Resistive Attenuator

https://www.electronics-tutorials.ws/attenuators/t-pad-attenuator.html

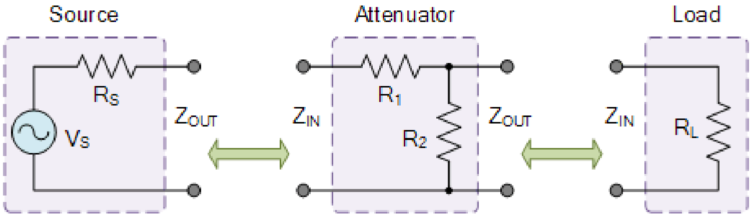
1. Passive Attenuators

An attenuator is a two port resistive network designed to weaken or "attenuate" (hence their name) the power being supplied by a source to a level that is suitable for the connected load.

A *passive attenuator* reduces the amount of power being delivered to the connected load by either a single fixed amount, a variable amount or in a series of known switchable steps. Attenuators are generally used in radio, communication and transmission line applications to weaken a stronger signal.

The **Passive Attenuator** is a purely passive resistive network (hence no supply) which is used in a wide variety of electronic equipment for extending the dynamic range of measuring equipment by adjusting signal levels, to provide impedance matching of oscillators or amplifiers to reduce the effects of improper input/output terminations, or to simply provide isolation between different circuit stages depending upon their application as shown.

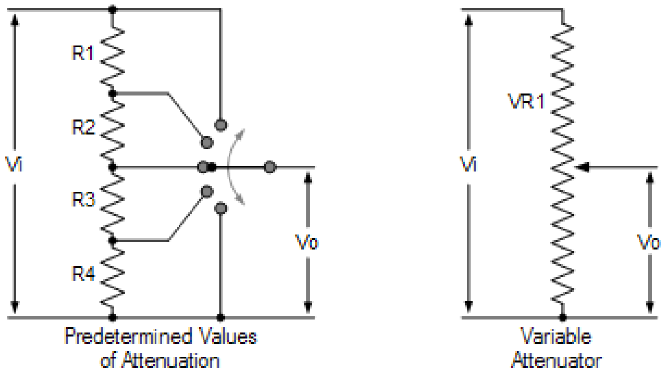
Attenuator Connection



Simple attenuator networks (also known as "pads") can be designed to produce a fixed degree of "attenuation" or to give a variable amount of attenuation in pre-determined steps. Standard fixed attenuator networks generally known as an "attenuator pad" are available in specific values from 0 dB to more than 100 dB. Variable and switched attenuators are basically adjustable resistor networks that show a calibrated increase in attenuation for each switched step, for example steps of -2dB or -6dB per switch position.

Then an **Attenuator** is a four terminal (two port) passive resistive network (active types are also available which use transistors and integrated circuits) designed to produce "distortionless" attenuation of the output electrical signal at all frequencies by an equal amount with no phase shift unlike a passive type RC filter network, and therefore to achieve this attenuators should be made up of pure non-inductive and not wirewound resistances, since reactive elements will give frequency discrimination.

Simple Passive Attenuator



Attenuators are the reverse of amplifiers in that they reduce gain with the resistive voltage divider circuit being a typical attenuator. The amount of attenuation in a given network is determined by the ratio of: Output/Input. For example, if the input voltage to a circuit is 1 volt (1V) and the output voltage is 1 milli-volt (1mV) then the amount of attenuation is 1mV/1V which is equal to 0.001 or a reduction of 1,000th.

However, using voltage, current or even power ratios to determine or express the amount of attenuation that a resistive attenuator network may have, called the **attenuation factor**, can be confusing, so for the passive attenuator its degree of attenuation is normally expressed using a logarithmic scale which is given in *decibels* (**dB**) making it easier to deal with such small numbers.

Degrees of Attenuation

An attenuators performance is expressed by the number of decibels the input signal has decreased per frequency decade (or octave). The *decibel*, abbreviated to "dB", is generally defined as the logarithm or "log" measure of the voltage, current or power ratio and represents one tenth 1/10th of a Bel (B). In other words it takes 10 decibels to make one Bel. Then by definition, the ratio between an input signal (Vin) and an output signal (Vout) is given in decibels as:

Decibel Attenuation

$$dB_v = 20\log_{10}\frac{Vout}{Vin}\quad(dB)$$

Note that the decibel (**dB**) is a logarithmic ratio and therefore has no units. So a value of -140dB represents an attenuation of 1:10,000,000 units or a ratio of 10 million to 1.

In passive attenuator circuits, it is often convenient to assign the input value as the 0 dB reference point. This means that no matter what is the actual value of the input signal or voltage, is used as a reference with which to compare the output values of attenuation and is therefore assigned a 0 dB value. This means that any value of output signal voltage below this reference point will be expressed as a negative dB value, (**-dB**).

So for example an attenuation of -6dB indicates that the value is 6 dB below the 0 dB input reference. Likewise if the ratio of output/input is less than one (unity), for example 0.707, then this corresponds to 20 log(0.707) = -3dB. If the ratio of output/input = 0.5, then this corresponds to 20 log(0.5) = -6 dB, and so on, with standard electrical tables of attenuation available to save on the calculation.

Passive Attenuators Example No1

A passive attenuator circuit has an insertion loss of -32dB and an output voltage of 50mV. What will be the value of the input voltage.

$$dB_v = 20\log_{10}\frac{Vout}{Vin} \quad (dB)$$

$$-32 = 20\log_{10}\frac{Vout}{Vin}$$

$$\therefore\ -1.6 = \log_{10}\frac{Vout}{Vin}$$

The antilog ($\log^{-1}$) of -1.6 is given as:

$$\frac{Vout}{Vin} = 0.025$$

$$\therefore\ Vin = \frac{Vout}{0.025} = \frac{50mV}{0.025} = 2\,volts$$

Then if the output voltage produced with 32 decibels of attenuation, an input voltage of 2.0 volts is required.

Attenuator Loss Table

Vout/Vin	1	0.7071	0.5	0.25	0.125	0.0625	0.03125	0.01563	0.00781
Log Value	20log (1)	20log (0.7071)	20log (0.5)	20log (0.25)	20log (0.125)	20log (0.0625)	20log (0.03125)	20log (0.01563)	20log (0.00781)
in dB’s	0	-3dB	-6dB	-12dB	-18dB	-24dB	-30dB	-36dB	-42dB

and so on, producing a table with as many decibel values as we require for our attenuator design.

This decrease in voltage, current or power expressed in decibels by the insertion of the attenuator into an electrical circuit is known as *insertion loss* and minimum loss attenuator designs match circuits of unequal impedances with a minimum loss in the matching network.

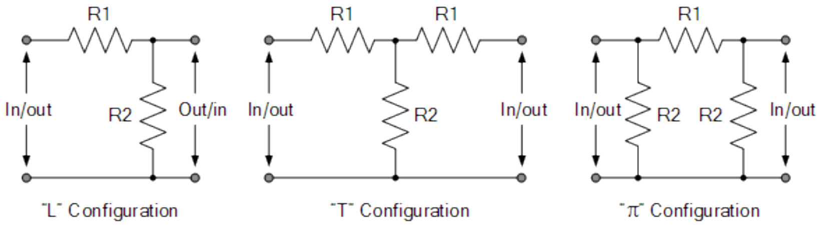
Now that we know what a **passive attenuator** is how it can be used to reduce or "attenuate" the power or voltage level of a signal, while introducing little or no distortion and insertion loss, by an amount expressed in decibels, we can begin to look at the different attenuator circuit designs available.

Passive Attenuator Designs

There are many ways in which resistors can be arranged in attenuator circuits with the **Potential Divider Circuit** being the simplest type of passive attenuator circuit. The potential or voltage divider circuit is generally known as an "L-pad" attenuator because its circuit diagram resembles that of an inverted "L".

But there are other common types of attenuator network as well such as the "T-pad" attenuator and the "Pi-pad" (π) attenuator depending upon how you connect together the resistive components. These three common attenuator types are shown below.

Attenuator Types



The above attenuator circuit designs can be arranged in either "balanced" or "unbalanced" form with the action of both types being identical. The balanced version of the "T-pad" attenuator is called the "H-pad" attenuator while the balanced version of the "π-pad" attenuator is called the "O-pad" attenuator. Bridged T-type attenuators are also available.

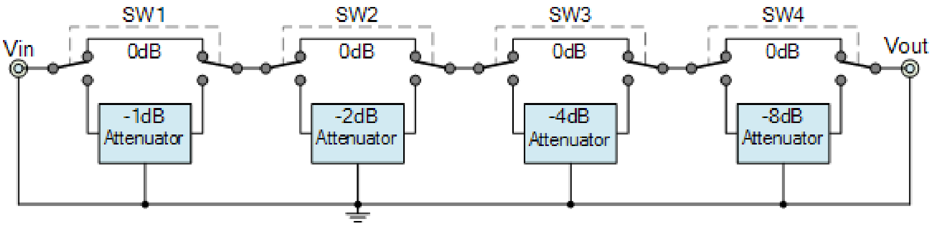
In an unbalanced attenuator, the resistive elements are connected to one side of the transmission line only while the other side is grounded to prevent leakage at higher frequencies. Generally the grounded side of the attenuator network has no resistive elements and is therefore called the "common line".

In a balanced attenuator configuration, the same number of resistive elements are connected equally to each side of the transmission line with the ground located at a center point created by the balanced parallel resistances. Generally, balanced and unbalanced attenuator networks can not be connected together as this results in half of the balanced network being shorted to ground through the unbalanced configuration.

Switched Attenuators

Instead of having just one attenuator to achieve the required degree of attenuation, individual **attenuator pads** can be connected or cascaded together to increase the amount of attenuation in given steps of attenuation. Multi-pole rotary switches, rocker switches or ganged push-button switches can also be used to connect or bypass individual fixed attenuator networks in any desired sequence from 1dB to 100dB or more, making it easy to design and construct switched attenuator networks, also known as a **step attenuator**. By switching in the appropriate attenuators, the attenuation can be increased or decreased in fixed steps as shown below.

Switched Attenuator



Here, there are four independent resistive attenuator networks cascaded together in a series ladder network with each attenuator having a value twice that of its predecessor, (1-2-4-8). Each attenuator network may be switched "in" or "out" of the signal path as required by the associated switch producing a step adjustment attenuator circuit that can be switched from 0dB to -15dB in 1dB steps.

Therefore, the total amount of attenuation provided by the circuit would be the sum of all four attenuators networks that are switched "IN". So for example an attenuation of -5dB would require switches SW1 and SW3 to be connected, and an attenuation of -12dB would require switches SW3 and SW4 to be connected, and so on.

Attenuator Summary

- An attenuator is a four terminal device that reduces the amplitude or power of a signal without distorting the signal waveform, an attenuator introduces a certain amount of loss.
- The attenuator network is inserted between a source and a load circuit to reduce the source signal's magnitude by a known amount suitable for the load.
- Attenuators can be fixed, fully variable or variable in known steps of attenuation, -0.5dB, -1dB, -10dB, etc.
- An attenuator can be symmetrical or asymmetrical in form and either balanced or unbalanced.
- Fixed attenuators also known as a "pad" are used to "match" unequal impedances.
- An attenuator is effectively the opposite of an amplifier. An amplifier provides gain while an attenuator provides loss, or gain less than 1 (unity).
- Attenuators are usually passive devices made to from simple voltage divider networks. The switching between different resistances produces adjustable stepped attenuators and continuously adjustable ones using potentiometers.

To simplify the design of the attenuator, a "K" (for constant) value can be used. This "K" value is the ratio of the voltage, current or power corresponding to a given value of dB attenuation and is given as:

$$\text{"K"} = \text{antilog}\left(\frac{dB}{20}\right) = 10^{\frac{dB}{20}} \text{ for Voltage or Current}$$

$$\text{"K"} = \text{antilog}\left(\frac{dB}{10}\right) = 10^{\frac{dB}{10}} \text{ for Power}$$

We can produce a set of constant values called “K” values for different amounts of attenuation as given in the following table.

Attenuator Loss Table

dB	0.5	1.0	2.0	3.0	4.0	5.0	6.0	10.0	20.0
“K” value	1.0593	1.1220	1.2589	1.4125	1.5849	1.7783	1.9953	3.1623	10.000

dB Loss	12.0	18.0	24.0	30.0	36.0	48.0	60.0	100
K value	3.9811	7.9433	15.849	31.623	63.096	251.19	1000	10^5

A voltage attenuation of 6dB will be $10^{(6/20)} = 1.9953$

Fixed value attenuators, called “attenuator pads” are used mainly in radio frequency (Rf) transmission lines to lower voltage, dissipate power, or to improve the impedance matching between various mismatched circuits.

Line-level attenuators in pre-amplifier or audio power amplifiers can be as simple as a 0.5 watt potentiometer, or voltage divider L-pad designed to reduce the amplitude of an audio signal before it reaches the speaker, reducing the volume of the output.

In measuring signals, high power attenuator pads are used to lower the amplitude of the signal a known amount to enable measurements, or to protect the measuring device from high signal levels that might otherwise damage it.

In the next tutorial about **Attenuators**, we will look at the most basic type of resistive attenuator network commonly called a “L-type” or “L-pad” attenuator which can be made using just two resistive components. The “L-pad” attenuator circuit can also be used as a voltage or potential divider circuit.

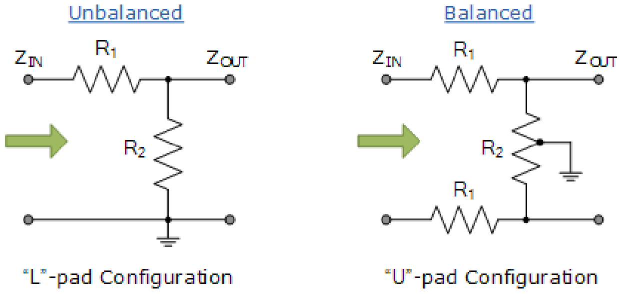
The **Passive Attenuator** is a purely resistive network that is used to weaken or “attenuate” the signal level of a transmission line while improving the impedance match, making *passive attenuators* the opposite of amplifiers.

Passive Attenuators are electrically connected between the source supply and the load with the amount of attenuation induced being of a fixed amount. The connected attenuator section can provide fixed attenuation, impedance matching or isolation between the source and the load. As a passive attenuator only has resistive elements within its design, the attenuated signal does not suffer from distortion or phase shift.

Passive attenuator designs can be either fixed, stepped or variable, with fixed attenuators being known as “pad attenuators” with commonly used attenuation networks ranging from 1dB to 20dB. The amount of attenuation presented by the attenuator pad is determined by the voltage ratio between the input source signal and the output load signal with this ratio being expressed in terms of decibels. The ratio between an input signal (Vin) and an output signal (Vout) is given in decibels as:

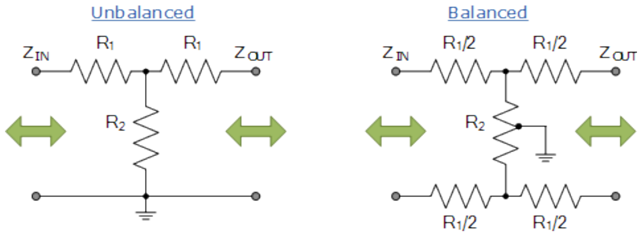
Passive Attenuators can be symmetrical or asymmetrical in form, and can be either a balanced or unbalanced type. Common passive attenuator circuits include “T-type”, “Pi-type” and “Bridged-T” type as shown below.

L-pad Attenuator Design



The **L-pad Attenuator** is the simplest attenuator design consisting of only two resistive elements and is more commonly known as a voltage divider circuit. The *L-pad attenuator* is an unbalanced asymmetrical attenuator circuit that can only impedance match in one direction. The balanced equivalent of the “L-pad Attenuator” is called a **U-pad attenuator**.

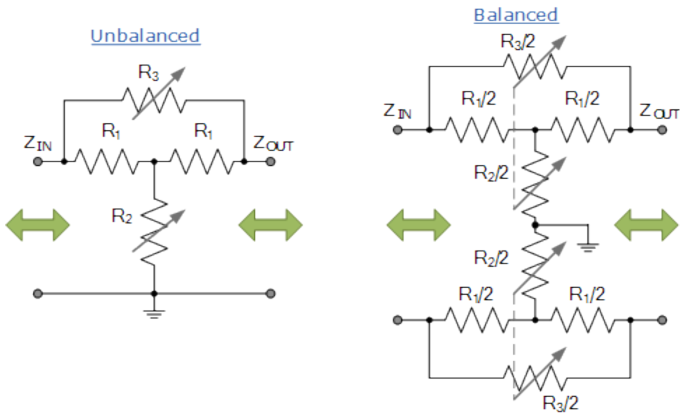
T-pad Attenuator Design



"T"-pad Configuration "H"-pad Configuration

The **T-pad Attenuator** is so called because its configuration resembles the letter "T". The "T-pad Attenuator" is a symmetrical attenuator that can be used either for attenuation between equal impedances or impedance matching between unequal impedances. When the attenuation is high, the parallel shunt arm impedance becomes small. The balanced equivalent of the *T-pad attenuator* is called an **H-pad attenuator**.

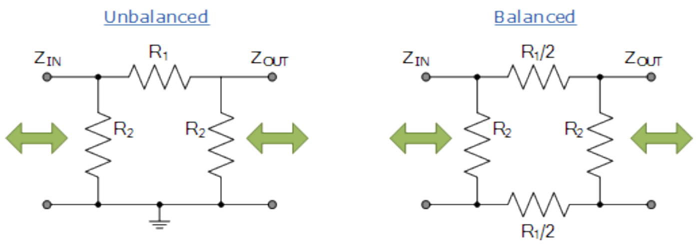
Bridged-T Attenuator Design



The **Bridged-T Attenuator** is variation on the standard T-pad design which has an additional resistive element forming a bridged network across the two series resistors and gains its name from the fact the input sources signal appears to "bridge" itself across the T-pad network without affecting the characteristic impedance of the circuit.

The "Bridged-T Attenuator" is a symmetrical purely resistive attenuator that can conveniently be used as a variable attenuator or a switchable attenuator. It is also possible to construct a balanced version of the *Bridged-T attenuator* circuit.

Pi-pad Attenuator Design



"Pi"-pad Configuration "O"-pad Configuration

The **Pi-pad Attenuator** is so called because its resistive configuration resembles that of the Greek letter "π" (pi). The "Pi-pad Attenuator" is the most common symmetrical passive attenuator that can be used between equal impedances or impedance matching between unequal impedances.

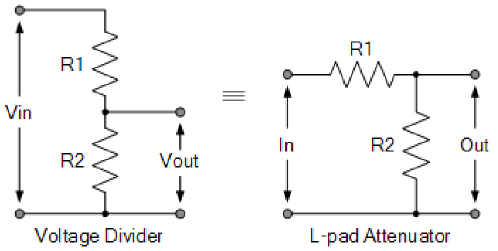
A single *Pi-pad attenuator* can achieve much higher levels of attenuation compared to the equivalent T-pad attenuator and when the attenuation is high, the series arm impedance in large. The balanced equivalent of the Pi-pad attenuator is called an **O-pad attenuator**.

2. L-pad Attenuators

The difference this time is that this type of attenuator is used in frequency dependent circuits to create loss (attenuation) in a transmission line or to match the impedances of unbalanced source and load networks.

The *L-pad attenuator* consists of two purely resistive elements in series with each other connected across a voltage source with the ratio between these two resistances forming a voltage divider network as shown below.

Basic L-pad Attenuator Circuit



We can see that the L-pad attenuator design is identical to the voltage divider circuit used to reduce its input voltage by some amount. The two resistors are connected in series across the whole of the input voltage, while the output signal or voltage is taken across just one resistance, with the two resistive elements forming the shape of an inverted letter "L" and hence their name, "L-pad Attenuators". For this types of circuit, attenuation is given as Vout/Vin.

Input resistor R1 is in series with the output, while resistor R2 is in parallel with the output and therefore the load. Then the output voltage provided by this "L" shaped arrangement is divided by a factor equal to the ratio of these two resistor values as shown.

$$V_{out} = V_{in} \times \frac{R2}{R1 + R2} \text{ volts}$$

As the L-pad attenuator is made of purely resistive components, there is no phase shift in the attenuator. The insertion of the attenuator between the source and the load must not alter the source voltage and therefore the resistance seen by the source must remain the same at all times. As the two resistive elements have constant values, if the impedance of the load is not infinite, the attenuation is altered and so to is its impedance. As a result the L-pad attenuator can only supply an impedance match in one direction only.

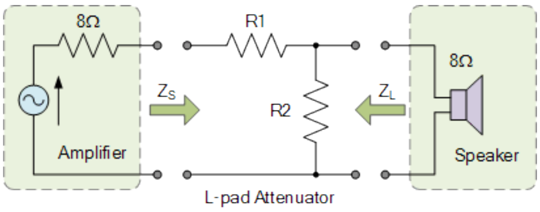
L-pad attenuators are commonly used in audio applications to reduce a larger or more powerful signal while matching the impedance between the source and load in provide maximum power transfer. However, if the impedance of the source is different to the impedance of the load, the L-pad attenuator can be made to match either impedance but not both.

This is because the arrangement of the resistive elements does not produce the same impedance looking into the network from both directions. In other words, the L-pad attenuator is an asymmetrical attenuator and therefore, if an attenuation network is required to match two unequal impedances in both directions, other types of attenuator such as the symmetrical “T-pad” or the “Pi-pad” attenuator should be used.

L-pad Attenuator with Equal Impedances

As mention previously, a passive attenuator is a resistive network designed to reduce the power or signal level of an audio or radio frequency signal without introducing any distortion to the signal. Sometimes the output from an audio amplifier maybe too high and attenuation is required to feed this signal into a loudspeaker. For example lets assume we want to reduce the power being delivered from an amplifier which has an output source impedance, (Z_S) of 8Ω feeding a loudspeaker load, (Z_L) of 8Ω by 6dB. The values of resistors R1 and R2 are as follows.

L-pad Attenuator Circuit



The equation for the L-pad attenuator circuit connected between two equal impedances ($Z_S = Z_L$) looking in the direction of the source impedance, Z_S will be.

$$R1 = Z_S\left(\frac{10^{\frac{dB}{20}} - 1}{10^{\frac{dB}{20}}}\right)$$

$$R2 = Z_S\left(\frac{1}{10^{\frac{dB}{20}} - 1}\right)$$

To simplify the design of the attenuator, a “K” value can be used in the attenuator equation above to simplify the maths a little. This “K” value is the ratio of the voltage, current or power corresponding to a given value of attenuation. The general equation for “K” is given as:

$$\text{"K"} = \text{antilog}\left(\frac{dB}{20}\right) = 10^{\frac{dB}{20}} \quad \text{for Voltage or Current}$$

$$\text{"K"} = \text{antilog}\left(\frac{dB}{10}\right) = 10^{\frac{dB}{10}} \quad \text{for Power}$$

So in our example the “K” value for a voltage attenuation of 6dB will be $10^{(6/20)} = 1.9953$. Substituting this value for attenuation into the two equations gives.

$$R1 = Z_S\left(\frac{K-1}{K}\right) = 8\left(\frac{1.9953-1}{1.9953}\right) = 4\Omega$$

$$R2 = Z_S\left(\frac{1}{K-1}\right) = 8\left(\frac{1}{1.9953-1}\right) = 8\Omega$$

Then between two equal impedances looking in the direction of the source impedance Z_S, the value of the series resistor, R1 is 4Ω and the value of the parallel resistor, R2 is 8Ω.

The problem with this type of L-pad attenuator configuration is that the impedance match is in the direction of the series resistor R1, while the impedance "mismatch" is towards the parallel resistor R2. The problem with this is that as the level of attenuation is increased this mismatch becomes increasingly larger and at high values of attenuation the value of the parallel resistor will become fractions of an Ohm.

For example, the values of R1 and R2 at an attenuation of -32dB would be 7.8Ω and 0.2Ω, that's 200mΩ effectively shorting out the loudspeaker which could have a serious effect on the amplifiers output circuitry. One way to increase attenuation without overloading the source is to impedance match the circuit in the direction of the load impedance, Z_L. However, as we are now looking into the L-pad attenuator circuit from the parallel resistor side, the equations are slightly different. Then between equal impedances and with the impedance match looking from the load, the values or resistors R1 and R2 are calculated as follows.

"Looking" from the Load

$$R1 = Z_L(K-1) = 8(1.9953-1) = 8\Omega$$

$$R2 = Z_L\left(\frac{K}{K-1}\right) = 8\left(\frac{1.9953}{1.9953-1}\right) = 16\Omega$$

If we know increase attenuation to -32dB, the value of the resistors will become, R1 = 310Ω and R2 = 8.2Ω respectively, and these values are safe enough for the source circuit to which it is connected.

L-pad Attenuator with Unequal Impedances

Thus far we have looked at connecting the **L-pad Attenuator** between to equal impedances in order to provide attenuation of a signal. But we can also use the "L-pad attenuator" to match the impedances of two unequal circuits. This impedance match may be in the direction of the larger or the smaller impedance but not both. The configuration of the attenuator will be the same as before, but the equations used in matching the two unequal impedances are different as shown.

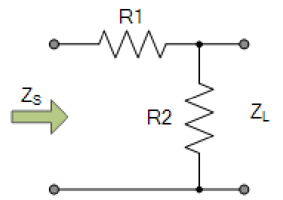
Between two unequal impedances, the impedance matching is towards the smaller of the two impedances from the source.

Impedance Match towards the small Impedance

$$R1 = \frac{Z_S}{S}\left(\frac{KS-1}{K}\right)$$

$$R2 = \frac{Z_S}{S}\left(\frac{1}{K-S}\right)$$

$$\text{where: } S = \sqrt{\frac{Z_S}{Z_L}}$$



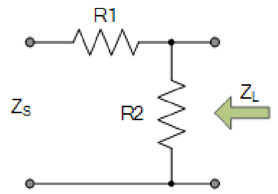
Between two unequal impedances, the impedance matching is towards the larger of the two impedances from the load.

Impedance Match towards the larger Impedance

$$R1 = \frac{Z_S}{S}(K-S)$$

$$R2 = \frac{Z_S}{S}\left(\frac{K}{KS-1}\right)$$

$$\text{where: } S = \sqrt{\frac{Z_S}{Z_L}}$$



<u>L-pad Attenuator Example No2</u>

A signal transmission line which has a source impedance of 75Ω is to be connected to a signal strength meter of impedance 50Ω which has a maximum display of -12dB. Calculate the values of resistors required in an L-pad attenuator circuit to operate the meter at maximum power.

With the impedance match towards the smaller 50Ω value, resistors R1 and R2 are calculated as follows.

$$S = \sqrt{\frac{Z_S}{Z_L}} = \sqrt{\frac{75}{50}} = 1.2247 \quad \text{and} \quad K = 10^{\left(\frac{12}{20}\right)} = 3.9811$$

$$R1 = \frac{Z_S}{S}\left(\frac{KS-1}{K}\right) = \frac{75}{1.2247}\left(\frac{(3.9811 \times 1.2247) - 1}{3.9811}\right) = 59.6\Omega$$

$$R2 = \frac{Z_S}{S}\left(\frac{1}{K-S}\right) = \frac{75}{1.2247}\left(\frac{1}{3.9811}\right) = 22.2\Omega$$

Then resistor R1 is equal to 59.6Ω and R2 is equal to 22.2Ω, or the nearest preferred values.

The **L-pad attenuator** can be used to perfectly match one impedance to another providing a fixed amount of attenuation, but the resulting circuit is “lossy”. However, if a fixed amount of attenuation is of no importance and only the minimum insertion loss is required between the source and the load, the **L-pad attenuator** can be used to match two impedances of unequal values using the following equations to calculate resistors, R1 and R2.

Minimum Insertion Loss

$$R1 = Z_S \sqrt{1 - \frac{Z_L}{Z_S}} \quad \text{and} \quad R2 = \frac{Z_L}{\sqrt{1 - \frac{Z_L}{Z_S}}}$$

Where: resistor R1 is on the side of the larger impedance and resistor R2 is on the side of the smaller impedance and in our example above that would be 75Ω and 50Ω respectively. The minimum insertion loss in decibels of an L-pad attenuator connected between a source and a load is therefore given as:

Minimum Attenuation in dB

$$dB_{min} = 20\log\left(\sqrt{\frac{Z_S}{Z_L}} + \sqrt{\frac{Z_S}{Z_L} - 1}\right)$$

For L-pad attenuators that have reactive components such as inductors and capacitors within their design, EEWeb have a free online **L-pad Attenuator Tool** for calculating component values at the require frequency.

L-pad Attenuator Summary

In this tutorial we have seen that a **L-pad attenuator** circuit is a passive and purely resistive network which can be used to reduce the strength of a signal while matching the impedances of the source and load. L-pad attenuators are commonly used in audio electronics to reduce the audio signal produced by an amplifier delivered to a speaker or headphones.

However, one of the main disadvantages of the “L-pad attenuator” is that because the L-pad attenuator is a constant impedance device, at low power settings the attenuator converts all of the energy not sent to the load into heat which can be considerable. Also, at much higher frequencies or where an attenuator circuit is required perfectly match the input and output, other improved attenuator designs are used.

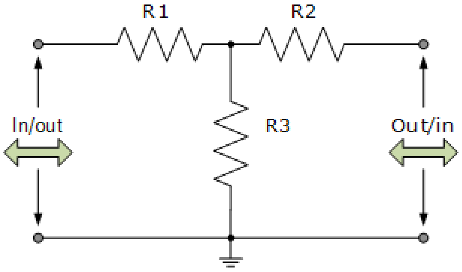
In the next tutorial about **Passive Attenuators**, we will look at another type of attenuator design called the **T-pad Attenuator** that uses three resistive components to produced a balanced attenuator.

3. T-pad Attenuators

Although not as common, this “T” (tee) configuration can also be thought of as a wye “Y” attenuator configuration as well. Unlike the previous L-pad Attenuator, which has a different resistive value looking into the attenuator from either end making it an asymmetrical, the T-pad attenuator is symmetrical in its design.

The formation of the resistive elements into a letter “T” shape means that the T-pad attenuator has the same value of resistance looking from either end. This formation then makes the “T-pad attenuator” a perfectly symmetrical attenuator enabling their input and output terminals to be transposed as shown.

Basic T-pad Attenuator Circuit



We can see that the T-pad attenuator is symmetrical in its design looking from either end and this type of attenuator design can be used to impedance match either equal or unequal transmission lines. Generally, resistors R1 and R2 are of the same value but when designed to operate between circuits of unequal impedance these two resistor can be of different values. In this instance the T-pad attenuator is often referred to as a “taper pad attenuator”.

But before we look at **T-pad Attenuators** in more detail we first need to understand the use of the “K factor” used in calculating attenuator impedances and which can make the reduction of the maths and our lives a little easier.

T-pad Attenuator with Equal Impedances

We have said previously, that the T-pad attenuator is a symmetrical attenuator design whose input and output terminals can be transposed with each other. This makes the T-pad attenuator ideal for insertion between two equal impedances ($Z_S = Z_L$) to reduce signal levels.

In this case the three resistive elements are chosen to ensure that the input impedance and output impedance match the load impedance which forms part of the attenuator network. As the T-pad’s input and output impedances are designed to perfectly match the load, this value is called the “characteristic impedance” of the symmetrical T-pad network.

Then the equations given to calculated the resistor values of a T-pad attenuator circuit used for impedance matching at any desired attenuation are given as:

T-pad Attenuator Equations

$$R1 = R2 = Z\left(\frac{K-1}{K+1}\right)$$

$$R3 = 2Z\left(\frac{K}{K^2-1}\right)$$

where: K is the impedance factor from the table above, and Z is the source/load impedance.

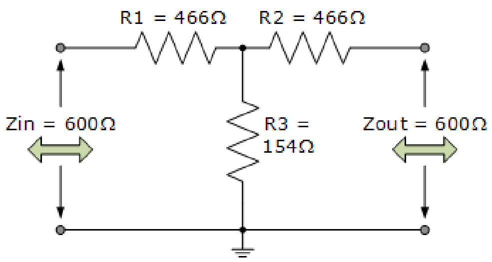
T-pad Attenuator Example No1

A T-pad attenuator is required to reduce the level of an audio signal by 18dB while matching the impedance of the 600Ω network. Calculate the values of the three resistors required.

$$Z = 600\Omega \quad \text{and} \quad K = 18dB = 7.9433$$

$$R1 = R2 = Z\left(\frac{K-1}{K+1}\right) = 600\left(\frac{7.9433-1}{7.9433+1}\right) = 466\Omega$$

$$R3 = 2Z\left(\frac{K}{K^2-1}\right) = 2\times600\left(\frac{7.9433}{(7.9433)^2-1}\right) = 154\Omega$$



Then resistors R1 and R2 are equal to 466Ω and resistor R3 is equal to 154Ω, or the nearest preferred values. Again as before, we can produce standard tables for the values of the series and parallel impedances required to construct a 50Ω, 75Ω or 600Ω symmetrical T-pad attenuator circuit as these values will always be the same regardless of application. The calculated values of resistors, R1, R2 and R3 are given below.

dB Loss	K factor	50Ω Impedance		75Ω Impedance		600Ω Impedance	
		R1, R2	R3	R1, R2	R3	R1, R2	R3
1.0	1.1220	2.9Ω	433.3Ω	4.3Ω	650.0Ω	34.5Ω	5K2Ω
2.0	1.2589	5.7Ω	215.2Ω	8.6Ω	322.9Ω	68.8Ω	2K58Ω

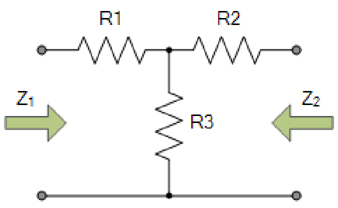
3.0	1.4125	8.5Ω	141.9Ω	12.8Ω	212.9Ω	102.6Ω	1K7Ω
6.0	1.9953	16.6Ω	66.9Ω	24.9Ω	100.4Ω	199.4Ω	803.2Ω
10.0	3.1623	26.0Ω	35.1Ω	39.0Ω	52.7Ω	311.7Ω	421.6Ω
18.0	7.9433	38.8Ω	12.8Ω	58.2Ω	19.2Ω	465.8Ω	153.5Ω
24.0	15.8489	44.1Ω	6.3Ω	66.Ω	9.5Ω	528.8Ω	76.0Ω
32.0	39.8107	47.5Ω	2.5Ω	71.3Ω	3.8Ω	570.6Ω	30.2Ω

Note, as the amount of attenuation required by the circuit increases the series impedance values for R1 and R2 also increase while the parallel shunt impedance value of R3 decreases. This is characteristic of a symmetrical T-pad attenuator circuit used between equal impedances.

T-pad Attenuator with Unequal Impedances

As well as using the T-pad attenuator to reduce signal levels in a circuit with equal impedances, we can also use it for impedance matching between unequal impedances ($Z_S \neq Z_L$). When used for impedance matching, the T-pad attenuator is called a **Taper Pad Attenuator**. However, to do so we need to modify the previous equations a little to take into account the unequal loading of the source and load impedances on the attenuator circuit. The new equations become.

Taper Pad Attenuator Equations for Unequal Impedances



$$R1 = Z_1\left(\frac{K^2+1}{K^2-1}\right) - R3$$

$$R2 = Z_2\left(\frac{K^2+1}{K^2-1}\right) - R3$$

$$R3 = 2\sqrt{Z_1 Z_2}\left(\frac{K}{K^2-1}\right)$$

where: K is the impedance factor from the table above, and Z_1 is the larger of the source/load impedances and Z_2 is the smaller of the source/load impedances.

T-pad Attenuator Example No2

A taper pad attenuator connected to a load impedance of 50Ω is required to reduce the level of an audio signal by 18dB from an impedance source of 75Ω. Calculate the values of the three resistors required. Then: Z_1 = 75Ω (the largest impedance), Z_2 = 50Ω (the smallest impedance) and K = 18dB = 7.9433 from the table above.

$$R3 = 2\sqrt{Z_1 Z_2}\left(\frac{K}{K^2 - 1}\right) = 2\sqrt{75 \times 50}\left(\frac{7.9433}{(7.9433)^2 - 1}\right) = 15.7\Omega$$

$$R1 = Z_1\left(\frac{K^2 + 1}{K^2 - 1}\right) - R3 = 75\left(\frac{(7.9433)^2 + 1}{(7.9433)^2 - 1}\right) - 15.7 = 62\Omega$$

$$R2 = Z_2\left(\frac{K^2 + 1}{K^2 - 1}\right) - R3 = 50\left(\frac{(7.9433)^2 + 1}{(7.9433)^2 - 1}\right) - 15.7 = 36\Omega$$

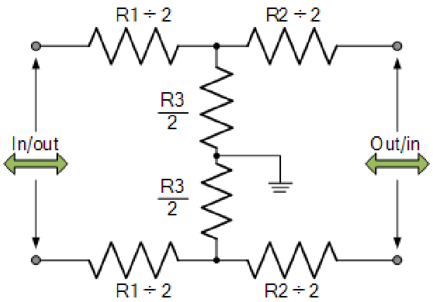
So resistor R1 is equal to 15.67Ω, resistor R2 is equal to 62Ω and resistor R3 is equal to 36Ω, or the nearest preferred values.

For T-pad attenuators that have reactive components such as inductors and capacitors within their design, EEWeb have a free online **T-pad Attenuator Tool** for calculating component values at the require frequency.

Balanced-T Attenuator

The *balanced T-pad attenuator* or **Balanced-T Attenuator** for short, uses two T-pad attenuator circuits connected together to form a balanced mirror image network as shown below.

Balanced-T Attenuator Circuit



The balanced-T attenuator is also referred to an **H-pad attenuator** because the layout of its resistive elements form the shape of a letter "H" and hence their name, "H-pad attenuators". The resistive values of the balanced-T circuit are firstly calculated as an unbalanced T-pad configuration the same as before, but this time the values of the series resistive in each leg are halved (divided by two) to provide a mirror image either side of ground. The total calculated resistive value of the center parallel resistor remains at the same value but is divided into two with the center connected to ground producing a balanced circuit.

Using the calculated values above for the unbalanced T-pad attenuator gives, series resistor R1 = R2 = 466Ω ÷ 2 = 233Ω for all four series resistors and the parallel shunt resistor, R3 = 154Ω the same as before and these values can be calculated using the following modified equations for a balanced-T attenuator.

Balanced-T Attenuator Equations

$$R1 = R2 = \frac{Z(K-1)}{2(K+1)}$$

$$R3 = 2Z\left(\frac{K}{K^2 - 1}\right)$$

T-pad Attenuator Summary

The **T-pad attenuator** is a symmetrical attenuator network that can be used in a transmission line circuit that has either equal or unequal impedances. As the T-pad attenuator is symmetrical in its design it can be connected in either direction making it a bi-directional circuit.

One of the main characteristics of the T attenuator, is that the shunt arm (parallel) impedance becomes smaller as the attenuation increases. T-pad attenuators that are used as impedance matching circuits are usually called “taper pad attenuators”.

We have seen that T-pad attenuators can be either unbalanced or balanced resistive networks. Fixed value unbalanced T-pad attenuators are the most common and are generally used in radio frequency and TV coaxial cable transmission lines were one side of the line is earthed.

Balanced-T attenuators are also called **H-pad Attenuators** due to their design and construction. H-pad attenuators are mainly used on data transmission lines which use balanced or twisted pair cabling.

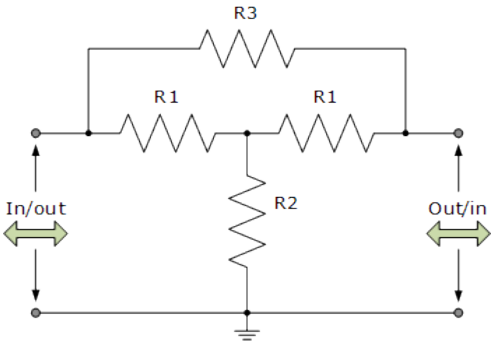
In the next tutorial about **Attenuators**, we will look at another type of T-pad attenuator design called the **Bridged-T Attenuator** that uses an additional resistive component in the series line.

4. Bridged-T Attenuators

As its name implies, the *bridged-T attenuator* has an additional resistive element forming a bridged network across the two series resistors of the standard T-pad.

This additional resistive element enables the circuit to reduce the level of a signal by the required attenuation without changing the characteristic impedance of the circuit as the signal appears to "bridge" across the T-pad network. Also the two series resistances of the original T-pad are always equal to the input source and output load impedances. The circuit for a "bridged-T attenuator", (T) is given below.

Bridged-T Attenuator Circuit



Resistor, R3 forms the bridge network across a standard T-pad attenuator. The two series resistors, R1 are chosen to equal the source/load line impedance. One major advantage of the bridged-T attenuator over its T-pad cousin, is that the bridged-T pad has a tendency to match itself to the transmissions lines characteristic impedance.

However, one disadvantage of the bridged-T attenuator circuit is that the attenuator requires that its input or source impedance, (Z_S) equals its output or load impedance, (Z_L) and therefore cannot be used for impedance matching.

The design of a bridged-T attenuator is as simple as for the standard T-pad attenuator. The two series resistors are equal in value to the lines characteristic impedance and therefore require no calculation. Then the equations given to calculated the parallel shunt resistor and the additional bridging resistor of a bridged-T attenuator circuit used for impedance matching at any desired attenuation are given as:

Bridged-T Attenuator Equations

$$R1 = Z_S = Z_L$$

$$R2 = \frac{R1}{K-1}$$

$$R3 = R1(K-1)$$

where: K is the impedance factor, and Z is the source/load impedance.

Bridged-T Attenuator Example No1

A bridged-T attenuator is required to reduce the level of an 8Ω audio signal line by 4dB. Calculate the values of the resistors required.

$$K = 4dB = 10^{(4/20)} = 1.5849$$

$$R1 = Z_S = Z_L = 8\Omega$$

$$R2 = \frac{R1}{K-1} = \frac{8}{1.5849-1} = 13.7\Omega$$

$$R3 = R1(K-1) = 8(1.5849-1) = 4.7\Omega$$

Then resistors R1 are equal to the line impedance of 8Ω, resistor R2 is equal to 13.7Ω and the bridging resistor R3 is equal to 4.7Ω, or the nearest preferred values.

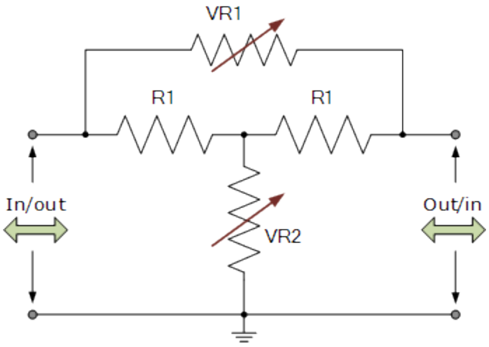
As with the standard T-pad attenuator, as the amount of attenuation required by the circuit increases, the series bridge impedance value of resistor R3 also increase while the parallel shunt impedance value of resistor R2 decreases. This is characteristic of a symmetrical bridged-T attenuator circuit used between equal impedances.

Variable Bridged-T Attenuator

We have seen that a symmetrical bridged-T attenuator can be designed to attenuate a signal by a fixed amount while matching the characteristic impedance of the signal line. Hopefully by now we know that the bridged-T attenuator circuit consists of four resistive elements, two which match the characteristic impedance of the signal line and two which we calculate for a given amount of attenuation.

But by replacing two of the attenuators resistive elements with either a potentiometer or a resistive switch, we can convert a fixed attenuator pad into a variable attenuator over a predetermined range of attenuation as shown.

Variable Bridged-T Attenuator



So for example above, if we wanted a variable bridged-T attenuator to operate on an 8Ω audio line with attenuation adjustable from -2dB to -20dB, we would need resistive values of:

Resistor values at -2dB

$$R1 = Z = 8\Omega, \quad K = 2dB = 1.2589$$

$$VR1 = \frac{R1}{K-1} = \frac{8}{1.2589-1} = 30.9\Omega$$

$$VR2 = R1(K-1) = 8(1.2589-1) = 2.1\Omega$$

Resistor values at -20dB

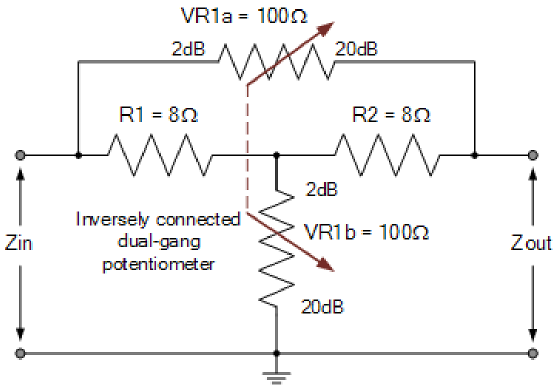
$$R1 = Z = 8\Omega, \quad K = 20dB = 10.00$$

$$VR1 = \frac{R1}{K-1} = \frac{8}{10.00-1} = 0.9\Omega$$

$$VR2 = R1(K-1) = 8(10.00-1) = 72.0\Omega$$

Then we can see that the maximum resistance required for an attenuation of 2dB is 31Ω and at 20dB is 72Ω. So we can replace the fixed value resistors with two potentiometers of 100Ω each. But instead of adjusting two potentiometers one at a time to find the required amount of attenuation, both potentiometers could be replaced by a single 100Ω dual-gang potentiometer which is electrically connected so that each resistance varies inversely in value with respect to the other as the potentiometer is adjusted from 2dB to 20dB as shown.

Fully Adjustable Bridged-T Attenuator



By careful calibration of the potentiometer, we can easily produce in our simple example, a fully adjustable *bridged-T attenuator* in the range of 2dB to 20dB. By changing the values of the potentiometers to suit the characteristic impedance of the signal line, in theory any amount of variable attenuation is possible by using the full range of resistance from zero to infinity for both VR1a and VR1b, but in reality 30dB is about the limit for a single variable bridged-T attenuator as the resistive values become to small. Noise distortion is also a problem.

Taking this idea one step further, we could also produce a steppable bridged-T attenuator circuit by replacing the potentiometers with fixed value resistances and a ganged rotary switch, rocker switches or push-button switches and by switching in the appropriate resistance, the attenuation can be increased or decreased in steps. For example, using our 8Ω transmission line impedance example above.

We can calculate the individual bridge resistances and parallel shunt resistances for an attenuation of between 2dB and 20dB. But as before, to save on the maths we can produce tables for the values of the series bridge and parallel shunt impedances required to construct either an 8Ω, 50Ω or 75Ω switchable bridged-T attenuator circuit. The calculated values of the bridging resistor R2 and parallel shunt resistor R3 are given below.

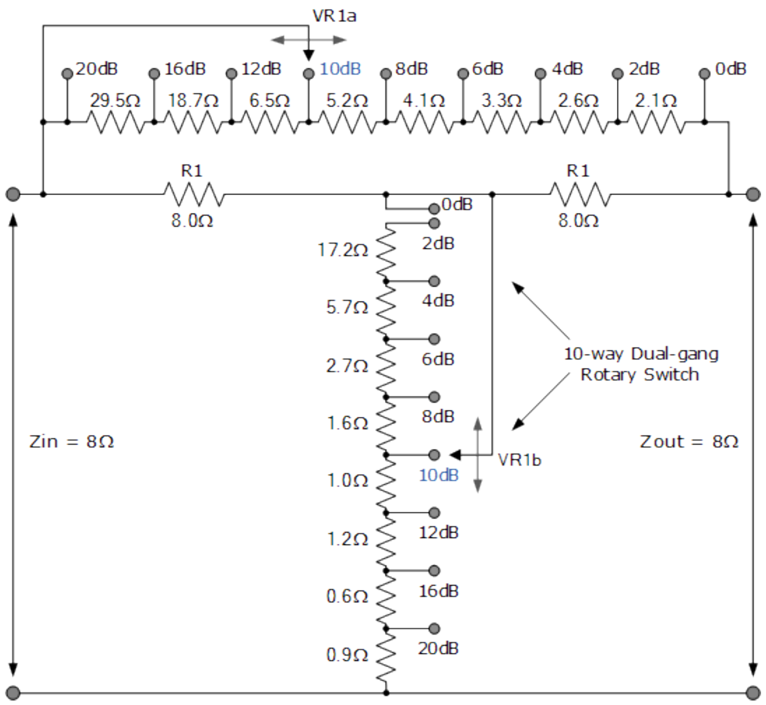
Bridged-T Attenuator Resistor Values

dB Loss	K factor	8Ω Line Impedance		50Ω Line Impedance		75Ω Line Impedance	
		R2	R3	R2	R3	R2	R3
2.0	1.2589	30.9Ω	2.1Ω	193.1Ω	12.9Ω	289.7Ω	19.4Ω
4.0	1.5849	13.7Ω	4.7Ω	85.5Ω	29.2Ω	128.2Ω	43.9Ω
6.0	1.9953	8.0Ω	8.0Ω	50.2Ω	49.8Ω	75.4Ω	74.6Ω
8.0	2.5119	5.3Ω	12.1Ω	33.1Ω	75.6Ω	49.6Ω	113.4Ω
10.0	3.1623	3.7Ω	17.3Ω	23.1Ω	108.1Ω	34.7Ω	162.2Ω
12.0	3.9811	2.7Ω	23.8Ω	16.8Ω	149.1Ω	25.2Ω	223.6Ω
16.0	6.3096	1.5Ω	42.5Ω	9.4Ω	265.5Ω	14.1Ω	398.2Ω
20.0	10.00	0.9Ω	72.0Ω	5.6Ω	450.0Ω	8.3Ω	675.0Ω

Note that the two fixed series resistors R1 of the circuit will always be equal to the transmission lines characteristic impedance.

Then using our 8Ω transmission line as our example, we can construct a switchable **bridged-T attenuator** circuit as follows using the resistive values calculated in the table.

Switchable Bridged-T Attenuator



So for the bridging resistance set by VR1a at the -10dB point, the total resistance is equal to the sum of the individual resistances as is given as:

5.2 + 4.1 + 3.3 + 2.6 + 2.1 = 17.3Ω

Likewise, for the parallel shunt resistance set by VR1b, the total resistance at the -10dB point will be equal to:

1.0 + 1.2 + 0.6 + 0.9 = 3.7Ω

Note that both of these resistive values of VR1a = 17.3Ω and VR1b = 3.7Ω correspond to the -10dB attenuation we calculated in the above table.

We have seen that the **Bridged-T attenuator** is a purely resistive fixed type symmetrical attenuator which can be used to introduce a given amount of attenuator loss when inserted between equal impedances with the bridged-T design being an improved version of the more common T-pad attenuator.

In some ways we can also think of the bridged-T attenuator as a modified Pi-pad attenuator we will look at in the next tutorial. One of the main disadvantage of this type of circuit is that due to the bridging resistor, this type of attenuator circuit can not be used for the matching of unequal impedances.

The bridged-T attenuator design makes it easy to calculate the resistances required for the network because the values of the two series resistances are always equal to the characteristic impedance of the transmission line making the attenuator symmetrical. Once the desired amount of attenuation is determined the maths involved in calculating the remaining resistance values is fairly simple.

Also this type of attenuator design allows for the bridged-T pad to be adjustable by changing only two of the resistive elements for potentiometers or switched resistors were as the standard T-pad attenuator would need three.

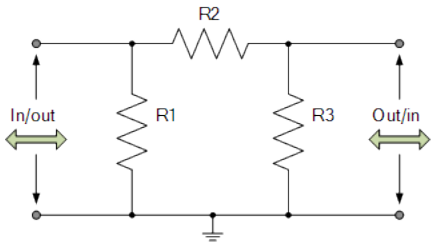
In the next tutorial about **Attenuators**, we will look at a different types of attenuator design called the **Pi-pad Attenuator** which uses only three resistive components to form a passive attenuator circuit, one in the series line and two in the parallel shunt line.

5. Pi-pad Attenuators

The *Pi-pad attenuator* is so called because its basic layout and design resembles that of the Greek letter pi (π), meaning that it has one series resistor and two parallel shunt resistors to ground at the input and the output.

The Pi-pad attenuator is another fully symmetrical purely resistive network that can be used as a fixed attenuator between equal impedances or for impedance matching between unequal impedances. The circuit configuration of the Pi-pad attenuator is given below.

Basic Pi-pad Attenuator Circuit



We can see that the standard pi-pad attenuator is symmetrical looking at the attenuator from either end and this type of attenuator design can be used to impedance match either equal or unequal transmission lines. Generally, resistors R1 and R3 are of the same value but when designed to operate between circuits of unequal impedance these two resistor can be of different values.

Pi-pad Attenuator with Equal Impedances

We have said previously, that the pi pad attenuator is a symmetrical attenuator design consisting solely of passive resistor elements making it linear in its design allowing for its input and output terminals to be transposed with each other. This makes the pi pad attenuator ideal for insertion between two equal impedances ($Z_S = Z_L$) to reduce signal levels.

In this case the three resistive elements are chosen to ensure that the input impedance and output impedance match the load impedance which forms part of the attenuator network. As the Pi-pad's input and output impedances are designed to perfectly match the load, this value is called the "characteristic impedance" of the symmetrical Pi-pad network.

Then the equations given to calculated the resistor values of a Pi-pad attenuator circuit used for impedance matching at any desired attenuation are given as:

Pi-pad Attenuator Equations

$$Z_S = Z_L = Z$$

$$R1 = R3 = Z\left(\frac{K+1}{K-1}\right)$$

$$R2 = Z\left(\frac{K^2-1}{2K}\right)$$

where: K is the impedance factor and Z is the source/load impedance.

Pi-pad Attenuator Example No1

A Pi-pad attenuator circuit is required to reduce the level of an audio signal by 10dB while matching the impedance of a 75Ω network. Calculate the values of the three resistors required.

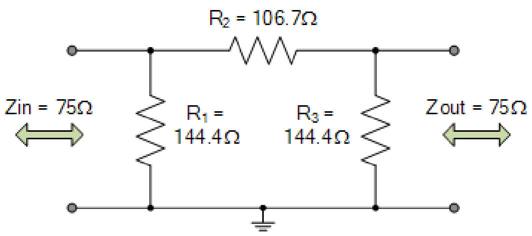
Using our simple table of "K factors", we can see that the "K" factor value for calculating attenuation loss of -10dB is given as **3.1623**.

dB	0.5	1.0	2.0	3.0	4.0	5.0	6.0	10.0	20.0
"K" value	1.0593	1.1220	1.2589	1.4125	1.5849	1.7783	1.9953	3.1623	10.000

$$Z = 75\Omega \quad \text{and} \quad K = 10\text{dB} = 10^{(10/20)} = 3.1623$$

$$R1 = R3 = Z\left(\frac{K+1}{K-1}\right) = 75\left(\frac{3.1623+1}{3.1623-1}\right) = 144.4\Omega$$

$$R2 = Z\left(\frac{K^2-1}{2K}\right) = 75\left(\frac{3.1623^2-1}{2\times 3.1623}\right) = 106.7\Omega$$



Then resistors R1 and R3 are equal to 144Ω and resistor R2 is equal to 107Ω, or the nearest preferred values. Also note that the same pi-pad attenuator design will have different resistor values for one used on a 75Ω network than for one that is being matched to a 50Ω or 600Ω network.

Again as with the **T-pad Attenuator**, we can produce standard tables for the values of the series and parallel impedances required to construct a 50Ω, 75Ω or 600Ω symmetrical Pi-pad attenuator circuit. The calculated values of resistors, R1, R2 and R3 are given as.

Pi-pad Attenuator Resistive Values

dB Loss	K factor	50Ω Impedance	75Ω Impedance	600Ω Impedance

		R1, R3	R2	R1, R3	R2	R1, R3	R2
1.0	1.1220	869.5Ω	5.8Ω	1K3Ω	8.7Ω	10K4Ω	69.2Ω
2.0	1.2589	436.2Ω	11.6Ω	654.3Ω	17.4Ω	5K2Ω	139.4Ω
3.0	1.4125	292.4Ω	17.6Ω	438.6Ω	26.4Ω	3K5Ω	211.4Ω
6.0	1.9953	150.5Ω	37.4Ω	225.7Ω	56.0Ω	1K8Ω	448.2Ω
10.0	3.1623	96.2Ω	71.2Ω	144.4Ω	106.7Ω	1K2Ω	853.8Ω
18.0	7.9433	64.4Ω	195.4Ω	96.6Ω	293.2Ω	772.8Ω	2K3Ω
24.0	15.8489	56.7Ω	394.6Ω	85.1Ω	592.0Ω	680.8Ω	4K7Ω
32.0	39.8107	52.6Ω	994.6Ω	78.9Ω	1K5Ω	630.9Ω	11K9Ω

Note, that as the amount of attenuation loss required by the Pi-pad circuit increases, the impedance of the series resistor R2 also increases while at the same time, the parallel shunt impedance values of both resistors R1 and R3 decrease.

This is a common characteristic of a symmetrical Pi-pad attenuator circuit used between equal impedances. Also, even at an attenuation of 32dB the series impedance values are still fairly high and not in the one or two ohm range as with the T-pad attenuator.

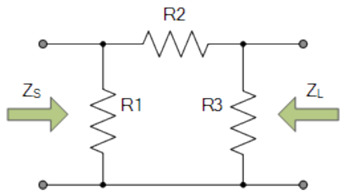
This means then that a single **Pi-pad attenuator** network can achieve much higher levels of attenuation compared to the equivalent T-pad network as the parallel shunt impedances are never less than the characteristic impedance of the transmission line due to the extremely high "K" factor value. For example, a transmission line with a characteristic impedance of 50Ω with an attenuation of -80dB would give shunt resistors R1 and R3 a value of 50Ω each while the series resistor R2 would be equal to 250KΩ.

Pi-pad Attenuator with Unequal Impedances

As well as using the Pi-pad attenuator to reduce signal levels in a circuit which has equal impedances, ($Z_S = Z_L$), we can also use this type of attenuator for impedance matching of unequal source and load impedances ($Z_S \neq Z_L$).

However, to do so we need to modify the previous equations a little to take into account the unequal loading of the source and load impedances on the attenuator circuit. The new equations given for calculating the resistive elements of a Pi-pad attenuator for unequal impedances are.

Pi-pad Attenuator Equations for Unequal Impedances



$$R_1 = Z_S\left(\frac{K^2-1}{K^2-2K\sqrt{\frac{Z_S}{Z_L}}+1}\right)$$

$$R_2 = 0.5\sqrt{Z_S \times Z_L}\left(\frac{K^2-1}{K}\right)$$

$$R_3 = Z_L\left(\frac{K^2-1}{K^2-\frac{2K}{\sqrt{Z_S \div Z_L}}+1}\right)$$

where: K is the impedance factor, Z_S is the larger of the source impedance and Z_L is the smaller of the load impedances.

We can see that the equations for calculating the Pi attenuators three resistor values are much more complex when it is connected between unequal impedances due to their effect on the resistive network. However, with careful calculation we can find the value of the three resistances for any given network impedance and attenuation as follows:

Pi-pad Attenuator Example No2

An unbalanced non-symmetrical **Pi-pad attenuator** circuit is required to attenuate a signal between a radio transmitter with an output impedance of 75Ω and a power signal strength meter of impedance 50Ω by 6dB. Calculate the values of the required resistors.

$$K = 6dB = 10^{(6/20)} = 1.9953$$

Resistor R1 Value

$$R_1 = Z_S\left(\frac{K^2-1}{K^2-2K\sqrt{\frac{Z_S}{Z_L}}+1}\right)$$

$$R_1 = 75\left(\frac{1.9953^2-1}{1.9953^2-2\times 1.9953\sqrt{\frac{75}{50}}+1}\right)$$

$$R_1 = 75 \times 31.8 = 2{,}385\Omega \ \ (\text{or } 2.37k\Omega\ 1\%)$$

Resistor R2 Value

$$R_2 = 0.5\sqrt{Z_S \times Z_L}\left(\frac{K^2 - 1}{K}\right)$$

$$R_2 = 0.5\sqrt{75 \times 50} \times \left(\frac{1.9953^2 - 1}{1.9953}\right)$$

$$R_2 = 30.62 \times 1.4941 = 45.7\Omega \ (\text{or } 45.3\Omega \ 1\%)$$

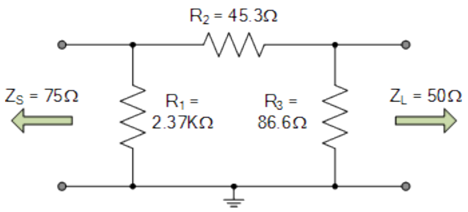
Resistor R3 Value

$$R_3 = Z_L\left(\frac{K^2 - 1}{K^2 - \dfrac{2K}{\sqrt{Z_S \div Z_L}} + 1}\right)$$

$$R_3 = 50\left(\frac{1.9953^2 - 1}{1.9953^2 - \dfrac{2 \times 1.9953}{\sqrt{\dfrac{75}{50}}} + 1}\right)$$

$$R_3 = 50 \times 1.7305 = 86.52\Omega \ (\text{or } 86.6\Omega \ 1\%)$$

Giving us the following non-symmetrical Pi attenuator circuit:



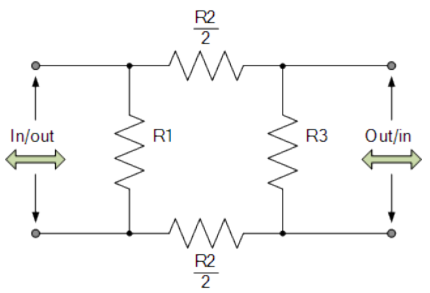
The maths involved for calculating the resistor values of a Pi-pad attenuator used between unequal impedances is more complex than those used to calculate the values between equal impedances. As such Pi-pad attenuators tend to be used more for signal attenuation on transmission lines with matching source/load impedances $Z_S = Z_L$.

For Pi-pad attenuators that have reactive components such as inductors and capacitors within their design, EEWeb have a free online **Pi-pad Attenuator Tool** for calculating component values at the require frequency.

Balanced-Pi Attenuator

The **balanced-Pi attenuator** or “Balanced-π Attenuator” for short, uses an additional resistive element in the common ground line to form a balanced resistive network as shown below.

Balanced-Pi Attenuator Circuit



The balanced-Pi attenuator is also called an **O-pad attenuator** because the layout of its resistive elements form the shape of a letter "O" and hence their name, "O-pad attenuators". The resistive values of the balanced-Pi circuit are firstly calculated as an unbalanced Pi-pad configuration connected between equal impedances the same as before, but this time the value of the series resistor R2 is halved (divided by two) placing half in each line as shown. The calculated resistive value of the two parallel shunt resistors remain at the same.

Using the values previously calculated above for the unbalanced Pi-pad attenuator gives, series resistor R2 = 106.7÷2 = 53.4Ω for the two series resistors and the parallel shunt resistors, R1, R3 = 144.4Ω the same as before.

Pi-pad Attenuators are one of the most commonly used symmetrical attenuator circuit and as such its design is used in many commercially available attenuator pads. While the Pi-pad attenuator can achieve a very high level of attenuation in one single stage, it is better to build a high loss attenuator over 30dB by cascading together several individual Pi-pad sections so that the final level of attenuation is achieved in stages.

By cascading together pi-pad attenuators, the number of resistive elements required in the design can be reduced as adjoining resistors can be combined together. So for the Pi-pad this simply means that the two adjoining parallel shunt resistors can be added together.

The accuracy of the calculated pi attenuator will determined by the accuracy of the component resistors used. Which ever tolerance of resistor is selected to construct a **Pi attenuator** circuit, 1%, 5% or even 10% they MUST all be non-inductive resistors and not wirewound types. Also as we are using resistors in the attenuation network these non-inductive resistors MUST be able to safely dissipate the required amount of electrical power as calculated using Ohms Law.