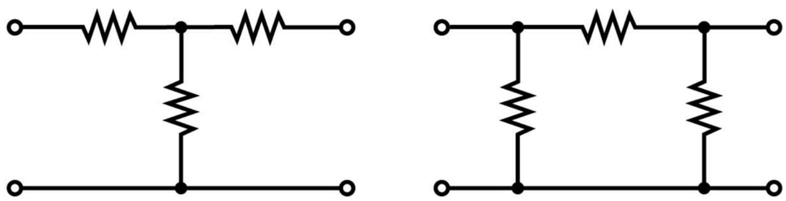
Attenuators

In the Electronics Track in Ph77, we often use attenuators to produce weak signals of known amplitude, as these are useful for examining and characterizing amplifier noise. A typical BNC attenuator has an input port, an output port and a dB attenuation value. And most have input and output impedances of 50 Ohms:

These devices are passive resistor networks, and the two most popular configurations are “T” and “Pi” circuits:



T attenuator   Π attenuator

Here are typical resistor values used to obtain 50Ω input and output impedances (from https://www.allaboutcircuits.com/textbook/semiconductors/chpt-1/attenuators/):

dB = attenuation in decibels

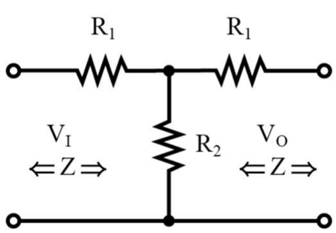
Z = source/load impedance (resistive)

$K > 1$

$$K = \frac{V_I}{V_O} = 10^{dB/20}$$

$$R_1 = Z\left(\frac{K-1}{K+1}\right)$$

$$R_2 = Z\left(\frac{2K}{K^2-1}\right)$$



T attenuator

Resistors for T-section			
Z = 50			
Attenuation			
dB	K=Vi/Vo	R1	R2
1.0	1.12	2.88	433.34
2.0	1.26	5.73	215.24
3.0	1.41	8.55	141.93
4.0	1.58	11.31	104.83
6.0	2.00	16.61	66.93
10.0	3.16	25.97	35.14
20.0	10.00	40.91	10.10

dB = attenuation in decibels

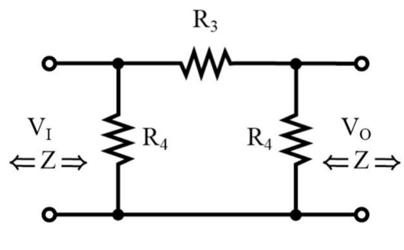
Z = source/load impedance (resistive)

$K > 1$

$$K = \frac{V_I}{V_O} = 10^{dB/20}$$

$$R_3 = Z\left(\frac{K^2-1}{2K}\right)$$

$$R_4 = Z\left(\frac{K+1}{K-1}\right)$$

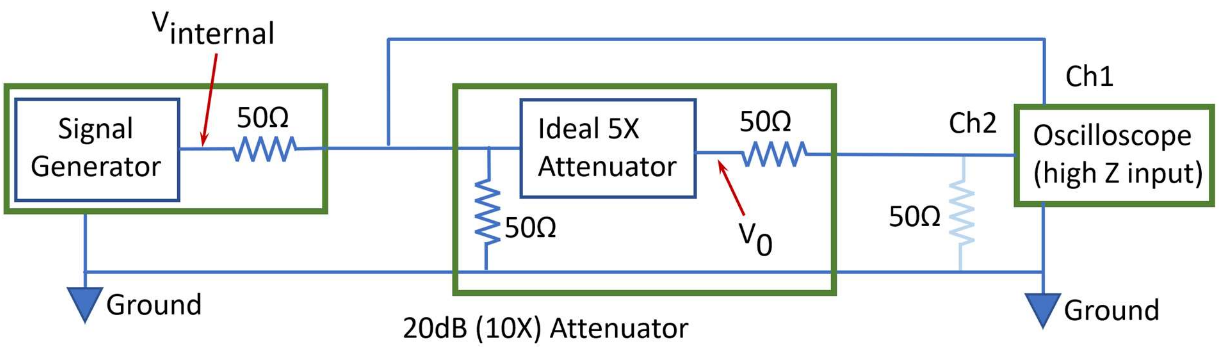


Π attenuator

Resistors for Π-section			
Z = 50.00			
Attenuation			
dB	K=Vi/Vo	R3	R4
1.0	1.12	5.77	869.55
2.0	1.26	11.61	436.21
3.0	1.41	17.61	292.40
4.0	1.58	23.85	220.97
6.0	2.00	37.35	150.48
10.0	3.16	71.15	96.25
20.0	10.00	247.50	61.11

A Laboratory Example

To see how an attenuator works in practice, consider the following circuit:



20dB (10X) Attenuator
with 50 Ω input & output impedances

Here we use a signal generator to produce a signal, which is sent to both Ch1 on the (high-Z) oscilloscope and also thru a 20dB (10x) attenuator to Ch2 on the oscilloscope. Note that:
1) The internal signal-generator box behaves ideally, as if it had zero output impedance.
2) The internal 5x attenuator box also behaves ideally, as if it had infinite input impedance and zero output impedance.
3) The oscilloscope box has an effectively infinite (1MΩ) input impedance.

If we want to use this attenuator at it was intended, then we would set the signal generator to a 50Ω output impedance (internally using the Utility/Ch1/50Ω setting), and we would similarly add a 50Ω resistor to the oscilloscope's Ch2 input (light blue above) so this channel has a 50Ω input impedance. With these settings, all the instruments have 50Ω input and output impedances.

In this case, Vinternal is actually double the set voltage (call it Vset, equal to whatever voltage you set the signal voltage to). Nothing else changes inside the signal generator, as the 50Ω output impedance is hardwired in. It just sets Vinternal to double whatever you decide for Vset. We then have:

Vinternal = 2*Vset
Ch1 = Vset
V0 = Ch1/5 = Vset/5
Ch2 = V0/2 = Vset/10

Note that both Ch1 and Ch2 have the expected voltages.

Say that again: if you set the signal generator to highZ output impedance, then Vinternal = Vset. But if you set the signal generator to 50Ω output impedance (using the Utility/Ch1/50Ω setting), then Vinternal = 2*Vset. This is all the Utility setting does – it makes a software change. The actual output impedance of the signal generator is always 50Ω. (Yes, it's confusing; you get used to it.)

If we set the signal generator to a high-Z output impedance (this is its default), and we leave off the 50Ω termination resistor at Ch2 on the oscilloscope. Then we have:

Vinternal = Vset
Ch1 = Vset/2
V0 = Ch1/5 = Vset/10
Ch2 = V0 = Vset/10

Note that Ch2 still gives Vset/10 in this case, as we would naively expect for a 10x attenuator. This only works, however, because two 2x errors cancel with these settings.

If you are thinking that all this is too complicated, well, the complications are all inevitable. The signal generator must have some output impedance because it cannot source infinite current. Likewise, the attenuator inevitably has some input and output impedances, because it uses a passive resistor network. Setting all these impedances to a single value – 50Ω – actually keeps the complications to a minimum.