Using the Bode 100 with standard 10:1 probes

It is essential to have the right measurement instruments in an electronics laboratory if someone has the aim to work on a high level in electronics R&D.

When it comes to a potential purchase of measurement equipment however, a lot of us engineers suffer from the very limited budget available for investment in such professional tools – and this is quite usual even at the biggest, well prospering R&D companies as well as for individual entrepreneurs.

One of the most important measurement tools I have got in my lab – besides the high bandwidth, high speed digital storage oscilloscope – is the great Bode 100 Vector Network Analyzer (VNA), made by Omicron Lab (**Figure 1**). This "low-frequency" VNA is a really versatile instrument supporting various measurement types like: transmission/reflection measurement, gain/phase frequency response measurement and many different types of impedance measurement as well. Whether one has to analyze power supply stability or to characterize passive components or filter networks, the Bode 100 can be incredibly useful, especially in a power electronics lab.

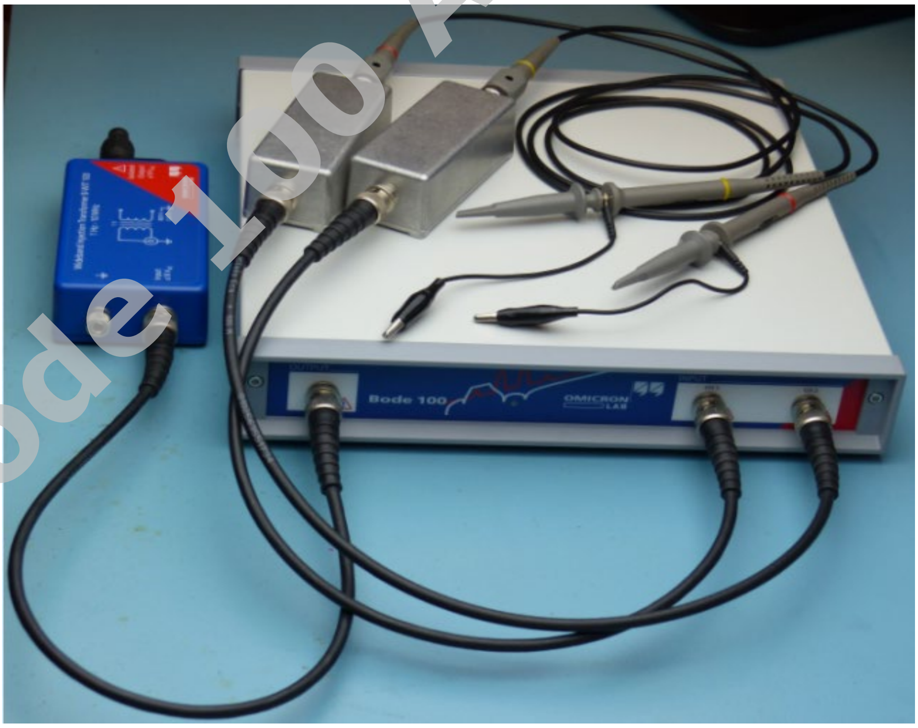

Figure 1. *Bode 100 Vector Network Analyzer with accessories*

Considering the build quality of the instrument and the features of the control software, the Bode 100 VNA is fairly priced. In contrast to this, the dedicated 10:1 probes (Type: PML 111O, made by PMK) seem to be a bit overpriced to me. Since the Bode 100 has an input termination different from the usual scope input (as shown in **Figure 2**), regular 10:1 scope probes cannot be used to ensure proper voltage division ratio at DC.

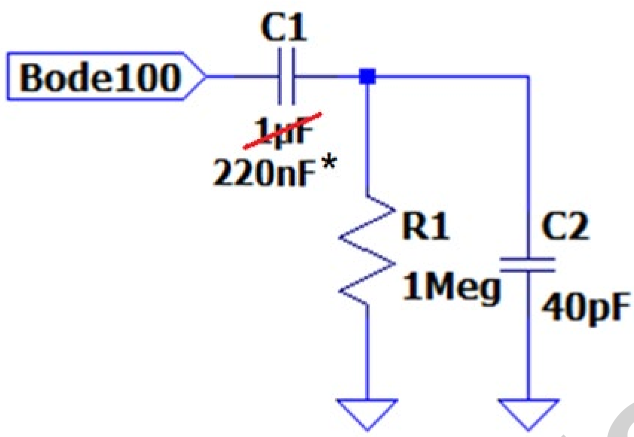

***Figure 2.** Bode 100 receiver input (simplified) equivalent circuit*

(*) C1 corrected 01/21/2022 – thanks to Florian Hämmerle !

As it can be seen in this equivalent circuit, the VNA input is terminated by a 1M resistor *after* the DC blocking (or: AC coupling) capacitor, which prevents the usual 10:1 probes from working properly: C1 blocks the full measured DC voltage without any voltage division regardless of the nominal probe ratio, and only the AC component is being divided. (The dedicated PML 111O probe oveercomes this issue with built-in termination resistor). According to the technical specification of the instrument [1], the maximum input voltage is 50V, which is limited by the voltage rating of the AC coupling capacitor at the receiver inputs.

Measuring off-line Power Factor Correction (PFC) circuits and isolated power supplies often calls for control loop measurements at high-voltage nodes of the circuit (typically around 400V), thus these require *at least* 10:1 divider ratio from DC over the whole measurement frequency range. Some measurements may require a probe with even higher divider ratio (ie. 100:1).

There is a simple way to turn a regular 10:1 scope probe into a properly terminated 100:1 probe that is specifically suitable for the Bode 100. A simple circuit for this purpose is shown in **Figure 3**. Besides providing the proper DC termination, this circuit also ensures the DC blocking happens outside the VNA, making the test setup even more flexible (and robust) in terms of voltage rating.

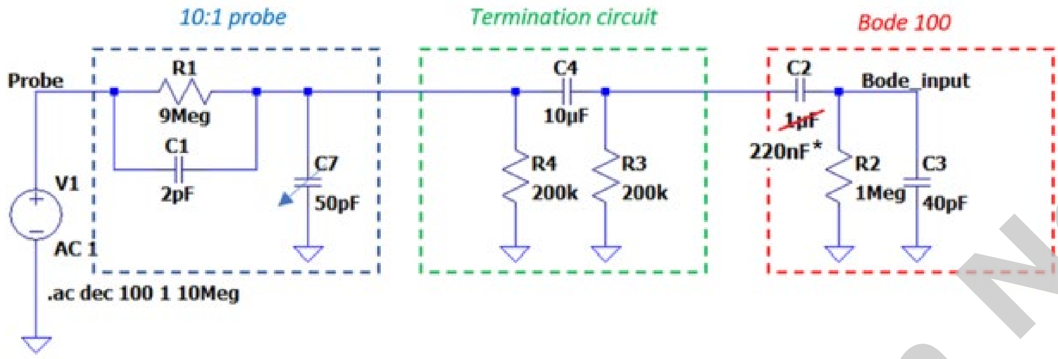

Figure 3. *Using standard 10:1 probe with additional termination circuit*

The resulting "AC" divider ratio (assumption: the frequency of the measured signal is above the cutoff frequency of the high-pass filters formed by C4-R3 and by C2-R2, respectively):

$$M_V = \frac{V_{receiver}}{V_{in}} = \frac{200k\Omega||200k\Omega||1M\Omega}{9000k\Omega + 200k\Omega||200k\Omega||1M\Omega} = \frac{90.9091k\Omega}{9000k\Omega + 90.9091k\Omega} = 0.01$$

So the used 10:1 probe has a 100:1 effective AC voltage measurement ratio with the additional termination, while the blocked DC voltage (measured across C4) is approximately 1/50 of the input DC component. R3 and R4 termination resistors can also be replaced by one resistor on the probe input of the circuit. Making the termination symmetrical has an advantage in implementation: the termination box does not need to have a dedicated direction, so the input and output ports are interchangeable.

It is important to note that the probe can be highly undercompensated with the shown termination resistors, causing a significantly higher gain above a few kHz (see **Figure 5**). The decreased value of the termination resistors shift the compensation pole upwards, altering the frequency response drastically. The unusual transfer characteristics caused by the undercompensation does not really matter in case of control loop measurements, since the ratio of the two receiver channels is being evaluated in this case. Thus, the only important factor is that the used *two probes have to be well matched* – this usually can be easily achieved in the *0Hz-10MHz* range by the adjustable built-in compensation capacitors of regular 10:1 probes.

Clearly, it is quite simple to eliminate this effect by adding extra compensation capacitors in parallel to the termination resistors (**Figure 4**). The bode plot for a properly compensated probe can also be seen in **Figure 5**. The remaining deviation in the amplitude and phase response is reasonably small this way.

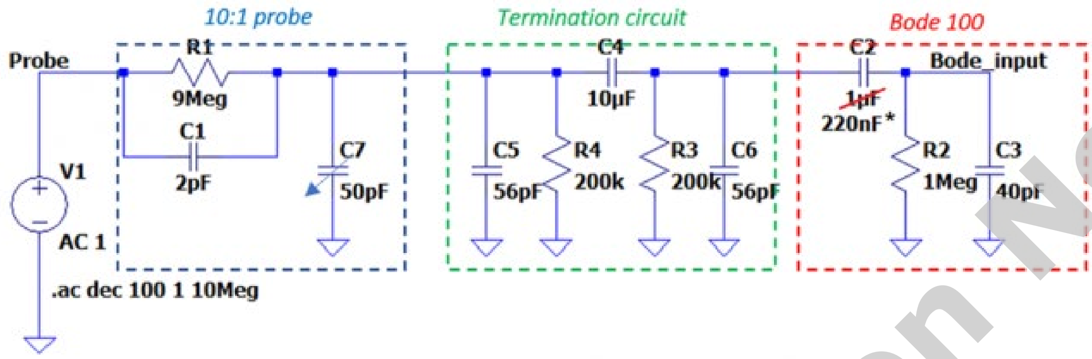

Figure 4. *Improved termination circuit with additional compensation capacitance*

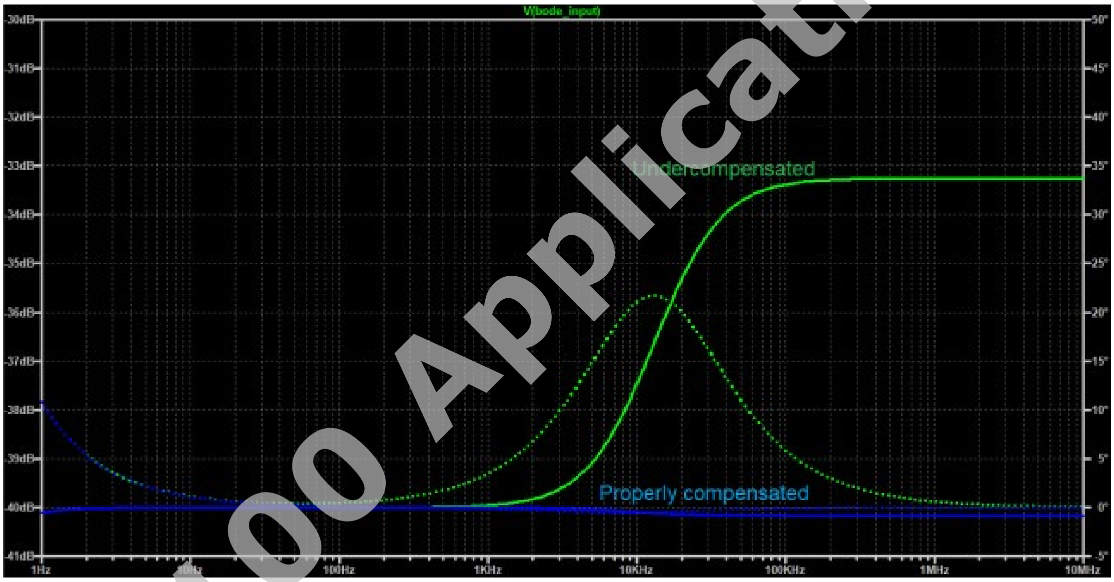

Figure 5. *Frequency response of the 10:1 probe with the additional termination circuit*

This additional termination circuitry can be built in separate, small metal boxes with BNC connectors and can be inserted to be signal paths without modifying the probes. Such an implementation is shown in **Figure 6** below.

10uF/63V rated film capacitors was used here. Note that it does not have to be high voltage rated, since the DC voltage gets already divided here properly. A low-inductance GND return path can be implemented by adding a copper strip next to the capacitor leads, soldered onto the GND joints of the two BNC connectors. One layer of insulator (tape) below the copper strip helps to avoid any short circuits.

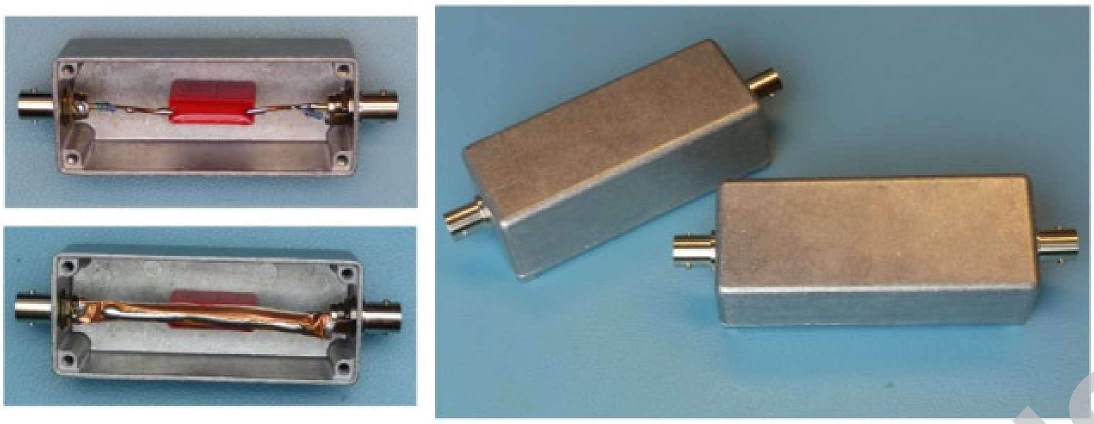

Figure 6. *The implemented termination boxes*

Figure 7 shows a test done with Bode 100 using low-cost 10:1 probes with the shown modified termination. Both probes are connected directly to the source output of the VNA and the ratio of the two receiver channels is plot here, therefore, unity gain and zero phase are expected over the measurement frequency range. As it can be seen from the bode plot, the probes can be matched very well by adjusting the capacitive compensation of the probes.

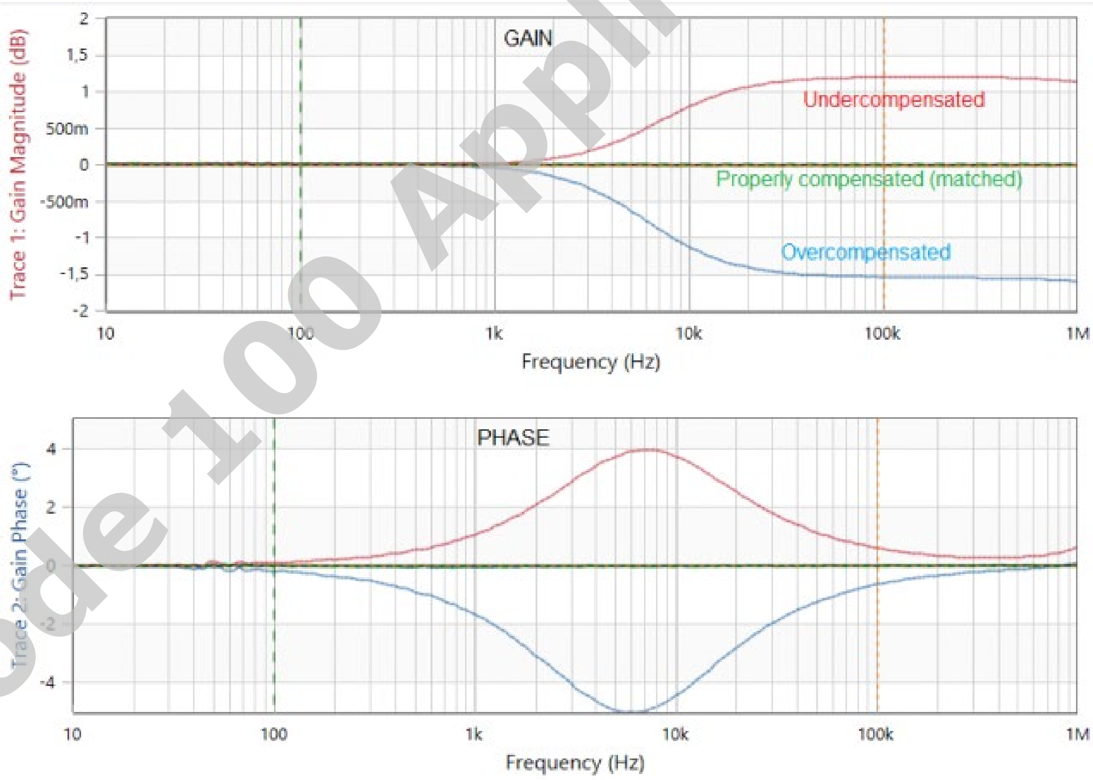

Figure 7. *Measured "unity gain" transfer characteristics with two modified probes*

Finally, I highly recommend watching the Bode 100 review and teardown videos from EEVblog on Youtube, showing some interesting details about this VNA.