ELECTRONIC BUILDING BLOCKS

PART TWO

by R. A. DARLEY

FOLLOWING last month's preview of the type of units which will be described in this series, we deal in more detail this month with passive networks, including attenuators and CR circuits.

ATTENUATORS

The simplest version of the passive attenuator is the potentiometer. As shown in Fig. 2.1, the input is connected across the total resistance and the required proportion taken from the variable arm. This is the arrangement that is generally used as a volume control. As the exact amount of attenuation provided is of little importance, 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 Fig. 2.2 may be used. It is important to note, however, that this circuit is designed to be fed into an infinite impedance, or at least one that is very large compared with the total resistance of the divider.

When designing an attenuator of this kind, the first step is to decide what its input impedance is to be, and this value then dictates the total value of the resistance chain. Next, the values of the individual resistances are determined, and here the design is carried out in a number of steps, there being as many of these 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 follows.

In the circuit shown in Fig. 2.2, it was decided that the input impedance, and therefore the total resistance of the chain, should be 600 ohms. Two attenuator positions, not including the zero attenuation one, were required, these being ÷10 and ÷100. The values for the greatest amount of attenuation are always determined first. For the ÷100 position, it is clear that the lower arm must contain one hundredth of the total resistance of the chain, giving 6 ohms. This gives the value for R3, and leaves the remaining 594 ohms in the upper arm. The values for the ÷10 position are next calculated, and it is found that here 60 ohms are needed for the lower arm. In this case, however, the lower arm consists of resistors R2 and R3. As the value of R3 has already been determined as 6 ohms, R2 must $= 60 - 6 = 54$ ohms. The upper arm (R1) must contain the remaining 540 ohms. This simple procedure may be carried on to give as many steps as are required.

It is often found that in practical circuits of this type small fixed or trimmer capacitors are wired in parallel with the resistors. These serve to give a degree of high frequency compensation or correction to the overall circuit with which they are used.

In many cases an attenuator is required to be terminated by a fixed load of some mind, and here the potential divider mentioned above is of little use. Instead, one of the many versions of the so-called matched resistance attenuators must be used.

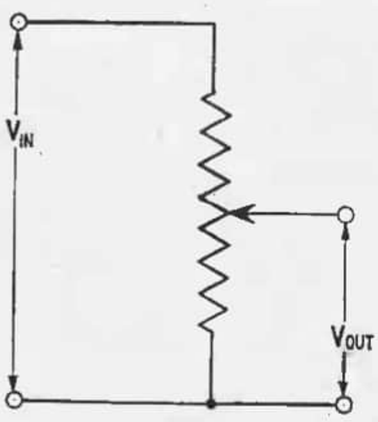


Fig. 2.1 (left). Simple passive attenuator or potentiometer

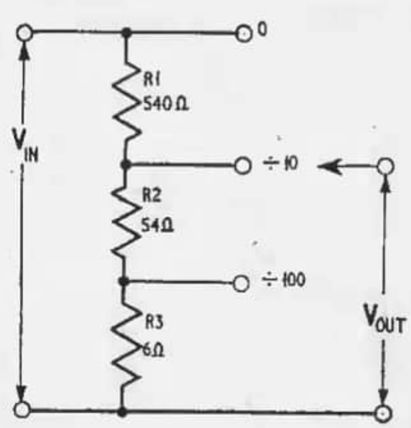
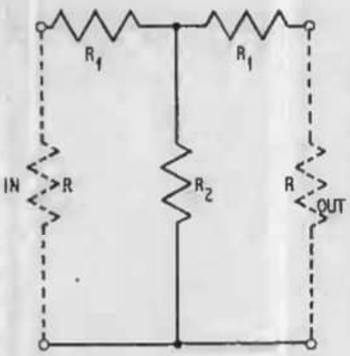


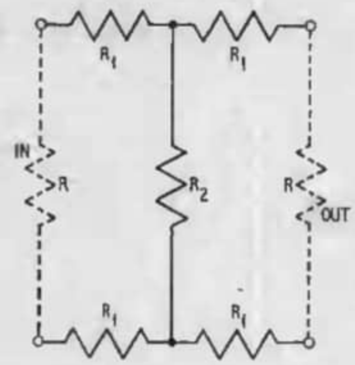
Fig. 2.2 (right). Switched potential divider network



$R_1 = R\left(\frac{a-1}{a+1}\right)$

$R_2 = R\left(\frac{2a}{a^2-1}\right)$

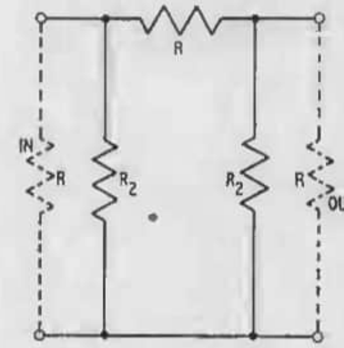
Fig. 2.3a. 'T' type



$R_1 = \frac{R}{2}\left(\frac{a-1}{a+1}\right)$

$R_2 = R\left(\frac{2a}{a^2-1}\right)$

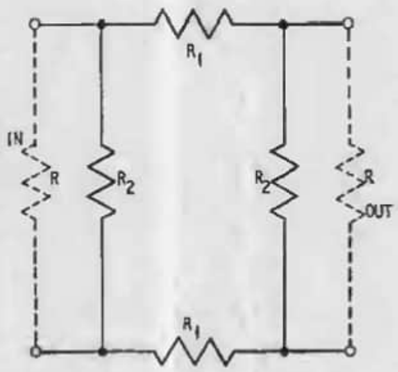
Fig. 2.3b. 'H' type



$R_1 = R\left(\frac{a^2-1}{2a}\right)$

$R_2 = R\left(\frac{a+1}{a-1}\right)$

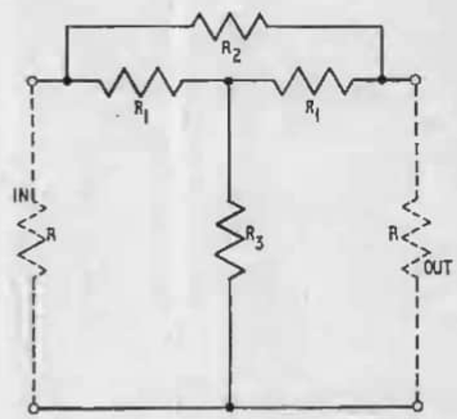
Fig. 2.3c. 'π' type



$R_1 = \frac{R}{2}\left(\frac{a^2-1}{2a}\right)$

$R_2 = R\left(\frac{a+1}{a-1}\right)$

Fig. 2.3d. 'O' type



$R_1 = R$

$R_2 = R\,(a-1)$

$R_3 = R\left(\frac{1}{a-1}\right)$

Fig. 2.3e. 'Bridged-T' type

NOTE: In Figs. 2.3a. to 2.3e, 'a' $= \frac{V_{in}}{V_{out}}$

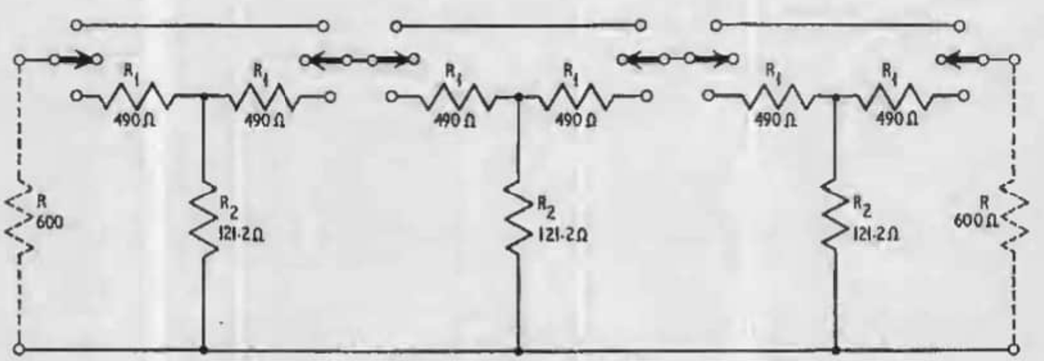


Fig. 2.3f. Three-stage 'T' type

MATCHED RESISTANCE ATTENUATORS

Many pieces of electronic equipment are designed to be driven from a particular impedance source. If the value of this impedance is altered, the working characteristics of the equipment will be upset. If, therefore, the input is fed via an attenuator, it is essential that the attenuator should have the same output impedance in all switched positions. Similarly, the input impedance of the attenuator may also be required to remain constant. As a general rule, the input and output impedances of the attenuator are required to be the same.

A large number of circuits have been developed to meet these requirements, and a few of them are illustrated in Fig. 2.3, together with their essential design formulae.

There is not a great deal to choose from between the performance of these attenuators; the range of circuits just gives a choice of ways of carrying out the same basic function, in much the same way as a bolt or nut can be made with any one of several alternative types of thread, or a mains plug with any one of a range of pin arrangements!

Fig. 2.3a shows the circuit of the "T" type attenuator. In all of these circuits the input and output impedances are represented by dotted resistors. The value of these is very important and should be adhered to, otherwise the calibration of the attenuator will be meaningless. In each of the circuits shown in Fig. 2.3 only one stage of a complete attenuator network is shown. Each one is designed to work from, and into, a particular impedance. It can be seen, therefore, that any number of the same type of attenuator can be wired in series providing that they all have the same impedance. An example of this is shown in Fig. 2.3f, where a three-stage "T" type, with input and output impedances of 600 ohms and attenuations of 0, 10, 100, or 1,000, is illustrated. Each stage is, in this case, identical. The formulae given in Fig. 2.3 only apply for circuits in which the input and output impedances are the same.

DIFFERENTIATING CIRCUIT

The simple circuit shown in Fig. 2.4, consists merely of a capacitor and resistor wired in series. The output is taken from between their junction and the input fed across the two ends. This is rather similar to a potential divider circuit, but in this case the degree of attenuation depends on frequency as well as component values. If phase effects are ignored, the capacitor C can be regarded as a resistor which increases in value as frequency falls, and decreases in value as frequency rises. Thus, the attenuation of the circuit increases as the frequency applied to the input falls. As this is the type of arrangement used to couple the output of one amplifier to the input of the following stage, it can be seen that this simple differentiating circuit sets a natural limit to the low frequency response of the complete amplifier. The low frequency end of the response curve of an existing amplifier can usually be improved by increasing the value of the coupling capacitors, this measure having no adverse effect on the actual operation of the complete circuit.

This voltage divider effect is not the only function of the CR circuit. We can put the circuit to one of good use as a time delay device.

TIME CONSTANT

Fig. 2.5b shows the voltage that results from wiring the circuit of Fig. 2.5a and closing S1. At the moment of switch-on, C acts as an effective short circuit and the full battery voltage is applied across R; a current of V_R thus flows in the circuit. As this current flows the capacitor begins to "charge-up" in a manner similar to that of an accumulator; the input voltage is thus "split" between C and R, so that the voltage across R decreases, as does the current and, therefore, the "charging" rate of the capacitor. The voltage across R continues to fall as C "charges-up", but at a progressively slower and slower rate as more and more voltage is "lost" across the capacitor. Eventually, the voltage across R decreases to almost zero.

The voltage across the capacitor rises, and that across the resistor decreases, in an exponential fashion. The most important thing about all this is that, since the graph follows a strict mathematical law, it is possible to predict the voltage appearing at a given moment after switch on, given certain essential information. The three most important factors are the values of resistance and capacitance used, and the time delay in question. It is found that the voltage across R falls by approximately two-thirds in a time of CR seconds, i.e., $T = CR$ seconds, where C is measured in farads, and R in ohms. Alternatively, R may be measured in megohms and C in microfarads.

A further sequence of operations using the CR circuit can now be considered. Fig. 2.5c shows the circuit rearranged with another switch, S2, wired across the input. This switch is ganged with S1 in such a way that when S1 is closed, S2 is open, and vice versa.

If S1 is closed, S2 will open, and the circuit will operate in the manner that has just been considered. The voltage across the resistor will be at maximum at "switch-on" and then decay as previously explained. Fig. 2.5d illustrates the voltages that will appear at the input, across the resistor, and across the capacitor. Note that the sum of V_R and V_C must equal V_{in}.

Consider now what happens if the capacitor is allowed to charge fully (or near enough), and S1 is then made open circuit and S2 short circuit across the input.

The capacitor is charged up to V_C, which is equal to the input voltage first applied; S2 shorts to give a discharge path for the circuit, with the top (positive) end of C connected to the lower end of the resistor, i.e. the voltage polarity across R is reversed, as shown in the V_R curve. The voltage across R now decays from this negative maximum to zero in the normal way, that is, exponentially. If, after the capacitor has fully discharged, the switches are again changed over, the cycle will repeat, as is shown in Fig. 2.5d.

Note that in practice the same results can be obtained by shorting S1 out and leaving S2 permanently open circuit. A square wave or pulse generator can be connected across the input, the generator output impedance providing the necessary discharge path with zero volts applied. There are certain limitations, however, which we shall now consider.

EFFECT OF CR VALUES ON SQUARE WAVE OR PULSE INPUTS

In the circuit which we have just considered, it was stipulated that the capacitor should be allowed to be fully charged or discharged before any change over of switching took place. In other words, the circuit's time constant ($T = CR$) was very short compared to the length of time for which any switch position was maintained. Consider now the effects that different

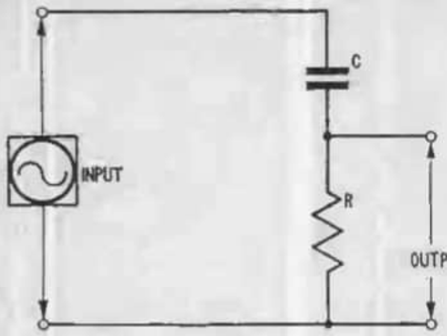


Fig. 2.4. Simple differentiating circuit

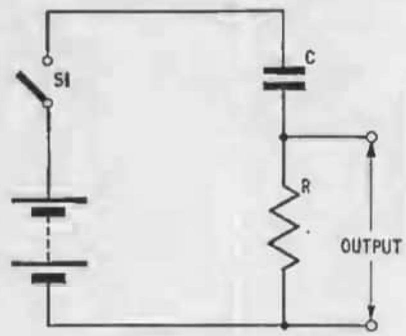


Fig. 2.5a. CR circuit with battery across input

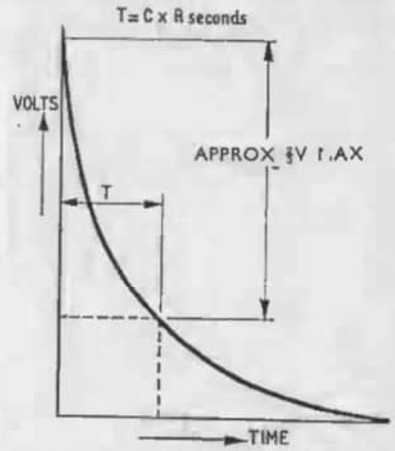


Fig. 2.5b. Resultant voltage across R when S1 is closed

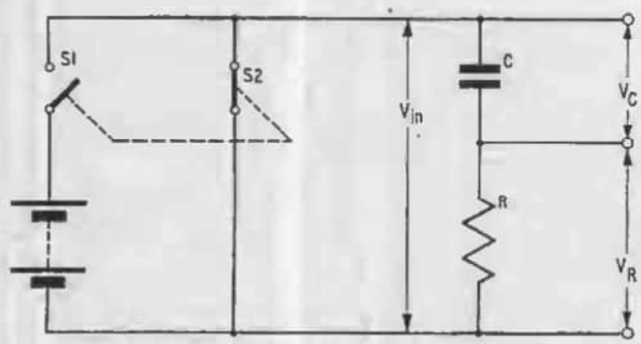


Fig. 2.5c. Circuit rearranged with two switches across the input

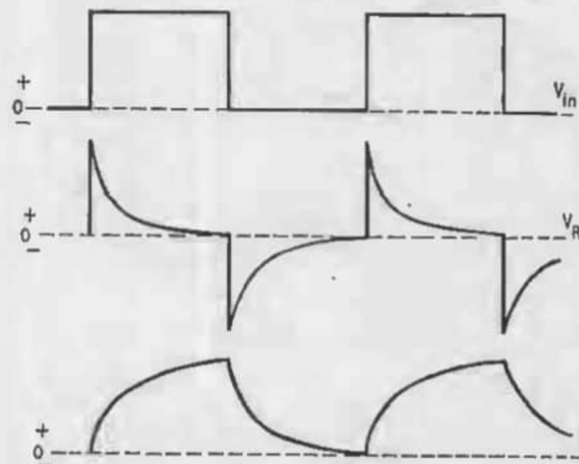


Fig. 2.5d. Shows the voltage that will appear across the input, the resistor and the capacitor

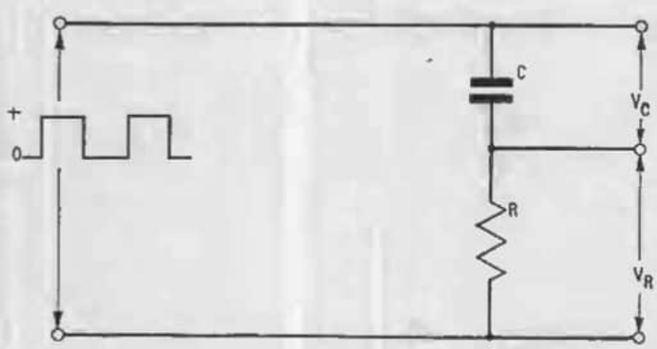
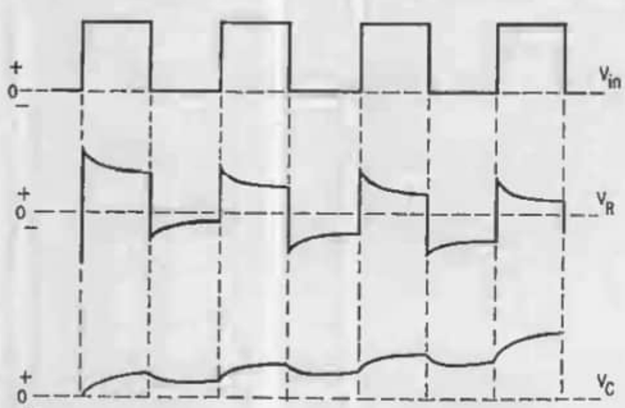
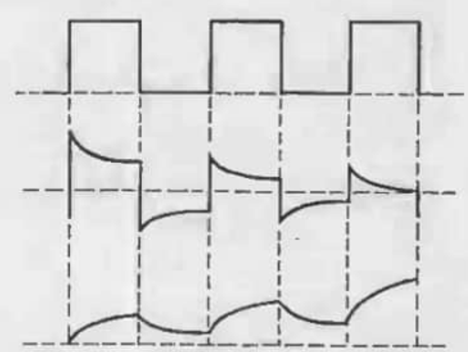


Fig. 2.6a (left). Square wave applied to input of CR circuit

Fig. 2.6b (below, left). Waveform obtained if the time constant is very large compared with the pulse duration

Fig. 2.6c (below). Shows the waveforms that result if the time constant is the same as the duration of the pulse





time constants will have on an applied square wave.

Fig. 2.6a shows the familiar CR circuit, in this case with a square pulse generator connected across the input. If the time constant of this circuit is very large compared with the length of the applied voltage period, the waveforms shown in Fig. 2.6b are obtained. Note that, in the examples which we are considering here, the applied square pulse is positive.

Referring to the voltage appearing across the resistor, the action is as follows: at the commencement of the first pulse the full voltage is developed across the resistor, and then it falls off exponentially. By the time the pulse cuts off this voltage has decayed by only a small amount from the applied value. With zero voltage applied and a discharge path provided through the generator, the voltage across the resistor swings negative by the amount by which it decayed when the pulse was on. This discharge voltage again falls exponentially towards zero, but the pulse switches on again before zero volts is reached; the resistor is thus still slightly negative when the new pulse voltage arrives. This new pulse will, on arrival, result in the full applied voltage again being developed across the resistor, but not in a positive direction. At the end of this pulse the resistor voltage again swings negative by the sum of the amount of decay and the amount by which the voltage was negative at the start of the pulse. This value is greater than the negative swing after the first pulse. This negative swing becomes progressively greater with each pulse applied, until eventually the amount of negative swing becomes the same as the amount of positive swing, and the waveform varies symetrically about zero.

The actual output waveform resulting from this circuit is very similar to the input one, and will become progressively more similar as the time constant is increased. The most important effect of the long time constant circuit in this application is to convert an all positive square pulse to one that swings symetrically about the zero voltage point, without destroying the basic waveform, i.e. it serves to shift the d.c. voltage level.

Fig. 2.6c shows the waveforms that result if the time constant is made the same as the period of the applied pulse. Here again the d.c. shift takes place, but in this case it is accompanied by considerable distortion of the applied pulse.

While all the CR circuits shown in this article have been referred to as "differentiating" circuits, true mathematical differentiation of the square wave is approached only in the case of the circuit with the very short time constant.

EFFECT OF CR VALUES ON OTHER WAVEFORMS

With most waveforms other than the sine wave the CR circuit will cause some degree of distortion of the applied signal, the degree of distortion depending on the time constant employed. In many cases this distortion will be undesirable (as in the case of CR coupling between stages of an amplifier) and component values should be chosen to keep it to a minimum. Generally, the longer the time constant employed, the lower is the distortion.

In other cases distortion may be desirable, perhaps as a method of wave shaping, and again the component values must be carefully chosen to give the best results.

In the case of the sine wave virtually no distortion of the waveform is caused by the circuit's time constant. The only important effect is the degree of attenuation which depends on the frequency of operation.

Next month we will see the effect of using a diode to provide wave shaping.

Contributed Articles

The Editor will be pleased to consider for publication articles of a theoretical or practical nature. Constructional articles are particularly welcome, and the projects described should be of proven design, feasible for amateur constructors and use currently available components.

Intending contributors are requested to observe the style in our published articles with regard to component references on circuit diagrams and the arrangement of the components list.

The text should be written on one side of the paper only with double spacing between lines. If the manuscript is handwritten, ruled paper should be used, and care taken to ensure clarity, especially where figures and signs are concerned.

Diagrams should be drawn on separate sheets and not incorporated in the text. Photographic prints should be of a high quality suitable for reproduction; but wherever possible, negatives should be forwarded.

The Editor cannot hold himself responsible for manuscripts, but every effort will be made to return them if a stamped and addressed envelope is enclosed.