PADS 101

Part 1 *by Rick Chinn*

Attenuation (loss) pads are handy tools, and understanding their design and application takes a few minutes and lasts a lifetime. We'll divide this discussion into two parts. The first part discusses pads to be used in traditional impedance-matched (power-based) systems, the second part discusses pads used in voltage-based (bridging) systems. Finally, we'll go through some construction techniques.

Pads are used anywhere within a system where you need to reduce a signal by some finite amount. Most commonly, this might be between a microphone and its preamp to prevent the preamp from clipping on loud signals. Another place is between a mixer and a power amp to absorb excess gain and to let the mixer operate in a better place from a signal/noise standpoint as well as matching the clip point of the mixer to that of the power amp. In loudspeaker systems using passive crossovers, L-pads are often used to equalize the outputs of the drivers used for each frequency band and to allow rudimentary voicing.

Pad Types

There are many different types of pads: L, T, Bridged Tee, Pi, O, and others. The names describe the physical appearance of the resistors in the circuit. To convert an unbalanced design to a balanced design, you split the series element into two equal parts and insert them in series with the two legs of the balanced line.

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L-pad is a $2 name for a voltage divider (Fig. 1). L-pads look like an upside-down letter L. Their input and output impedances are different. The L-pad is asymmetrical and its inputs and outputs are not interchangeable. A U-pad is a balanced L-pad.

T-pads look like the letter T (Fig. 2). Input and output impedances are usually equal, however a T-pad can also be designed as a taper pad; designed to match one circuit impedance to another. An H pad is a balanced T pad. A T-pad designed for equal impedances is symmetrical; it reflects impedances equally well in either direction and may be used in either direction.

Bridged-T pads look like a T-pad but with an additional resistor connected between the input and output (Fig. 3). A bridged-T pad only needs two variable elements to make it adjustable. The input and output impedances are always equal. This pad configuration is somewhat less sensitive to source and load impedance errors. Bridged-T pads reflect impedances symmetrically and may be used in either direction.

The **Pi pad** looks like the Greek letter Π. An O-pad (balanced Π) looks like a squared letter O. These pads can be designed to operate between equal or unequal impedances. With equal send and receive impedances, these pads maybe used in either direction.

All pads work on the basis of voltage division: a series arm and a shunt arm. In an L-pad, the ratio of the two resistor values determines the loss. The source impedance is reflected to the load as well as the load impedance being reflected to the source. You can work through this on the basis of the resistor ratios themselves, or you can solve it using Ohm's Law.

The most basic circuit for any of these attenuators works for unbalanced sources. Sometimes you see an unbalanced attenuator used in a balanced circuit: but the maximum loss, especially at high frequencies, is a function of the common mode rejection (CMR) of the balanced input. Many classic mixers (where everything was 600-ohms) did this with impunity.

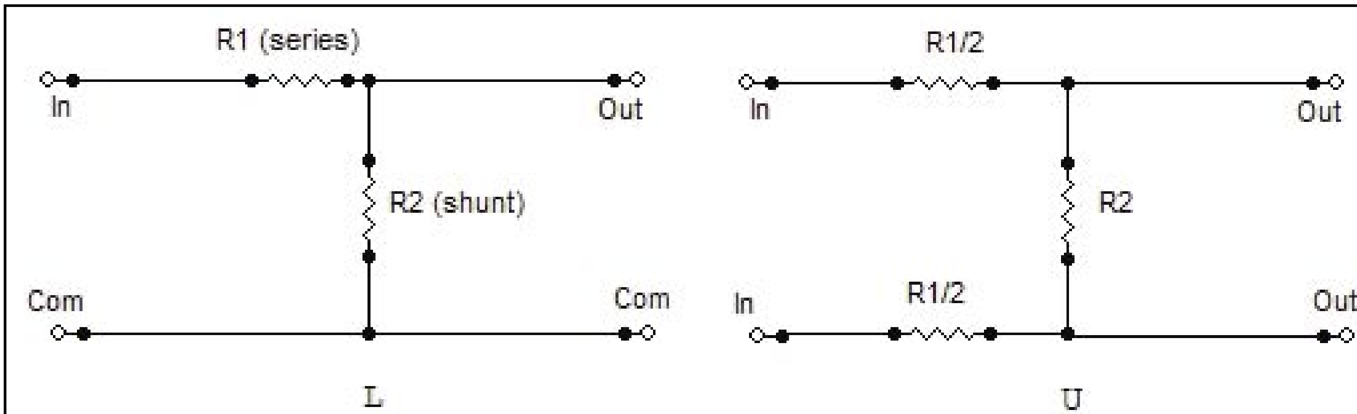

Figure 1 - unbalanced and balanced L-Pads

Impedance Matched Systems

In these systems, sources match loads and the load impedance are low enough that you can't ignore it. They are based on the concept of maximum power transfer which occurs when the source impedance matches the load impedance. Looking in the classic texts: Motion Picture Sound Engineering, Audio Cyclopedia, Sound System Engineering, or the Electronics Data Handbook from Allied Radio, you'll find tables devoted to designing these pads. The tables simplify matters because they supply precalculated values for the attenuation factor k for use in the pad design formulas (remember that a scientific calculator used to be something that you could only dream about).

Voltage Transmission Systems

The modern audio world has embraced voltage transmission as the de-facto standard for interconnecting analog equipment where the length of the wiring is a fraction of the wavelength at the highest frequency of interest. Above this limit, transmission line effects dominate and you must be careful to source and terminate the line at its characteristic frequency. For the wiring employed in most facilities, the source and termination impedance is not an issue from a transmission line standpoint.

Voltage transmission systems are characterized by low sending impedances (like 100 ohms) and bridging (at least 10x the source impedance) inputs, resulting in most of the source's output voltage being delivered to the load (the source and load impedances form an L-pad). In impedance matched systems, the source and load impedances form a 2:1 voltage divider. You get maximum power transfer, but you lose half of the source voltage.

Pads for these systems are relatively easy to design, and either an L-pad or its balanced brother U will suffice.

Source Impedance and Load Impedance

One concept that is often misunderstood is that of source impedance and load impedance. The source impedance is the impedance seen looking into the output terminals of a source. This is not the same as the load impedance, which is the minimum impedance that the output can drive and still meet its specifications or it is the impedance that the output must be terminated in for specified performance. The minimum impedance condition applies to voltage transmission (bridging) systems and the terminated impedance condition applies to impedance-matched or power-based systems.

The load impedance is usually a device's input impedance. Newer equipment usually has bridging inputs (10k impedance or higher). You must connect a 600 ohm resistor in parallel with the input to use it in an impedance-matched system.

Passive networks such as the old Altec passive equalizers have a 600 ohm input impedance as defined by their circuit design. These devices present a 600-ohm load impedance to whatever drives them as well as presenting a 600 ohm source impedance to whatever they are driving. Furthermore, they expect a 600 ohm source impedance looking backwards from their input and their output expects a 600 ohm termination.

For consumer gear, the output impedance specified, if specified at all, is usually the minimum load impedance rather than the output source impedance. The giveaway clue is an unreasonably high value of source impedance, such as 50Kohms for solid state equipment.

Microphone inputs are also misunderstood. Although they are designed for a 150 ohm source, modern preamp designs all bridge rather than terminate the source. Beware…some vintage preamp designs were designed to terminate their sources.

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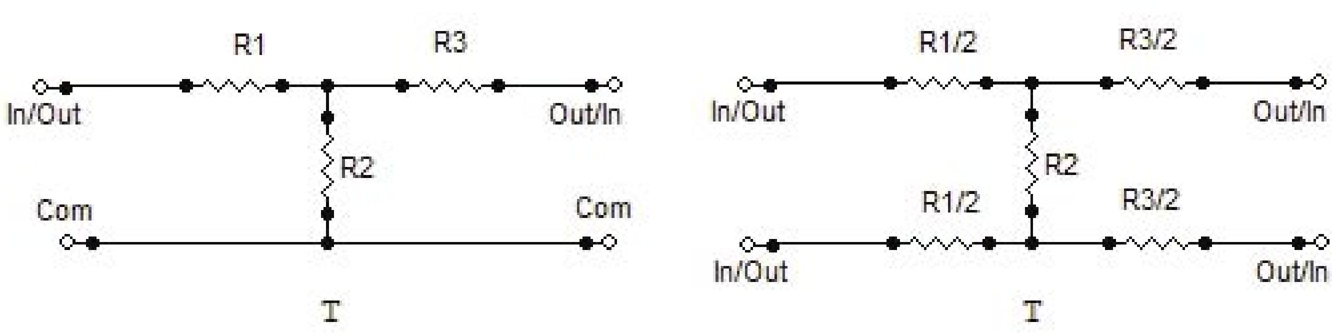

Figure 2 - unbalanced and balanced T-Pads

The Voltage Divider

If you've ever studied electronics, the voltage divider equations should be familiar. You can analyze this circuit two different ways, getting the same answer at the end.

For the following discussion, R_1 = 10k, R_2 = 1k, V_{in} is 1V (Fig. 4). (Purists, please forgive me for using V rather than E for the applied voltage in the interest of clarity.)

Using Ohm's law, calculate the total current in the circuit:

$I_t = V/R_t = 1/(10k+1k) = 1/11k = 90.9$ microamps

In a series circuit, the current through the circuit is the same at any node. The voltage across any resistor is equal to the current through the resistor times the resistance:

$V_{R1} = I_tR_1 = 90.9\mu A * 10k = .9091V$
$V_{R2} = I_tR_2 = 90.9\mu A * 10k = .09091V$

Finally, as a check, Kirchoff's law says that the sum of the voltage drops in a circuit equals the applied voltage:

$V_{R1} + V_{R2} = .9091 + .09091 = 1V$

Now look at the circuit from the standpoint of the resistor ratios (Fig. 5). The applied input voltage is divided by a factor of 1 plus the ratio of the resistors. You can visualize this easily with a simple 1:1 divider; two equal-value resistors. By inspection you already know that the input voltage will be divided by two. The division ratio is 2, which is 1 plus the ratio of the resistor values. Revisiting the 10:1 voltage divider:

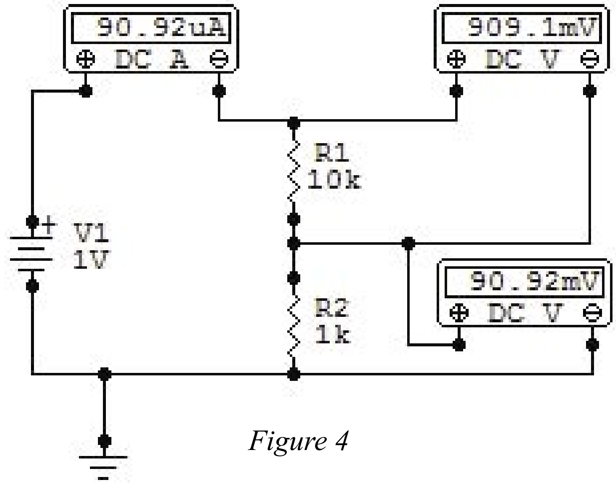

Figure 4

$V_o = V_{in} / k$, where k is the attenuation ratio, or $1+(R_1/R_2)$.

$k = 1+(10k/1k) = 11$

Substituting 1V for V_{in}:

$V_o = 1/11 = .0901V$

As you see, both methods arrived at the same answer: 90.1mV. You can also see that for this divider,

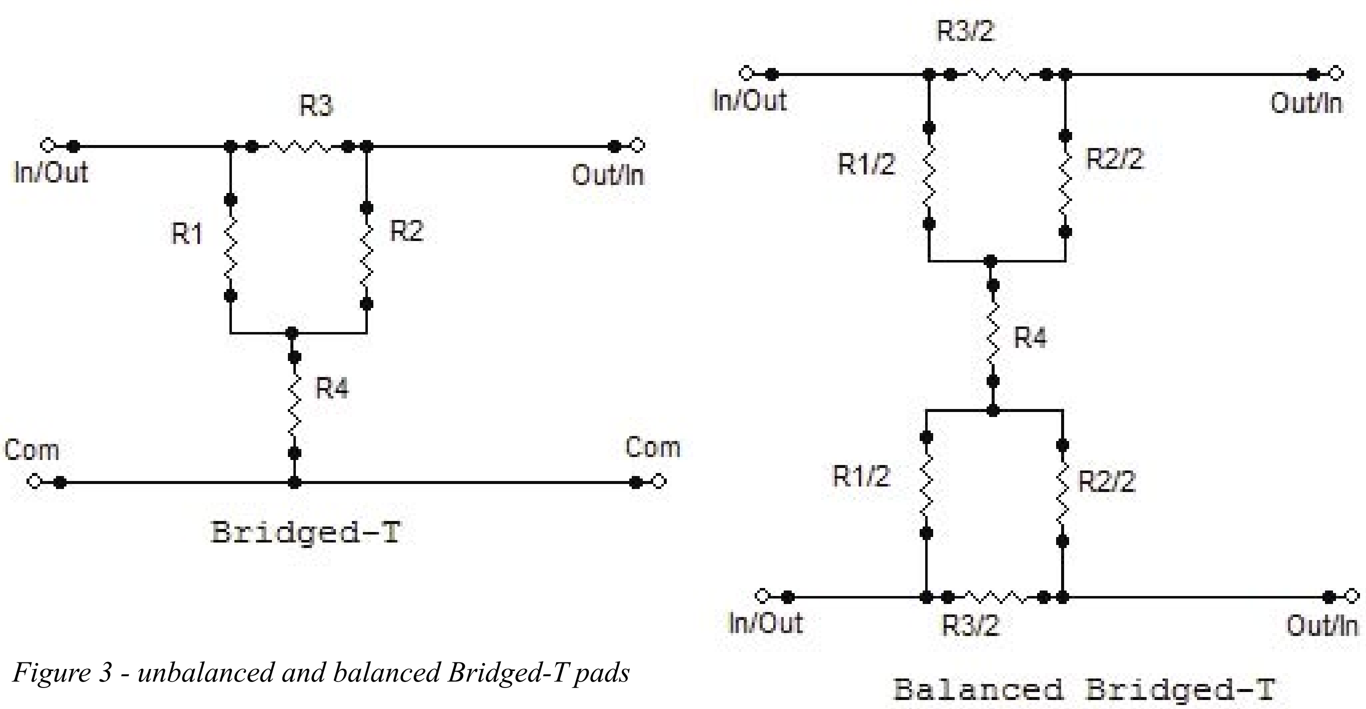

Figure 3 - unbalanced and balanced Bridged-T pads

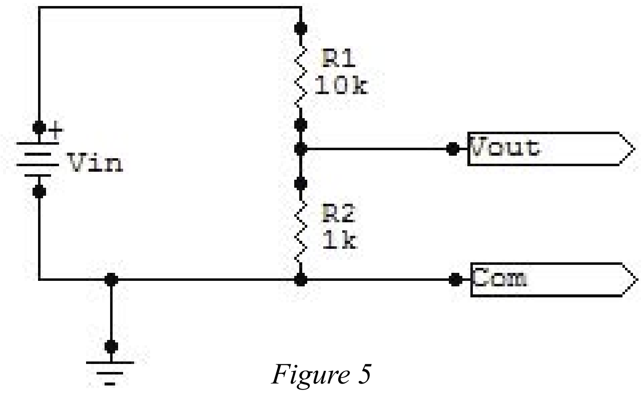

Figure 5

$$\frac{V_{in}}{V_{out}} = \frac{(R_1+R_2)}{R_2} = \frac{R_1}{R_2}+\frac{R_2}{R_2} = 1+\frac{R}{R}$$

solving for V_{out}

$$V_{out} = \frac{V_{in}}{1+\frac{R_1}{R_2}}$$

although the resistor values have a 10:1 ratio, the actual voltage division was 11:1. To obtain a 10:1 division ratio, the resistors must have a 9:1 ratio.

To use a voltage divider, even in a voltage transmission system, you must take into account the source and load impedances. The source impedance must be added to the series arm (R_1) and the load impedance must be added in parallel with the shunt arm (R_2).

Pads for Voltage Transmission Systems

As mentioned previously, pads used in voltage transmission systems must take the source and load impedances into account to deliver the calculated loss. Typically the load bridges the source, so if the load is 10x the source impedance then you can ignore these impedances as long as your pad design fulfills the same source/load impedance relationship. Yes, there will be an error, but it will be in the 1dB area. The calculations are an extension of the voltage divider formulas. Pads for microphone inputs are an exception because many microphone inputs only barely bridge the source. (1000 ohms is common for transformer-coupled inputs).

Special Considerations for Microphones

A common application for a pad is to attenuate the output of a microphone that is too high for the dynamic range of the following microphone preamp. Using a matched-impedance pad is not optimum (this is not to say that it won't work) because most microphones expect to have their output bridged by the input impedance of the microphone preamp.

Another issue here is one of coloration. The microphone and preamp operate together as a system. The input impedance of the preamp (which is not resistive) varies with frequency and this interacts in a complex manner with the output impedance of the microphone (also not resistive). If there are transformers involved at either end, that's an additional factor in the equation. This complex interaction causes coloration, which may be good or bad, beneficial or harmful. It's one of the things that make different preamps and microphones sound different. The point is that you can minimize the change in coloration caused by inserting a pad by paying attention to this detail and designing the pad to mimic the conditions present before its insertion. The easiest parameter to mimic, and the one that is the biggest contributor is the impedance that the pad presents to the microphone, and the source impedance that it presents to the microphone preamp.

For phantom powered microphones, the pad should be connected after the phantom feed resistors and before the microphone preamp input. This eliminates the additional voltage drop in the phantom power voltage caused by IR drop in the pad resistors. In most cases, this is not the case but many phantom powered microphones will tolerate 10 to 20 dB of padding without difficulty. Try it first before worrying about it.

Last is the issue of thermal noise. The noise spec of the preamp is based on the preamp being driven from a specific source impedance. If the source impedance is higher than expected, then the noise performance degrades somewhat. *rc*

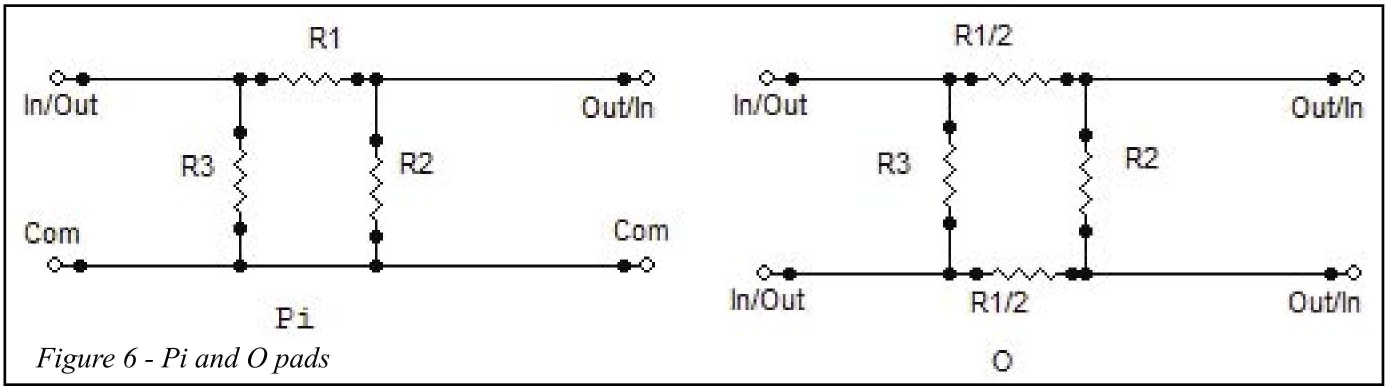

Figure 6 - Pi and O pads