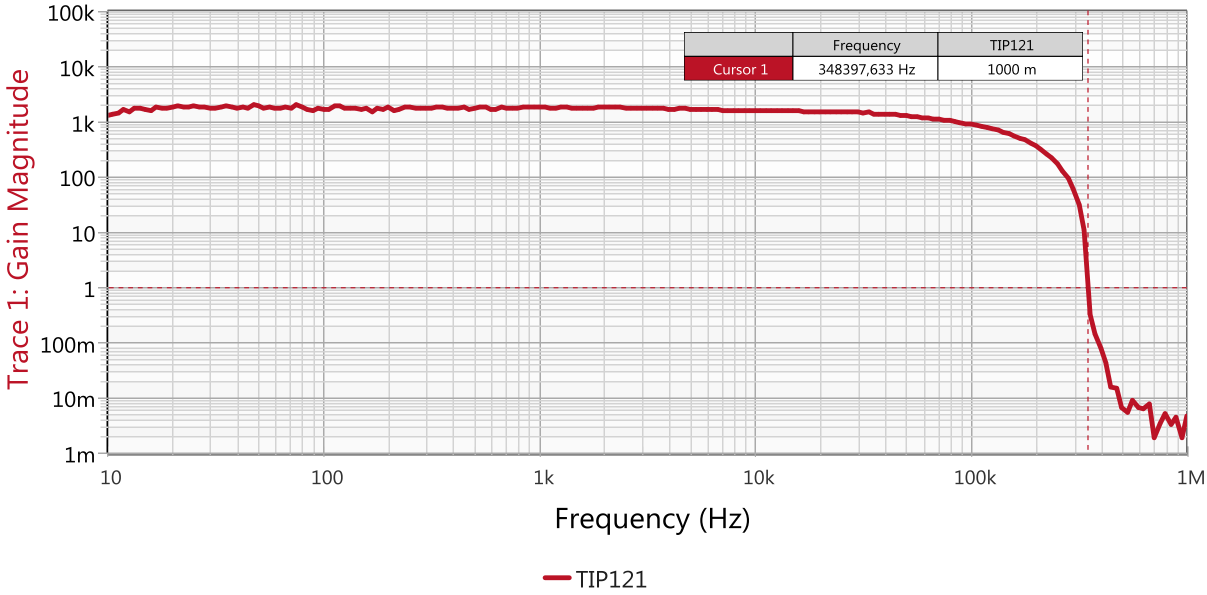

Figure 16: TIP121, AC current gain magnitude

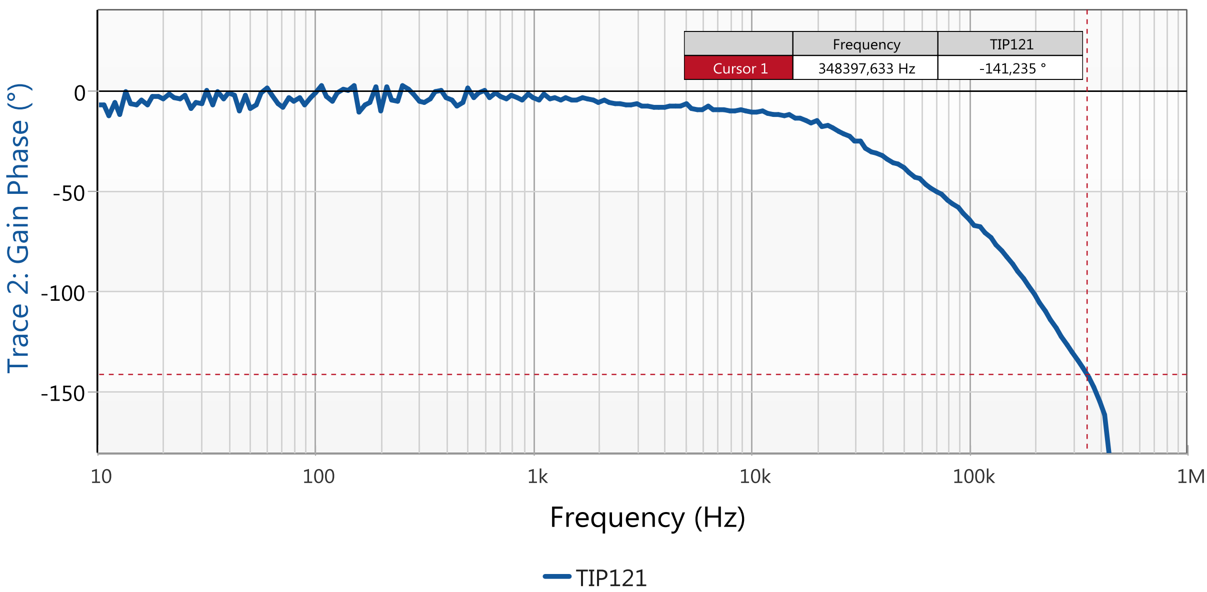

Figure 17: TIP121, AC current gain magnitude

The TIP121 compared to the BDX53C, shows a lower gain of roughly 2000 and the cutoff edge is steeper. The transit frequency f_T is at $\approx 348\ \mathrm{kHz}$.

5 Conclusion

This application notes shows how to measure the AC current gain h_{fe} of a bipolar transistor. It also shows that the high frequency output impedance of a lab power supply can be critical for correct measurement results.

The Bode 100 vector network analyzer in conjunction with the J2130A DC Bias Injector suits perfect to measure the AC current gain of bipolar transistors. The Bode 100 is an easy to use but powerful base for a wide range of measurements.

6 References

[1] OMICRON Lab. (2015). *Traditional and Non-Invasive Stability Measurements.* Retrieved from OMICRON Lab "Smart Measurement Solutions": https://www.omicron-lab.com/fileadmin/assets/application_notes/App_Note_Traditional_NoninvasiveStability_V2_0.pdf

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