Technical Article

Power Tips: Where to Connect Frequency Analyzer Reference Leads for Bode Plot Measurement – Part 1

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Whenever a system incorporates a negative feedback loop, the loop gain, T, becomes an important performance parameter to measure and optimize for stability, output regulation and transient-response performance. Voltage injection is a widely adopted method for measuring T. Figure 1 shows a typical voltage-injection T measurement setup. The feedback path is cut off between V_{OUT} and R_{up}. A disturbance voltage is inserted. All signals refer to ground.

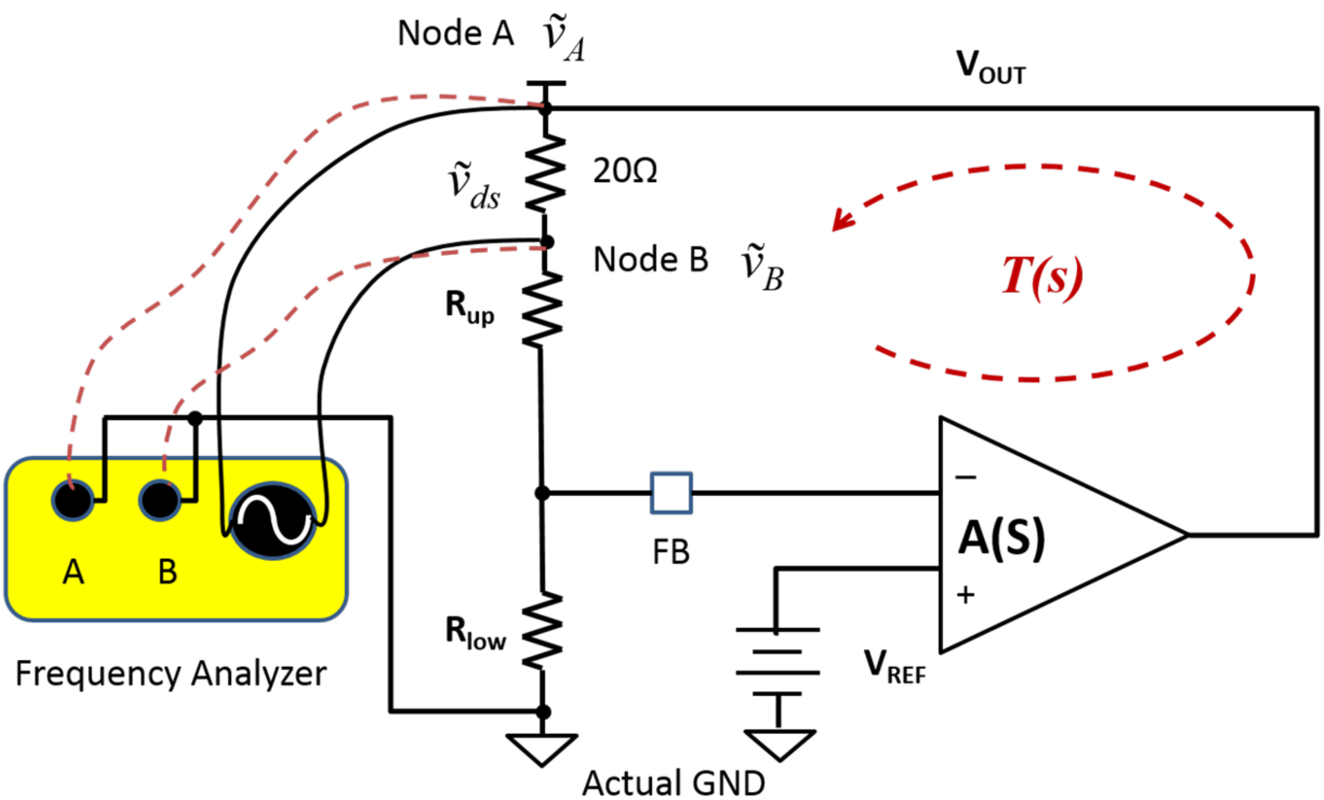

Figure 1. Typical T Measurement Setup

Figure 1 measures T as:

$$T = -\frac{\widetilde{v_A}}{\widetilde{v_B}} \tag{1}$$

Signal receivers A and B have two leads which provide a reference point for signals A and B, respectively. Figure 2 shows the leads.

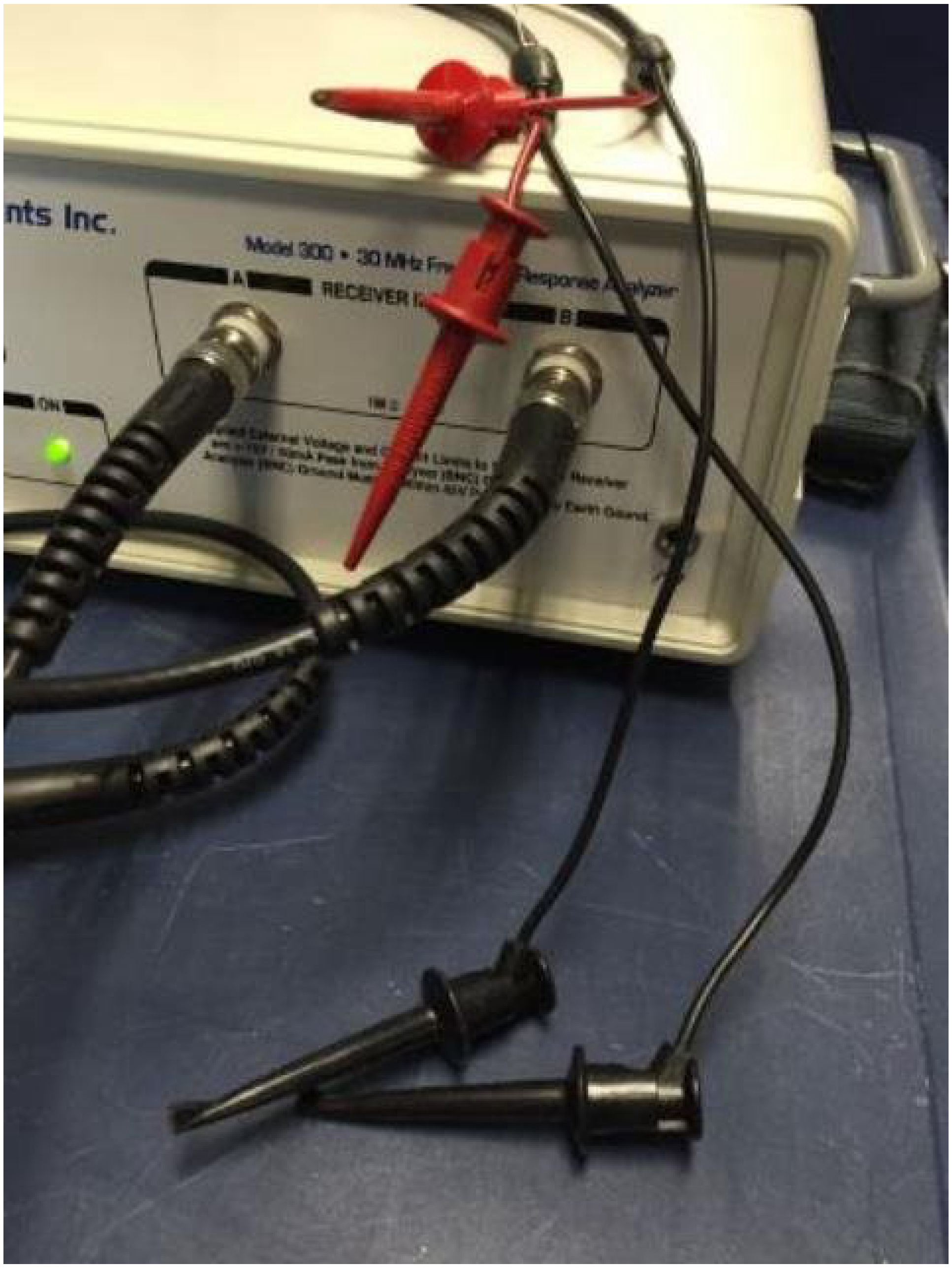

Figure 2. Probes of Receivers a and B with Their Reference Leads

In most cases, these leads connect to ground, and because of that, they are called GND leads. But is that always the case? To answer that question, I will demonstrate an example using the LM4041-N, a precision shunt voltage reference. Figure 3 shows a typical application circuit for the LM4041-N.

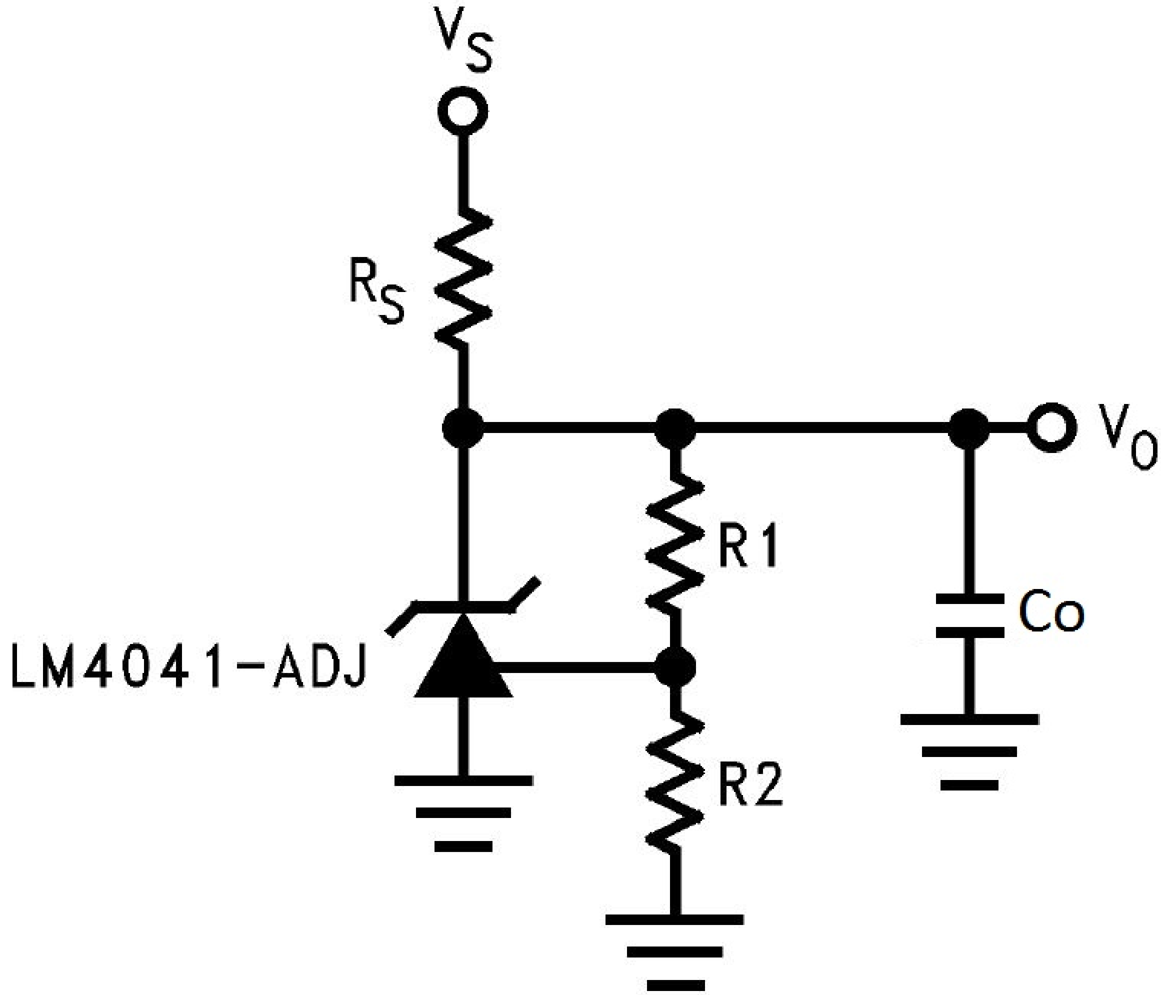

Figure 3. LM4041-N Typical Application Circuit

The LM4041-N keeps the voltage across V_O to the FB pin at 1.24V, as Figure 4 shows. The resistor divider sets the output DC voltage. R_S provides current for the LM4041-N and load.

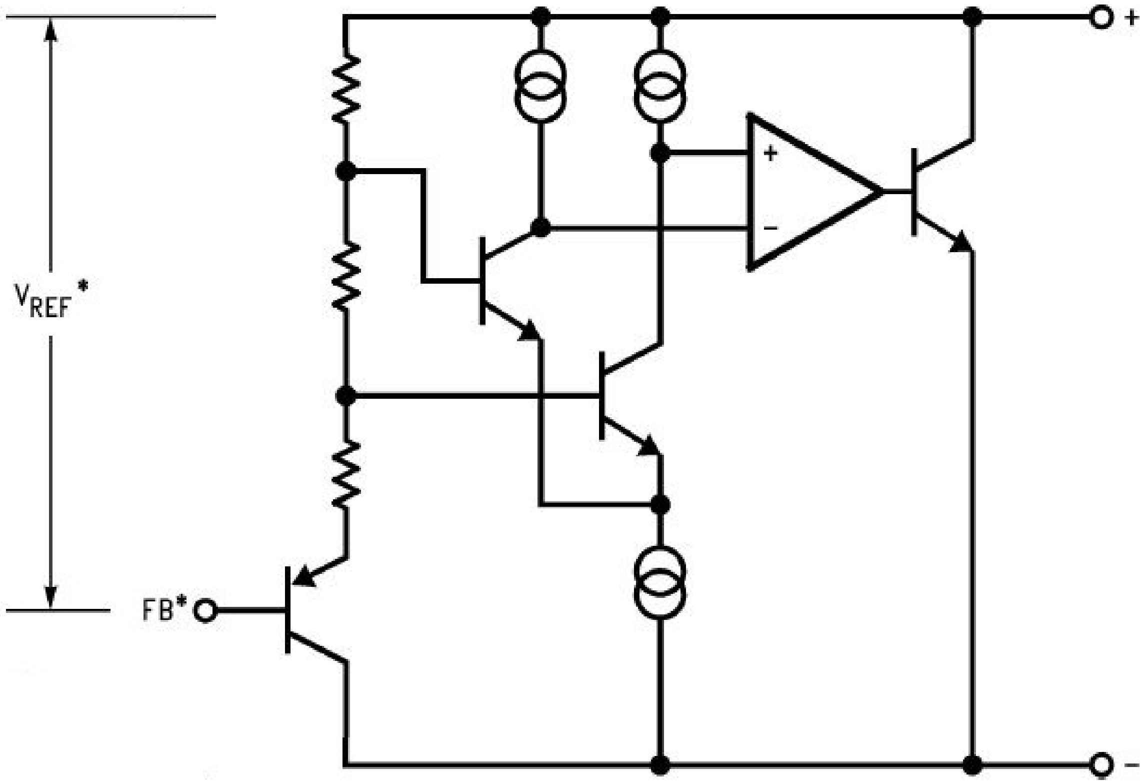

Figure 4. LM4041-N Block Diagram

To generate a 2.5V reference from a 12V bus, I used these components:

- R1 = 10kΩ.
- R2 = 10kΩ.
- R_S = 10kΩ.
- Co = 0.22µF.

Figure 5 shows the Bode plot measurement result using the setup shown in Figure 1. The result does not correspond to tight DC regulation, as I expected. Nor does it provide a direct indication of stability.

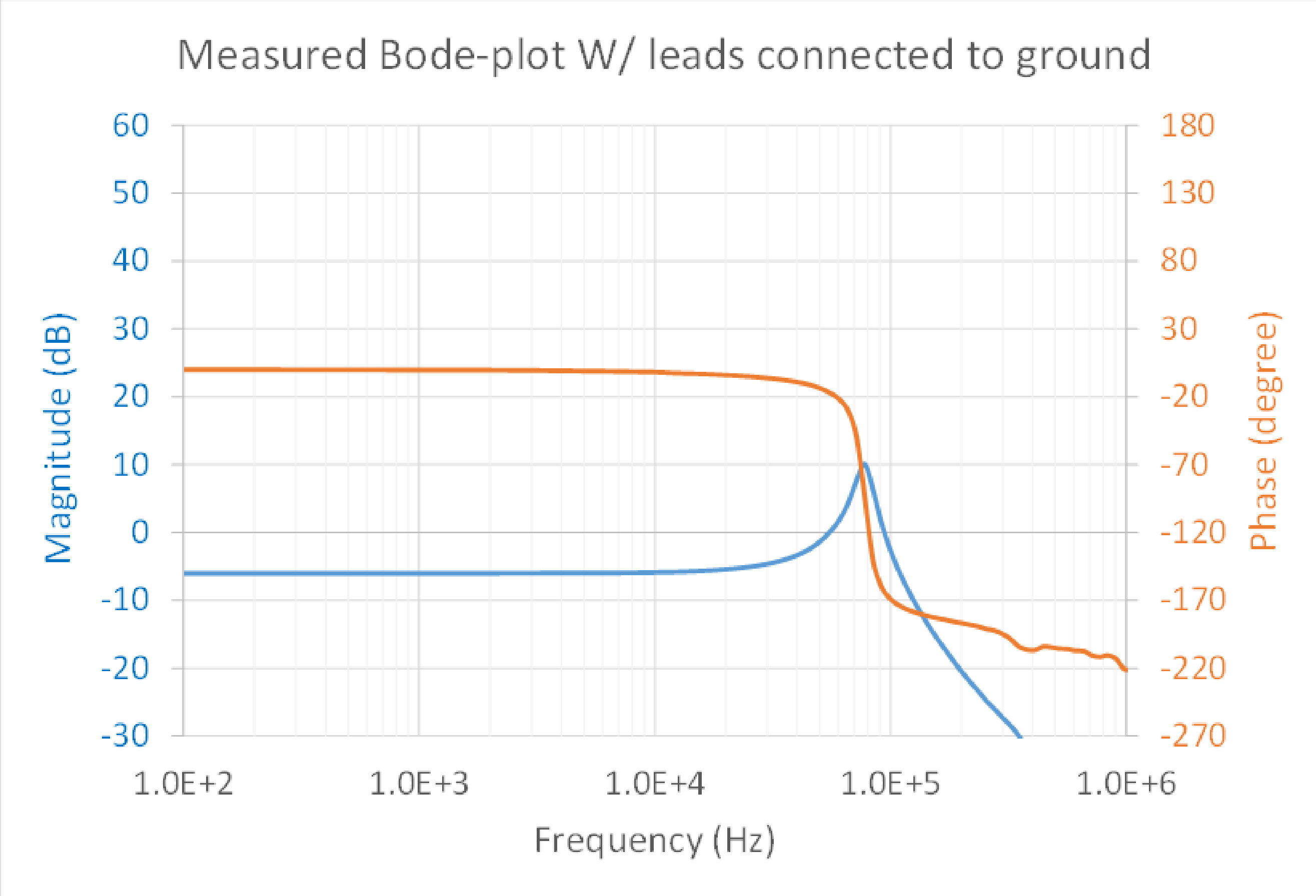

Figure 5. Measured Bode Plot with Reference Leads Connected to Ground

I derived the AC small-signal models referring to ground. Figure 6 shows the model.

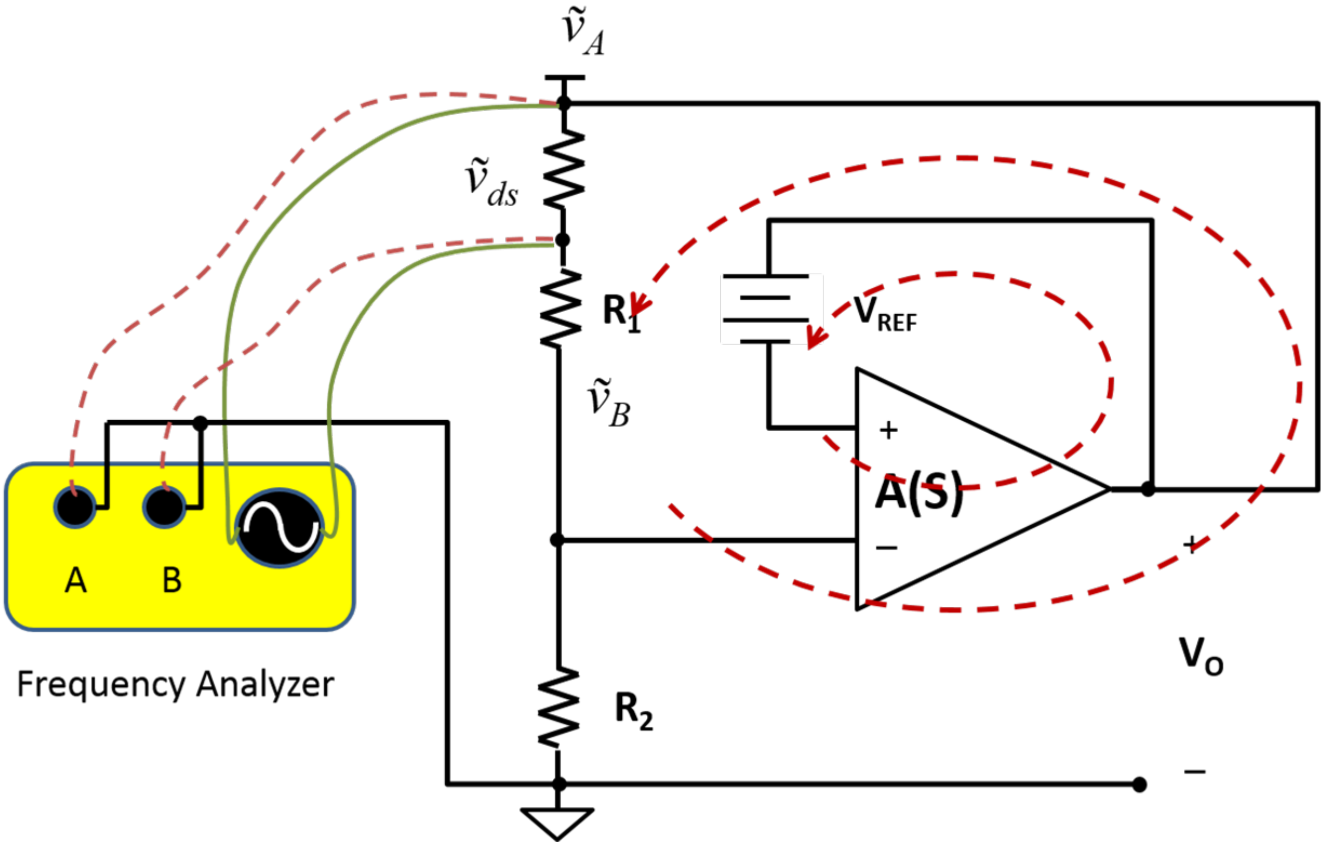

Figure 6. Small-signal Model Referring to Ground

With the reference leads connected to ground, the break point between V_o and R_1 only cutting off part of the feedback path. I examined the LM4041-N block diagram. The positive input of the gain stage connects to V_o from the AC perspective. By moving the reference leads to V_o, I now can break the feedback loop completely between R_2 and ground. At this break point, looking backward is the regulator output, R_S and Co in parallel. R_2 is the impedance looking forward. For most frequencies, the impedance of Co is much smaller than R_2. Figure 7 shows the small-signal model referring to V_o.

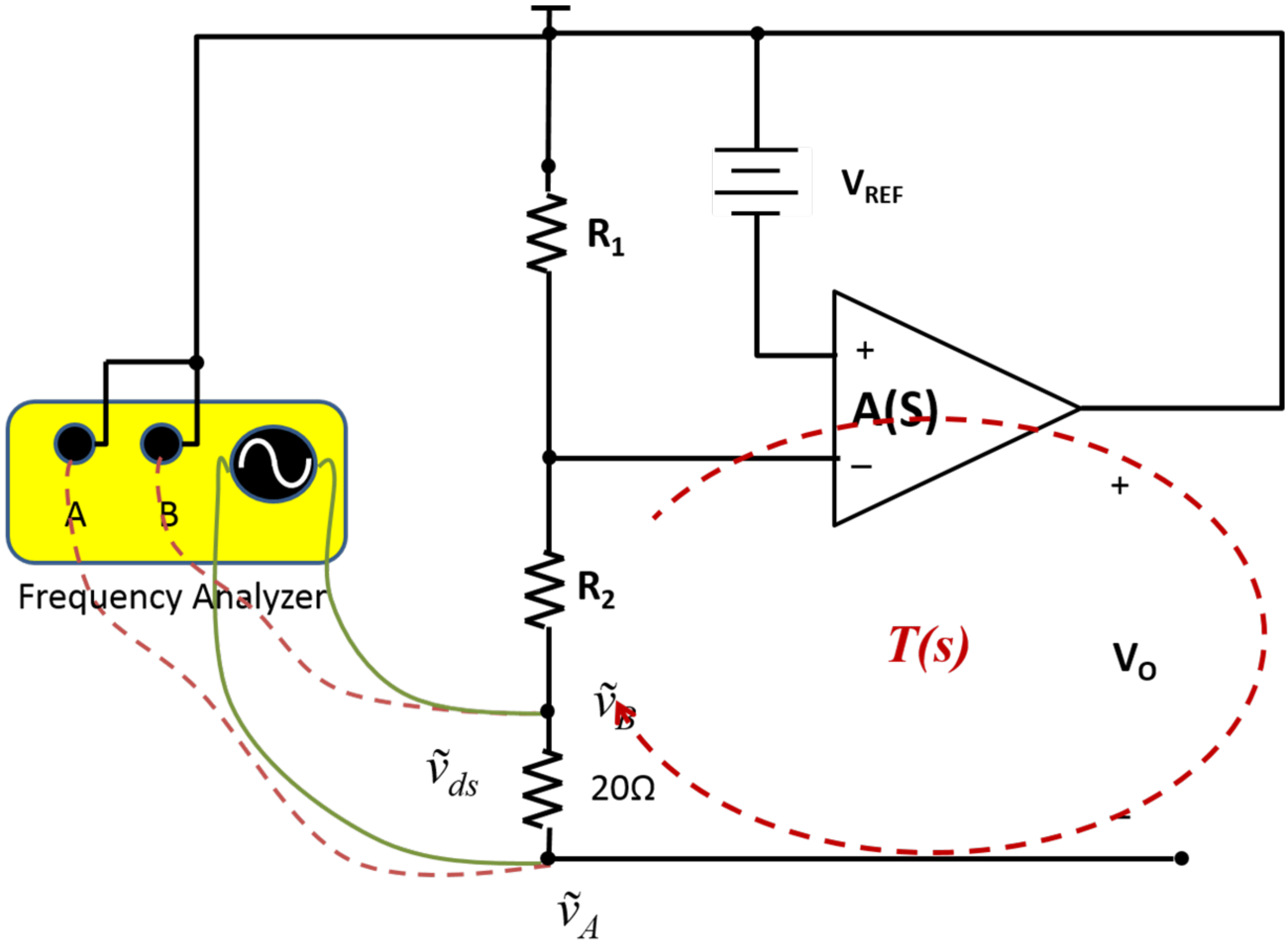

Figure 7. Small-signal Model Referring to the Output

Figure 8 shows the measurement results using the setup shown in Figure 7.

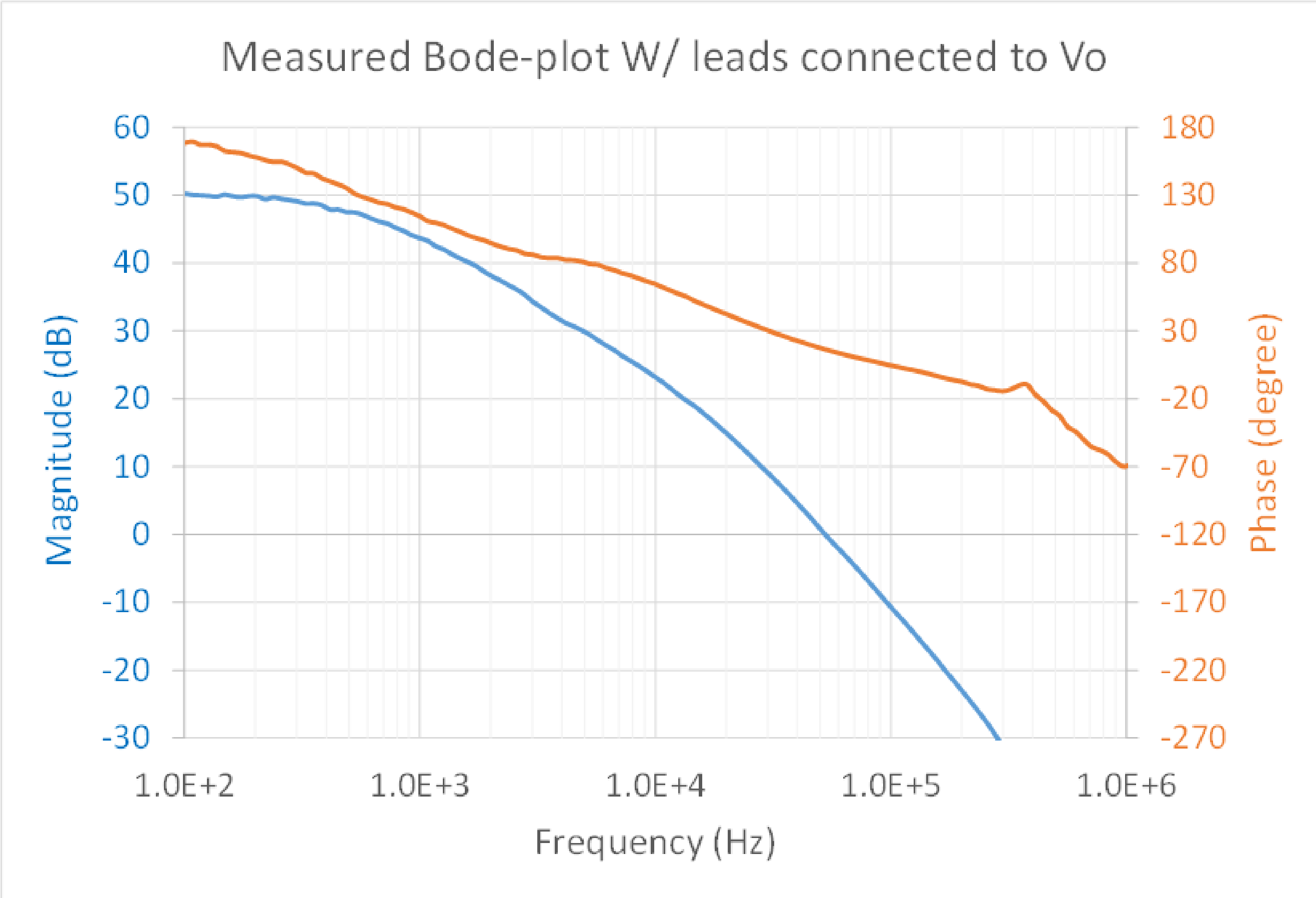

Figure 8. Measured Bode Plot with Reference Leads Connected to v_o

The result shown in Figure 8 indicates that the stability needs improving. I reduced the output capacitor from 0.22µF to 47nF and added a phase-boosting capacitor in parallel to R_2, as shown in Figure 9.

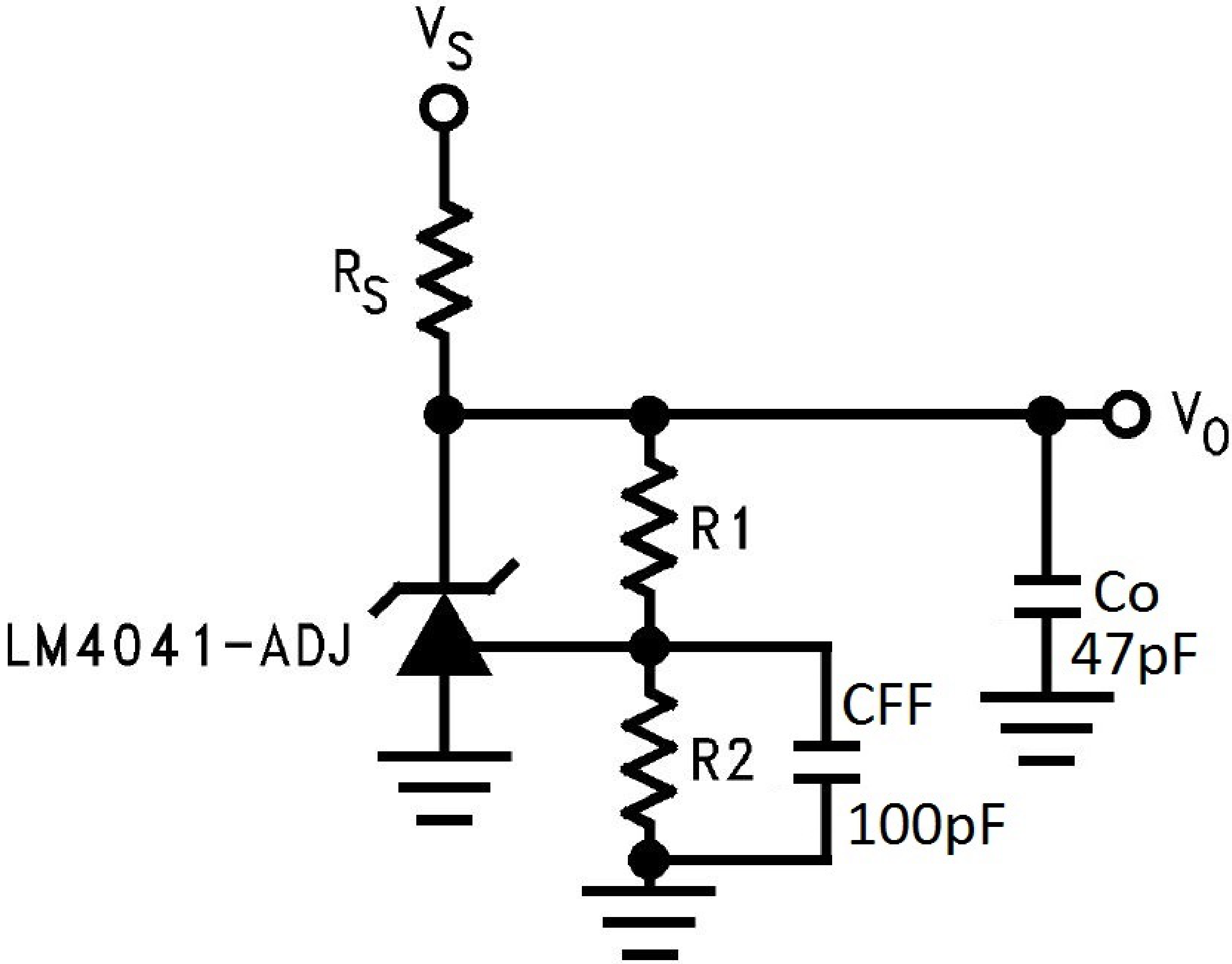

Figure 9. Final Schematic of LM4041-N as a 2.5V Voltage Reference

Figure 10 shows the improvement with the reduced Co and phase-boost capacitor, Cff. With the changes, phase margin has increased from 16 degree to 45 degree.

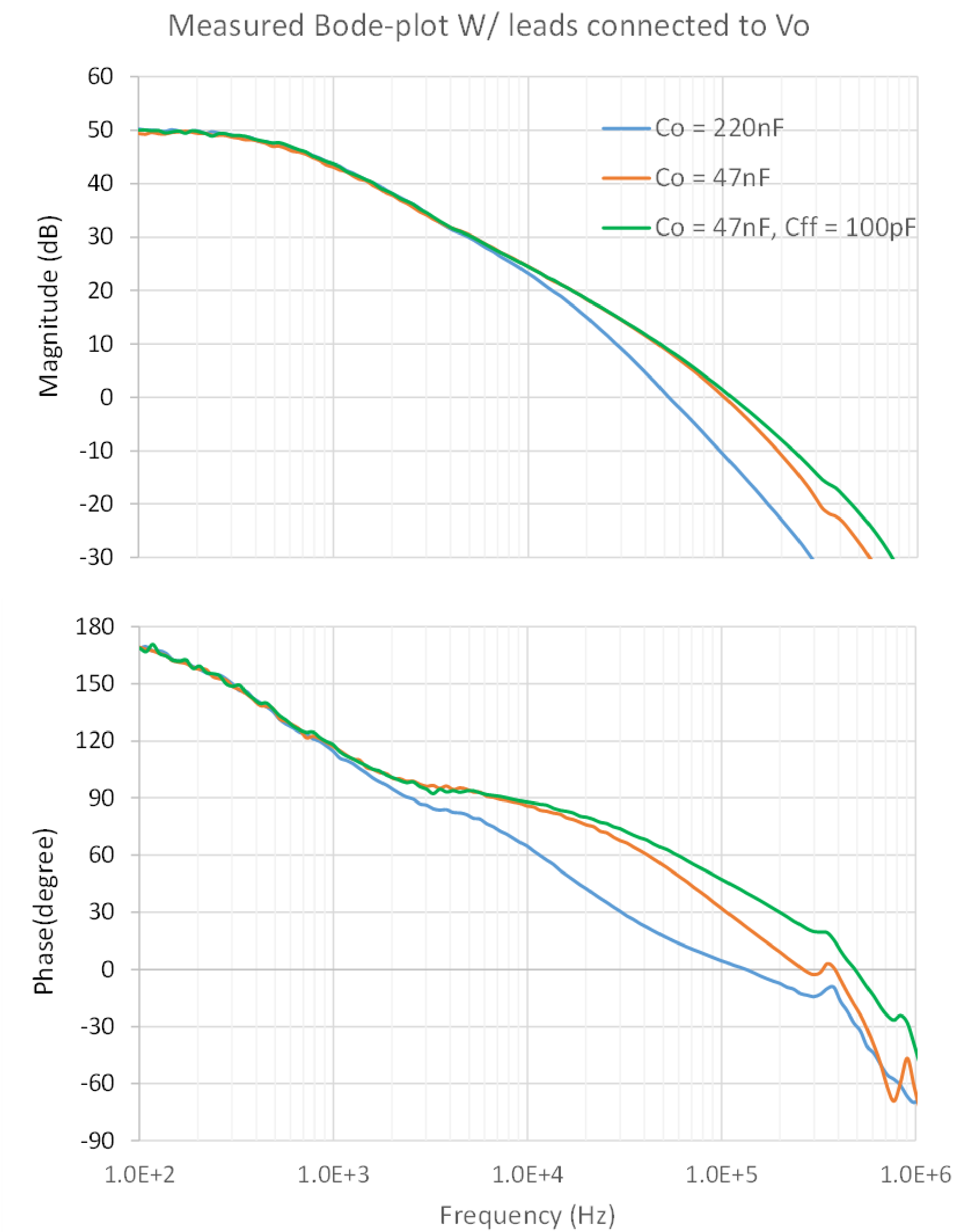

Figure 10. Measured Bode Plot with a Different Co and Cff

You can use the LM4041-N to show how to find a point to connect the reference leads of a frequency analyzer for Bode plot measurement. First, develop an AC small-signal model. Then, identify a reference point so you can find a break point to meet both of these requirements:

- All feedback paths are cut off at the break point.
- The impedance of the break point looking backward is much smaller than the impedance looking forward.

Additional Resources

- Read more Power Tips.
- View Power Tips videos.