Lab Notes

Attenuator ups and downs

One of the most important types of artillery in the design engineer's armoury of 'vital weapons' is the apparently simple passive circuit known as the 'attenuator'. Naturally, these apparently simple weapons are full of nasty little surprises and have a tendency to explode in the face of the unwary designer, says Ray Marston.

Ray Marston

ATTENUATORS are used to reduce an awkward value input or output signal to a lower and more convenient level. The simplest example of a practical attenuator is the 'pot' circuit of Figure 1, which may be used as a volume control in an audio system or as an output level control in a simple audio generator, etc.

The input signal to the pot attenuator is connected across the total resistance chain and the output is taken from the pot slider. Note that the pot effectively comprises an upper (R1) and a lower (R2) resistive arm, thus forming a basic 'L'-type attenuator, and that the degree

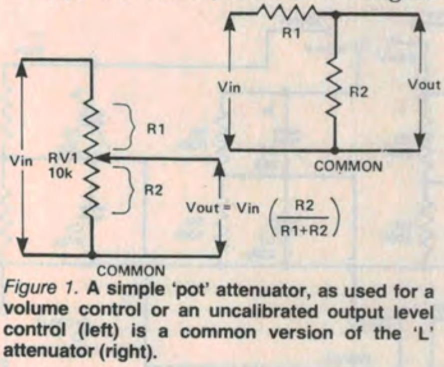

Figure 1. **A simple 'pot' attenuator, as used for a volume control or an uncalibrated output level control (left) is a common version of the 'L' attenuator (right).**

of attenuation is determined by the ratio of lower arm resistance divided by the total resistance.

The precise amount of attenuation provided by a pot is generally of little importance and the control is usually left uncalibrated. If a precise amount of attenuation is required, a simple switched potential divider network of the type shown in Figure 2 may be used. It is important to note, however, that this circuit is designed to feed into an *infinite* impedance, or at least one that is very large compared to the total resistance of the divider chain.

Design tips

The first step in designing an attenuator of the Figure 2 type is to decide what its input impedance or total resistance is to be. Next, the values of the individual resistors are determined. Here the design is carried out in a simple sequence of logical steps, there being as many steps as there are attenuator switched positions. In each of these steps, the circuit is considered to consist of an upper and a lower half only. An example will help clarify matters.

Assume (as in our example) that the total resistance is to be 10k and that two attenuation positions (excluding unity) are required and are ÷ 10 and ÷ 100. The values for the greatest amount of attenuation are always determined first, so for ÷ 100 the lowest arm must contain 1/100th of the total resistance, or 100R. This gives the value for R3 and leaves the remaining 9900R in the 'upper' (R1 + R2) arm.

The values for the ÷ 10 position are next calculated and it is found that 1k is needed for the 'lower' arm. In this case, however, the 'lower' arm consists of R2 + R3, but as R3 is already known to be 100R, R2 must be 1k − 100R = 900R. The upper arm, R1, must obviously contain the remaining 9k of the 10k chain.

This simple design procedure may be expanded up to give as many attenuator steps as are required for a particular application.

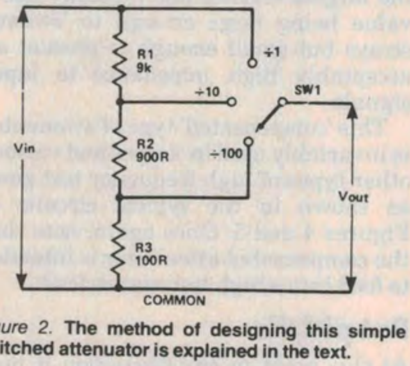

Figure 2. **The method of designing this simple switched attenuator is explained in the text.**

It should be noted that the simple attenuator circuit of Figure 2 is only accurate at low frequencies or when▶

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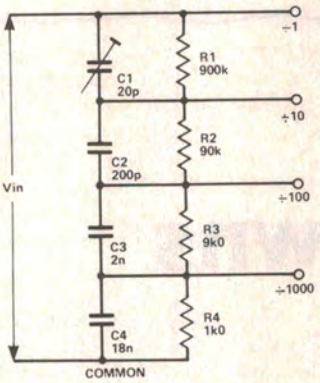

Figure 3. **A method of providing frequency compensation (to give a wide frequency response) to a simple attenuator network.**

moderately low values of resistance are used. At high frequencies, stray capacitance will shunt the values of all resistors and may significantly reduce their values and thus the accuracy of the attenuator. This effect is particularly acute when high value resistors are used: a mere 2 pF of stray capacitance represents a reactance of about 800k at 100 kHz and will have a very significant shunting effect on any resistor with a value greater than a few tens of kilohms.

Compensation

This problem can readily be overcome by shunting all resistors with correctly chosen values of capacitance, as shown in Figure 3.

Here, each resistor of the chain is shunted with a fixed capacitor, the reactance values of capacitance being in the same ratios as the resistive arms of the attenuator. The highest reactance (smallest capacitance) is connected to the largest resistor and typically has a value being large enough to 'swamp' strays but small enough to present an acceptably high impedance to input signals.

This 'compensated' type of attenuator is invariably used in 'scopes and various other types of high frequency test gear, as shown in the typical circuits of Figures 4 and 5. Once again, note that the compensated attenuator is intended to feed into a high impedance load.

Pot pitfalls

At this point in our discussion it may have dawned on you that, because of the effects of stray capacitance, there can be certain pitfalls in using pots in some types of circuit. Suppose, for example, that you have designed an audio amplifier with a beautifully flat frequency response but have, in a moment of madness, fitted it with a 500k volume control. You will (hopefully) not be unduly surprised to subsequently find that, at low volume settings, stray capacitance of a few picofarads across the upper arm of the pot causes the amplifier's treble response to be boosted by several dB at 12 kHz or so!

Again, suppose that you have designed a superb LF sine/square generator which produces square waves with rise and fall times of a mere 50 nS or so, but have fitted the beast with a simple 10k pot as an output level control. Naturally, you will not be surprised to find that the few picofarads of strays across the upper arm of the pot act as a reactance of only a couple of thousand ohms to your fast rise and fall time signals and consequently cause

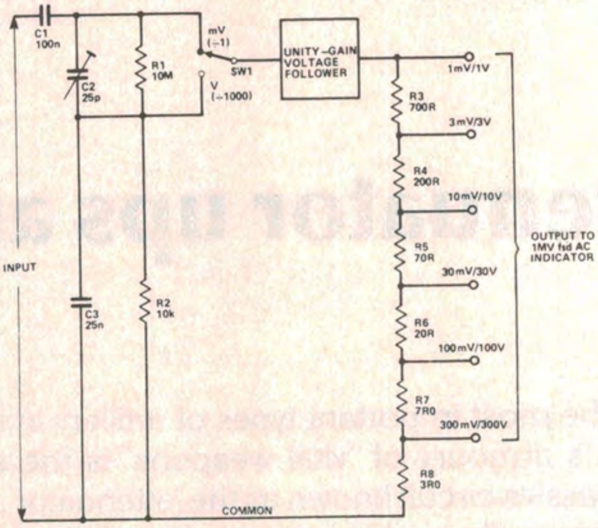

Figure 5. **Typical attenuator sections of an ac millivoltmeter.**

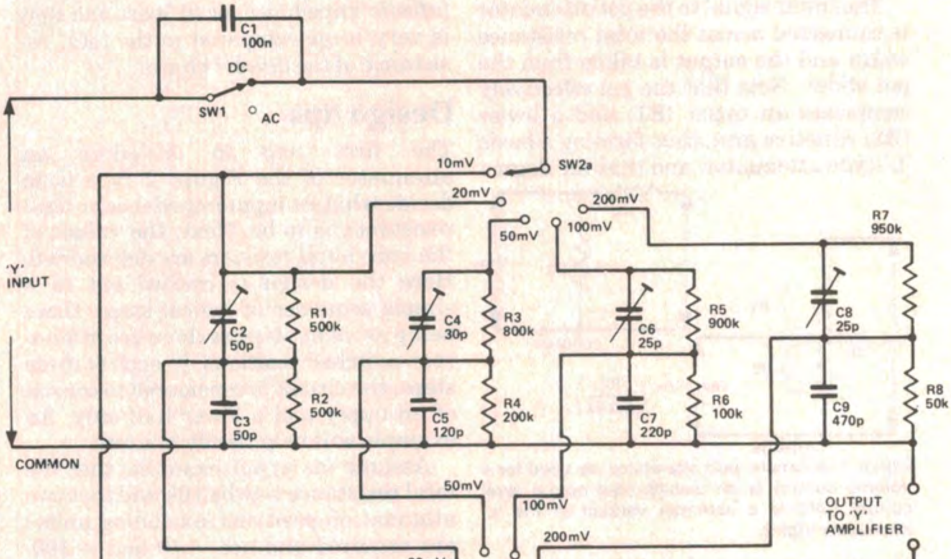

Figure 4. **Section of a typical scope 'Y' amplifier attenuator.**

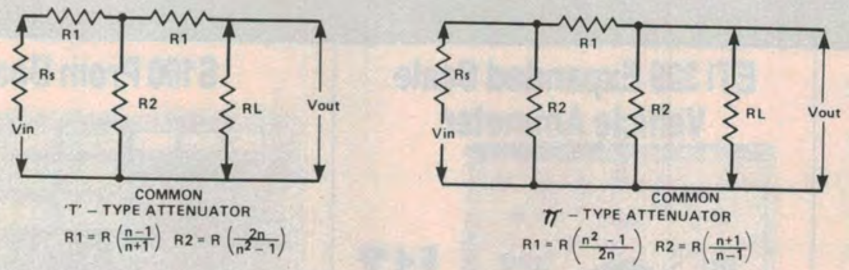

Figure 6. **Two popular types of matched-resistance attenuator.**

your square waves to appear incredibly 'spiky' at low amplitude settings.

Both of the above problems can be solved or minimised by using pots with sensible low resistance values, bearing in mind the effects of strays at the operating frequencies in question.

Matched-resistance attenuators

Often, an attenuator is needed to feed into and/or from a fixed load of some kind, in which case the simple potential divider types of circuit discussed above are of little use. Instead, one of the many versions of the so-called matched-resistance attenuator must be used. Two of the most popular attenuators of this type are shown in Figure 6, together with their basic design formulae. Note that these formulae are valid only when the attenuators are correctly terminated at each end.

The 'T'-type attenuator is a perfectly simple design and several sections can readily be cascaded to form variable attenuator networks, as shown in the practical circuit Figure 7. Here, the attenuation can be varied from 0 dB to 60 dB in 20 dB steps by switching individual sections into or out of the circuit.

The π attenuator sections cannot be directly cascaded, as is made clear in Figure 8. Nevertheless, sections can be cascaded in modified form to produce a laddered attenuator network, the most popular of all attenuator types.

Looking at Figure 8, you can see that if three individual π sections are wired in cascade (Figure 8a) their adjacent R2 sections connect in parallel to give an impedance of P/2 (Figure 8b), while the two R2 end sections have impedances of P. If an external load, RL, is simply switched to the different outputs of the cascaded π attenuator sections (Figure 8c) the load will clearly see impedances of roughly half of the correct value and so be severely mismatched. To put things right, the formula for the component values of the ladder network of Figure 8c are re-jigged as shown.

The ladder attenuator of Figure 8c is very widely used in AF and RF signal generators. Figure 9 shows the practical circuit of a fully variable 600 ohm attenuator that can be used in sine/square generators, etc. The odd resistor values (correct within 2%) can be made up by wiring pairs of resistors in series or parallel. ●

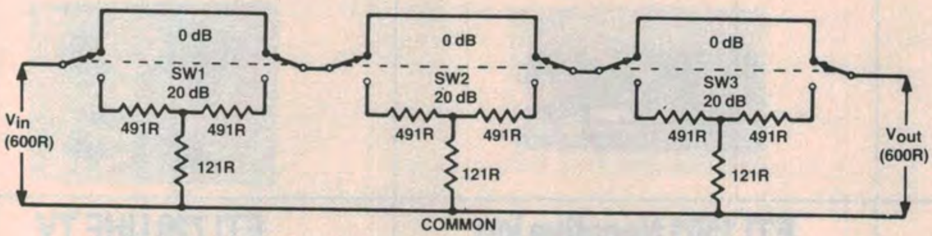

Figure 7. **Three identical 20 dB 600R 'T' attenuators cascaded to make a 0-60 dB switched attenuator unit.**

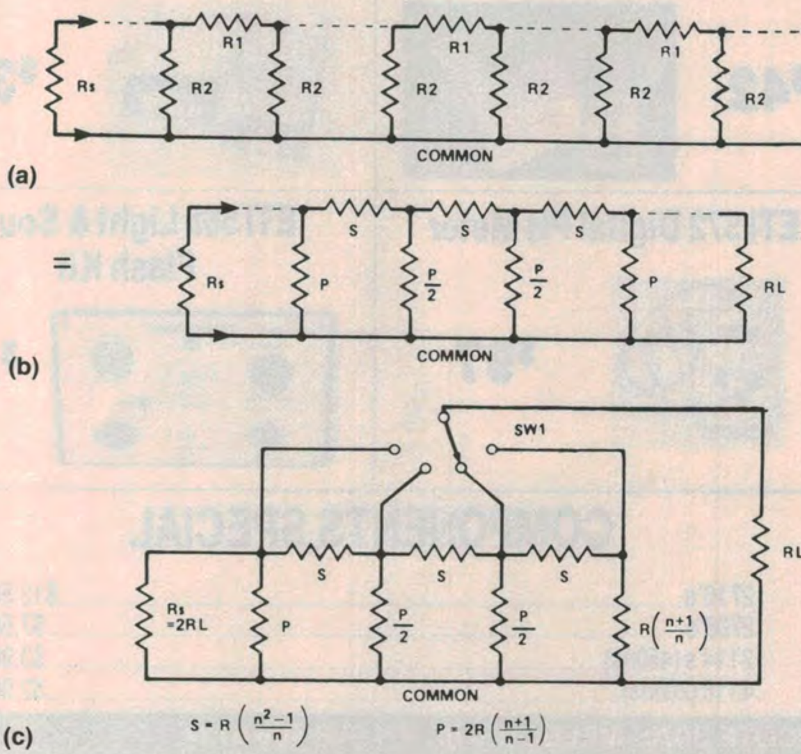

Figure 8. **The ladder attenuator (c) is a development of the basic π attenuator (a and b).**

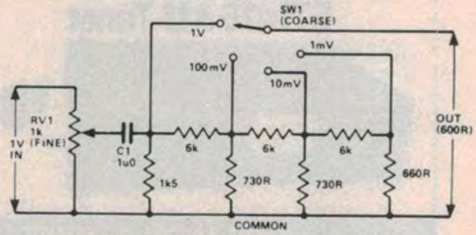

Figure 9. **Practical 600R output attenuator network for a modern sine/square generator. RV1 gives fine control. SW2 gives coarse control.**