
Experiment 1 - Introduction to Electronic Test Equipment

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1.0 Objective

In this experiment you will become familiar with the test equipment in the laboratory and will become adept at using the Tektronix 2235 oscilloscope to perform DC and AC measurements. A functional knowledge of Bode Plots is necessary. A review of this material is included

2.0 Prelab

Before beginning this experiment, read **CONTROLS, CONNECTORS, AND INDICATORS**, an excerpt from the Tek 2235 manual reprinted in this lab manual. This should help you understand the operation and function of most of the controls on the front of the oscilloscope. You should also read the **HP GAIN-PHASE METER OPERATING GUIDE, HP 8116A OPERATING GUIDE, and HP 4145B OPERATING GUIDE**. Also read the appendix at the end of this section on good breadboard layout technique.

For the circuit in Fig. 3, derive an expression for $v_{out}(t)$ for both a high to low transition and a low to high transition. Your EE 40 textbook may help.

For the circuit in Fig. 3, derive the expression $\frac{V_{out}(j\omega)}{V_s(j\omega)}$. See the notes on Bode plots at the end of this lab.

3.0 Procedure

3.1 Oscilloscope and Signal Generator

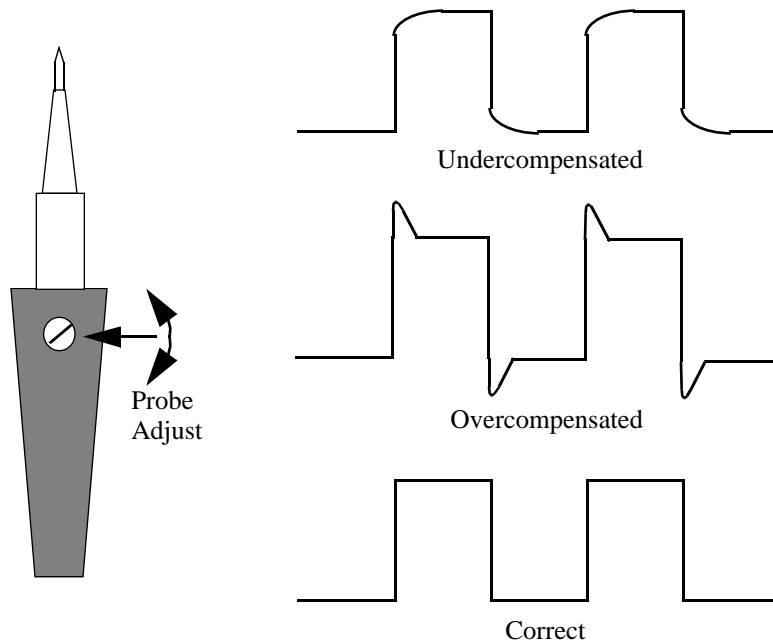
1. Use “PROBE ADJUST” signal (under the “beam find” button) to insert a 1 kHz, 0.5 volt p-p (peak to peak) square wave into the first input, Ch1. Set that channel for AC coupling. The waveform should be 5 divisions high on the 0.1V/div scale. (Look at the 10X marker) If the waveform looks very distorted, adjust the probe using a screwdriver.

Lab Tip

The probes that come attached to the oscilloscopes are 10x probes. Readings should be read from the 10x markings. All other cables are 1x cables and results should be read using the 1x markings.

FIGURE 1.

Effects of adjusting the Probe Adjust screw on test waveform



2. Repeat these steps for the second channel, Ch2.

Lab Tip

It is important that both channel on the scope are calibrated correctly. The easiest way to do this is to turn the red *calibration* dial to the right completely. Use the test square wave to make sure that the waveforms are five divisions high. You may need to adjust the calibration dials. Can you think of reasons why calibration is important?

2. Set the external trigger to “LINE” (What does this do?), and the vertical input to the DC mode. Short the vertical input (Ch1 or Ch2) to ground and set the vertical, position control so that the trace is at some convenient reference point. Now connect a DC power supply to the vertical input and vary its voltage. Check the accuracy of the panel meter on the power supply using the scope readings. What is the maximum voltage the supply will produce? How accurate is the power supply’s panel? Can this experiment be done with the vertical input on AC mode? why or why not? What is the difference between DC and AC coupling?

3. Now connect the HP 8116A signal generator to the vertical input. Move the trigger control to “INTERNAL” (What does this do?) Set the generator to an arbitrary frequency and determine the accuracy of the generator’s display by comparing the period of the sinusoid on the scope with the period of the sinusoid on the display. How closely does it agree? What is the maximum peak-to-peak amplitude available from the generator? The minimum? Vary the *TRIGGER LEVEL* control and note the effect on the waveform. What is happening? Press *TRIG VIEW* to view the signal that is used to trigger the sine-wave while varying the *TRIGGER LEVEL* control.

4. Set the generator to output a pulse. Compare the period and frequency readings on the generator controls to those actually observed on the scope. Observe both the ‘+’ and ‘-’ pulses. What is the shortest pulse width (in seconds) that you can generate? The longest?

Lab Tip

You will always be using the HP 8116A in *Normal Mode*. The unit saves the settings each time it is turned off. To ensure that the signal generator is operating properly make sure:

- The following lights are **OFF**: [AUTO], [LIMIT], [COMPL] and [DISABLE].
- Always operate the generator with the **AMP** and **OFS** instead of **HIL** and **LOL**.
- DTY setting should be 50

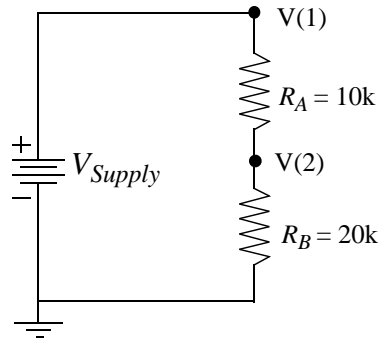
All other lights should be off; for further explanation, see the 8116A manual. .

3.2 The Digital Multimeter

1. Construct the circuit below. Let V_{Supply} be 10V.

FIGURE 2.

Simple Resistive Divider Circuit



2. Use the digital multimeter and the oscilloscope to determine the voltages at nodes 1 and 2. Compare the readings between the digital multimeter and the oscilloscope.
3. Derive a relationship for $V(2)$ in terms of V_{Supply} , R_A and R_B .
4. Calculate the current through resistor R_B . Measure the current with the digital multimeter. How do the results compare?

Lab Tip

Cables for the digital multimeter can be connected to it from both the front and the rear. This allows for quick voltage and current measurements by simply switching between the *Front/Rear* button.

3.3 The HP 4145 Parameter Analyzer

1. Using the digital multimeter, measure the resistance on a 10k carbon resistor.
2. Carefully plot the resistor's I-V characteristic, using the oscilloscope. Label all relevant points.
3. Using the HP 4145, determine the resistor's I-V. Load the program **PR**.
4. Connect **SMU1** to the '+' terminal of the resistor and **SMU2** to the '-' terminal of the resistor. See the quick reference in Section 4.2 of this lab.
5. Use the cursor and marker to find the slope of the curve. From the slope, find the resistance of the resistor.

Procedure

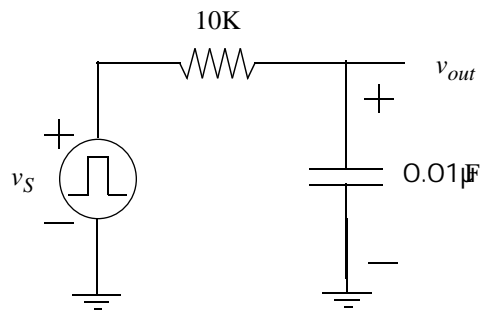
6. Use the **[PLOT]** key to obtain a hard-copy of the graph.
7. Comment on the similarities and differences of the two I-V characteristics.

3.4 AC and Transient analysis

1. Construct the following lowpass filter circuit.

FIGURE 3.

Lowpass Filter Circuit



2. Let v_s be a square wave with a frequency of 1kHz and a 50% duty cycle.
3. Place channel 1 of the oscilloscope at v_s and channel 2 at v_{out} .
4. Display both waveforms on the oscilloscope. Sketch the waveforms and label all the relevant points.
5. How does $v_{out}(t)$ compare with the results from prelab?
6. With the gain-phase meter, connect channel A to the input and channel B to v_{out} .
7. Vary the frequency of a sine wave v_s from 100 Hz to 100 kHz. Plot the ratio B/A as well as the phase. From the data you obtained. Sketch the Bode plot for the lowpass filter. (magnitude and phase) Label the -3dB point.
8. How does $\frac{v_{out}(j)}{v_s(j)}$ compare with the results from prelab?

Lab Tip

When using the gain-phase meter, make sure you use matched probes (1x or 10x) for channel A and channel B.

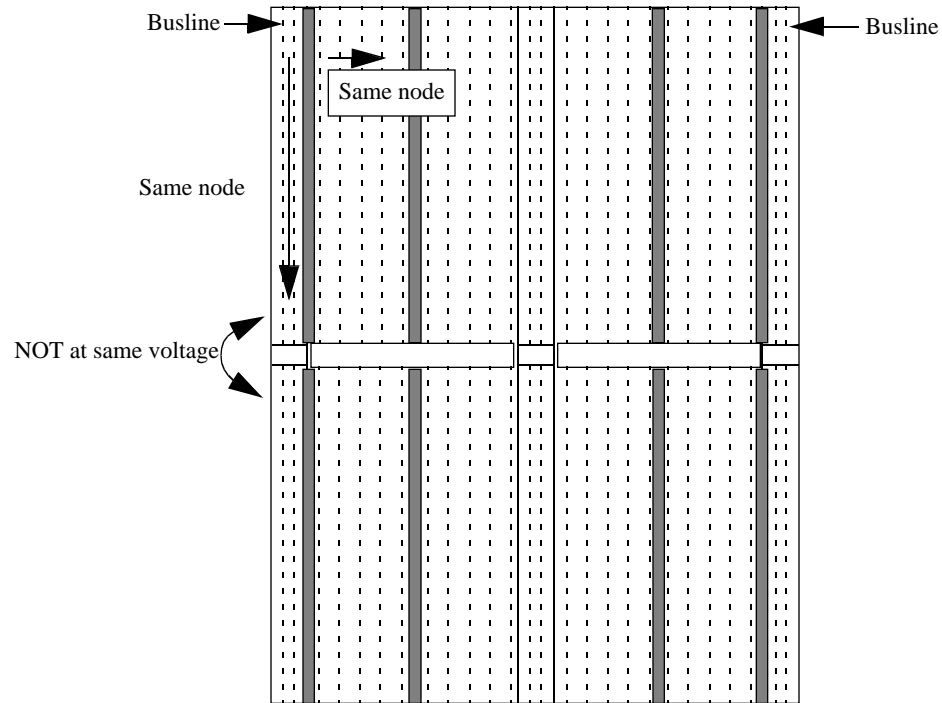
It is also advisable to observe the waveforms on the oscilloscope.

4.0 Appendix

4.1 Breadboard Basics

FIGURE 4.

Layout of breadboard -- Fig. 5 has wiring. Two vertical buslines in center are omitted.

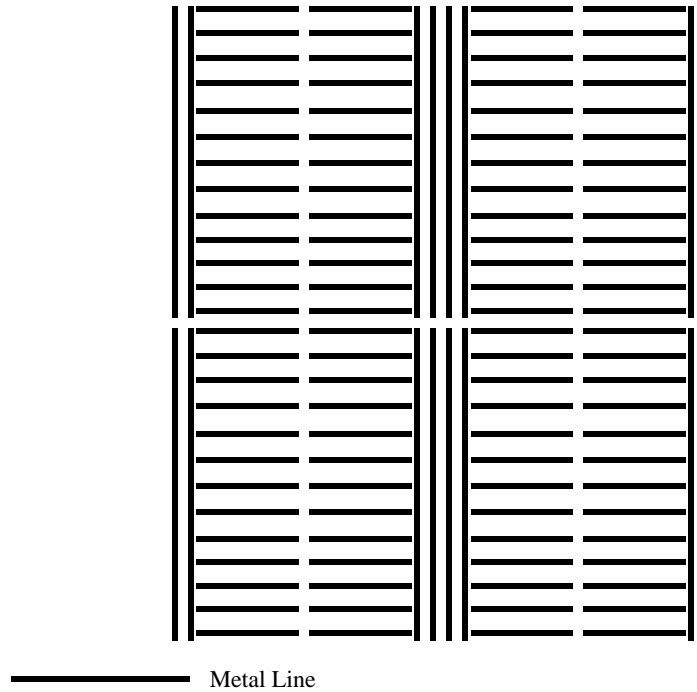


The breadboard is where you will be doing most of your work in lab. Here are some points to remember:

- The buslines are at the same voltage vertically.
- The top half of the busline is not at the same voltage as the bottom half. You should use a jumper if you intend to work on both halves of the board.
- The central sections of the breadboard are at the same voltage horizontally.

Shown below is the metal network for the breadboard.

FIGURE 5. Metal Connections within the Breadboard

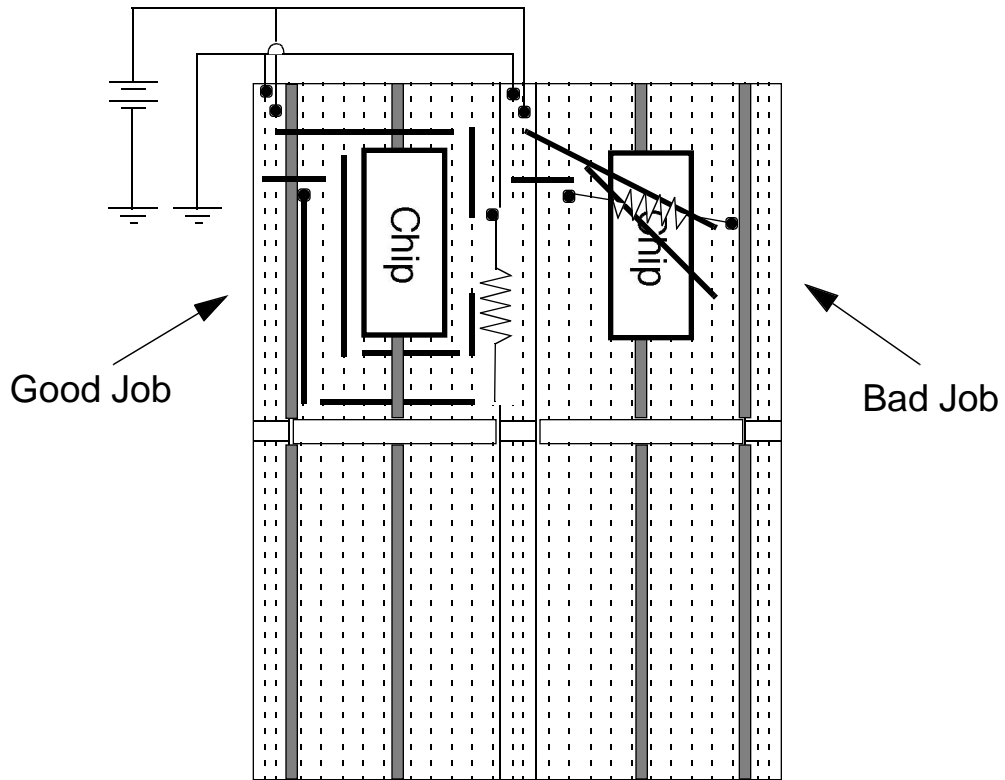


When wiring, it is important to keep your work neat! This discipline will save time for you (and your TA) in debugging when your circuit doesn't work. Below are some tips.

- Keep your wires short
- Do not loop wires over the chip.
- Use the buslines for Ground or a DC supply voltage (e.g. V_{CC})
- Sometimes, you can get cleaner signals if you short the metal base of the breadboard to the circuit's ground.

Figure 6 shows identical connections using good and bad wiring techniques. Note how the resistor on the good side does not "loop" over the chip. Instead, it gets from point A to B by making "manhattan" (90 degrees) turns along unoccupied sections of the breadboard.

FIGURE 6. Proper and Improper Wiring Practices



4.2 HP 4145 Quick Reference

4.2.1 Convention

The following convention will be used in regards to commands for the 4145.

- References to a button will be enclosed with bold brackets. (e.g. **[EXE]** refers to the **execute** key.)
- References to keystrokes which need to be “typed in” will be in bold italics. (e.g. ***VGS*** means type in the keystrokes V-G-S.)
- References to “softkeys” will be represented by bold braces. (e.g. **{CURSOR}** refers to the key that corresponds to the cursor key shown on the CRT.)

4.2.2 Loading a Program

1. Hit the **[GET]** key
 2. Type in the name of the program. Programs always begin with the letter P.
 3. Hit the **[EXECUTE]** key
- For a list of programs, hit the **CAT** key.

4.2.3 The Softkey Menu

1. The {EXTN} softkey toggles through the hierarchy of menus of softkeys.
2. For a complete list of softkeys, consult the **OPERATIONS MANUAL**.

4.2.4 Using the Cursor and Marker to Obtain the Slope of a Line

1. Hit the {MARKER} key
2. The marker can be moved using the circular knob. Notice that as the marker moves, its current x and y value is displayed at the top of the graph.
3. When the marker reaches the first point of your line, hit the {SHORT CURSOR} key. Notice that a small crosshair has appeared in the center of the graph.
4. Hit the {CURSOR > O} key and now the crosshair lies on the marker.
5. Hit the {LINE ON} key and now the first point of the line is set. Notice that a small box has appeared below the graph and contains information of the line such as its gradient, and intercepts.
6. Move the marker using the knob to the second point of your line.
7. Hit {CURSOR > O} and now the line has been properly fitted.

4.2.5 Getting a Hardcopy of Your Data

1. Hit the [PLOT] key
2. Enter the print parameters (size and orientation) or accept the default settings
3. Hit the [EXE] key

FIGURE 7.

Steps 1 - 3: Moving the cursor and bringing up the short cursor

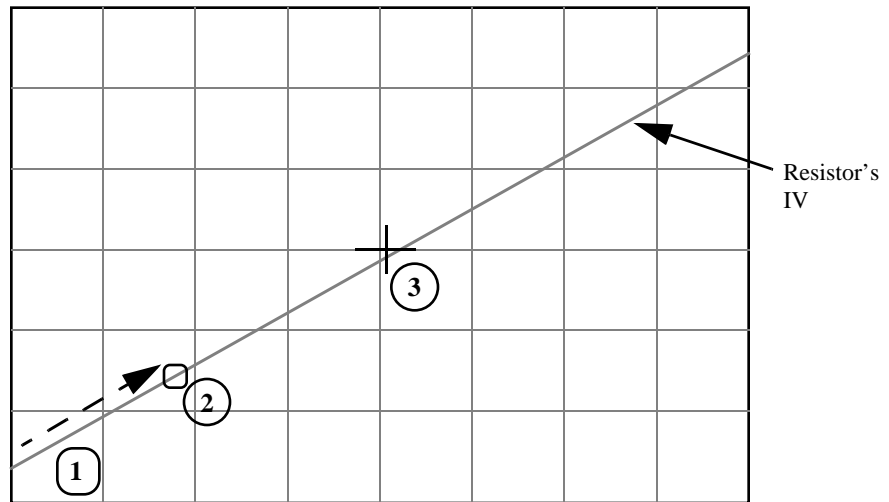


FIGURE 8.

Steps 4 and 5: Placing the Cursor on the Marker and Turning on the Line

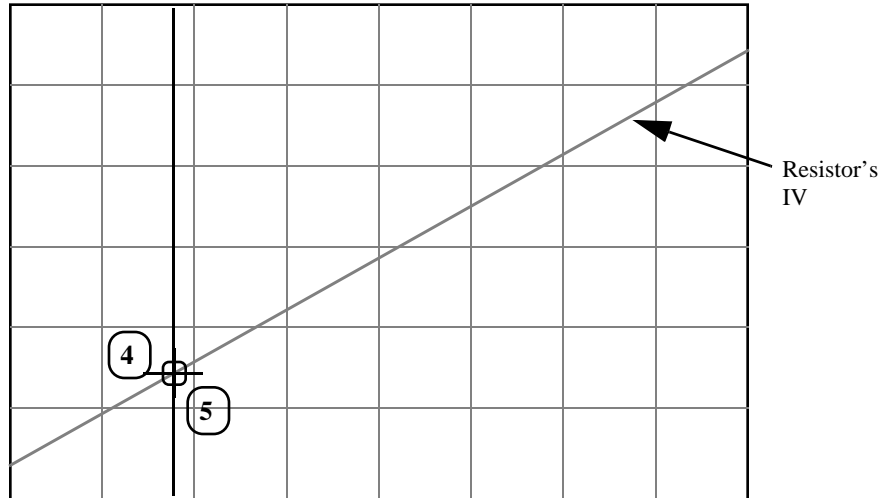
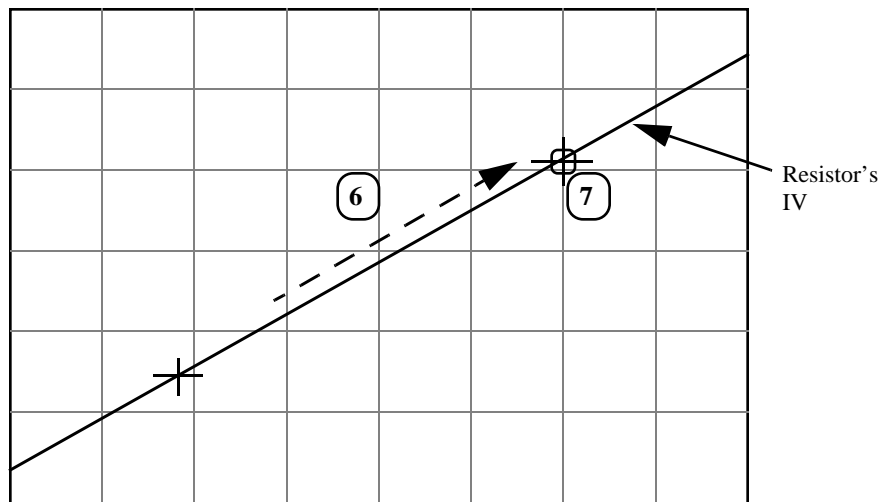


FIGURE 9.

Steps 6 and 7: Moving the Marker and Placing the Cursor on the 2nd Point of the Line



Lab Tip

Should you get lost at any of the screens, you can hit [PREV] to go to the previous screen and return to what you were doing by hitting [NEXT]. You can then start over.

4.3 Bode Plots

A network function $H(j\omega)$ can be represented in the following manner.

$$H(j\omega) = \frac{A \prod_{k=1}^n (1 + j\omega\tau_k)}{\prod_{l=1}^m (1 + j\omega\tau_l)}$$

Let us consider the function $N(j\omega) = \frac{1}{1 + j\omega\tau_1}$. As we vary ω , we can get a good approximation for $N(j\omega)$ for three particular values of ω .

- When $\omega \ll \frac{1}{\tau_1}$, $N(j\omega)$ is approximately 1 since $\omega\tau_1 \ll 1$. The magnitude of the phasor is approximately 1.
- When $\omega \gg \frac{1}{\tau_1}$, $N(j\omega)$ is approximately equal to $\frac{1}{j\omega\tau_1}$ since $\omega\tau_1 \gg 1$. The magnitude of the phasor is approximately $\frac{1}{\omega\tau_1}$.
- When $\omega = \frac{1}{\tau_1}$, $N(j\omega) = \frac{1}{1 + j}$ since $\omega\tau_1 = 1$. The magnitude is approximately $\frac{1}{\sqrt{2}}$.

We now can define the decibel voltage gain:

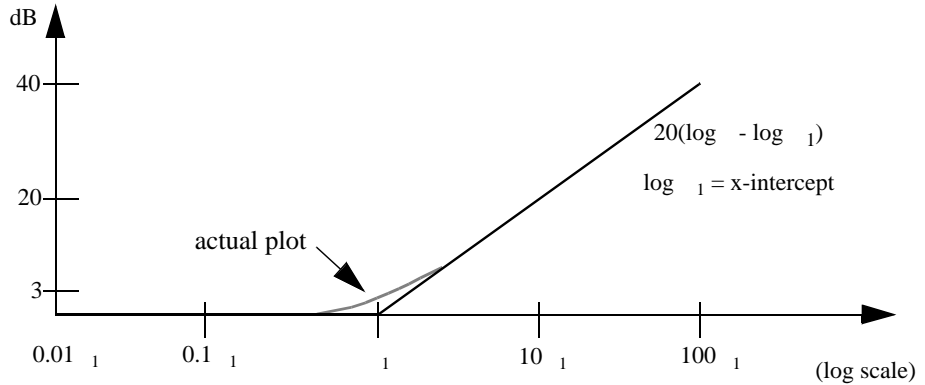
$$A_{dB}(\omega) = 20 \log |A(j\omega)|$$

If we convert the function $N(j\omega)$ into decibels, we can sketch it using the following guidelines:

- $\omega \ll \frac{1}{\tau_1}$, $N(j\omega)$ is approximately 1. So $20 \log |N(j\omega)| = 0$ dB.
- $\omega \gg \frac{1}{\tau_1}$, $N(j\omega)$ is approximately equal to $\frac{1}{j\omega\tau_1}$. So $20 \log |N(j\omega)| = 20 \log \left(\frac{1}{\omega\tau_1} \right)$
- $\omega = \frac{1}{\tau_1}$, $N(j\omega) = \frac{1}{1 + j}$. So $20 \log |N(j\omega)| = 20 \log \frac{1}{\sqrt{2}} = -3$ dB.
- We can easily graph this approximate sketch as shown in Fig. 10.

FIGURE 10.

Magnitude plot for $N(j\omega)$



We note that the Bode plot starts at 0 dB, and “corners” at ω_1 and increases at a rate of 20 dB/decade. We can “smooth” out the curve by noticing that at ω_1 , the gain is 3 dB.

We can extend this concept for a network function with many terms in the numerator and denominator such as the one mentioned in the beginning of this section. We simply apply the product rule and quotient rule for logarithms and add the plots.

EXAMPLE

Sketch the Bode plot for the magnitude of the following function.

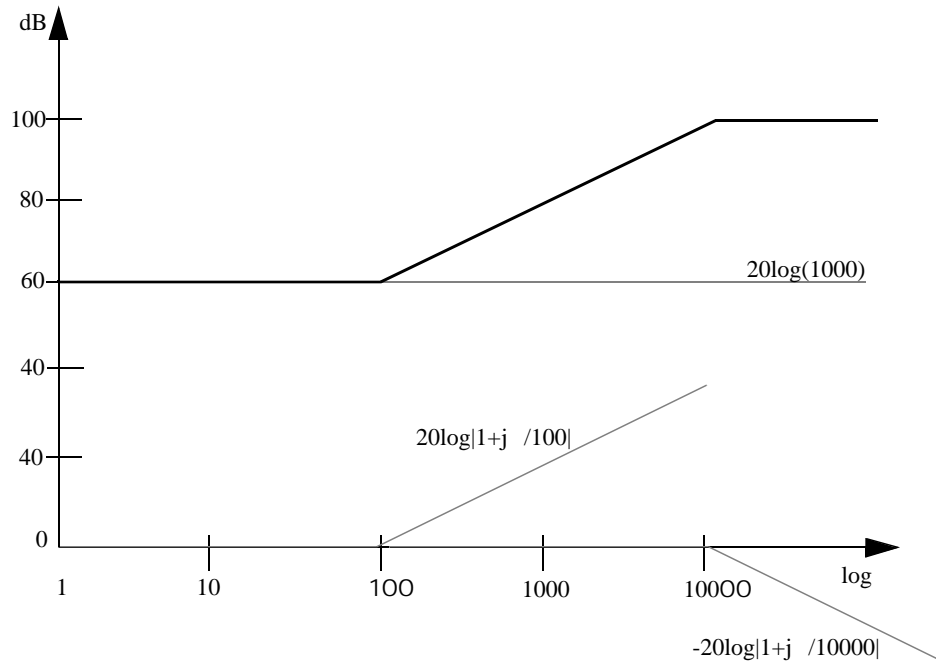
$$H(j\omega) = \frac{1000 \left(1 + j\frac{\omega}{100}\right)}{1 + j\frac{\omega}{10000}}$$

We first convert the function into the decibel scale using the product rule and quotient rule for logarithms.

$$H_{dB}(j\omega) = 20\log(1000) + 20\log \left(1 + j\frac{\omega}{100}\right) - 20\log \left(1 + j\frac{\omega}{10000}\right)$$

We can use the quick sketching rule above to sketch the following three terms. The sketch is shown below

FIGURE 11. Bode plot (magnitude) of example showing each term and the sum of terms (in bold)



We can extend this analysis for the phase of the phasor representing any network function. If we examine the function in the example:

$$A(j\omega) = \frac{1000 \left(1 + j\frac{\omega}{100}\right)}{1 + j\frac{\omega}{10000}}$$

Let's examine the three terms separately and find the angle of the phasors as a function of ω .

For the term 1000, there is no angle (0°) since it is a real number.

For the numerator term $1 + j\frac{\omega}{100}$, the angle is 0° for $\omega \ll 100$ and is 90° if $\omega \gg 100$.

The angle is 45° at $\omega = 100$.

For the denominator term $1 + j\frac{\omega}{10000}$, the angle is 0° for $\omega \ll 10000$ and is -90° if $\omega \gg 10000$. The angle is 45° at $\omega = 10000$.

We can now easily plot the phase of the function.

FIGURE 12.

Phase plot of the function in the previous example

