$$(x^{63}+1)=(x+1)(x^2+x+1)(x^3+x+1)(x^3+x^2+1)(x^6+x+1)(x^6+x^3+1)$$
$$(x^6+x^4+x^2+x+1)(x^6+x^4+x^3+x+1)(x^6+x^5+1)(x^6+x^5+x^2+x+1)$$
$$(x^6+x^5+x^3+x^2+1)(x^6+x^5+x^4+x+1)(x^6+x^5+x^4+x^2+1).$$

Each of these factors is irreducible in that it cannot be factored further while keeping real coefficients that are 0 or 1. In MPT 1317, the generator polynomial has the following factors:

$$x^{15}+x^{14}+x^{13}+x^{11}+x^4+x^2+1=(x^3+x^2+1)(x^6+x+1)(x^6+x^4+x^2+x+1)$$

and is a factor of $(x^{63}+1)$ as per the mathematical conditions.

Appendix 4

Consider the generation of a parity bit in the following table

d3	0 0 1 1
d2	0 1 0 1
c1	0 1 1 0

In mathematical terms, the appropriate generator polynomial, $g(x)$, divides the polynomial $(d_3x^2+d_2x+1)$. Let

$$g(x)=(x+1) \quad \text{and} \quad d_3x^2+d_2x+c_1=(w_1x+w_2)(x+1)$$

Equating terms on each side gives

$$w_1=d_3 \qquad w_1+w_2=d_2 \qquad w_2=c_1$$
$$w_2=w_1+d_2=d_3+d_2=c_1$$

as per the table. In Appendix 3, the generator polynomial is not a factor of $(x^{64}+1)$, but of $(x^{63}+1)$. The 64th parity bit has the generator polynomial $(x+1)$

Appendix 5

For the *POCSAG*, the modulus has the following factors

$$(x^{31}+1)=(x+1)(x^5+x^2+1)(x^5+x^3+1)(x^5+x^3+x^2+x+1)$$
$$(x^5+x^4+x^2+x+1)(x^5+x^4+x^3+x+1)(x^5+x^4+x^3+x^2+1)$$

and the generator polynomial consists of the factors

$$x^{10}+x^9+x^8+x^6+x^5+x^3+1=(x^5+x^2+1)(x^5+x^4+x^3+x^2+1)$$

and thus divides $(x^{31}+1)$

Appendix 6

ADPCM (adaptive differential pulse code modulation) was accepted by the CCITT in 1984 for encoding speech. Each sampled speech signal is originally encoded into a 12-bit block. This is compared with 16 quantizing levels and the nearest level chosen. This means that a block of 12 bits can now be replaced by a block of only four bits. The actual mechanism is quite complicated and is considerably different from PCM. The final result is a transmission rate of 12 kbit/sec ■

FOUR-TERMINAL NETWORKS - PART 1

Getting to grips with attenuators

by Steve Knight, BSc

Most electronic equipment has an attenuator or attenuators of one sort or another. The object of these is to reduce to manageable levels a signal we have elsewhere worked like mad to build up. The usual objective is to turn out more than we want, then cut it down to the size we do want. This might sound like an easy option but, like many other things electronic, what we want and what we get aren't always identical. So, apart from the intrusion of Sod's Law which reigns universally, I hope that what follows will cast a ray of light on the often neglected subject of attenuator systems.

WE might define transmission networks in general terms as circuits that have two input terminals and two output terminals which are introduced between a generator and its load impedance. These networks, which are referred to as four-terminal networks, have properties that depend on the work they have to do in the transmission system; in the case of an attenuator, which is our main concern, it must enable us to obtain as output some desired fraction of the input which is entirely independent of the signal frequency. Clearly such an attenuator system must be built up from purely resistive elements since reactive components will lead to frequency discrimination over all or certain parts of the band. Further existing impedance conditions in the system into which the attenuator is introduced must not be disturbed.

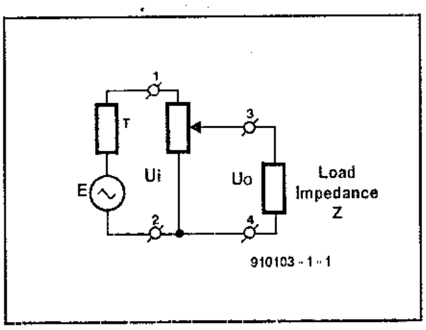

Fig. 1. Elementary attenuator

The most elementary attenuator of all is the potential divider network that usually turns up in the form of a variable resistor. Figure 1 shows the system; our input goes between terminals 1 and 2 and we get the output from terminals 3 and 4. This is a four-terminal network, two of whose terminals are commoned, and we obtain an output that can be a fraction of the input lying between the limits of 0 and 1. This is, no doubt, quite a satisfactory arrangement for turning the volume up and down on a radio receiver, but it fails dismally if we harbour ambitions for making precise quantitative measurements. Outside of the simplest applications to which such an attenuator might be put, the disadvantages are not hard to find.

The output has to feed into some kind of load impedance; assume for a moment that this is resistive. What the input terminals 'see', therefore, is not a constant resistance, but one that is made up of a non-linear combination of two resistances in parallel. Hence, the generator loading is variable and the potential difference—p.d.—at the input terminals is itself changing as the attenuator is operated. Not really the sort of thing we want if we are concerned with exactly how much attenuation we are getting and how it might affect the characteristics of the transmission path. What do we require from an attenuator if it is to do a worthwhile job? Well, we want it to introduce any needed degree of attenuation but at the same time we want the input and output resistances to be such that the impedance conditions existing in the circuit are not upset in any way: if I want to insert an attenuator into a 300 Ω line, the attenuator impedance must also be 300 Ω.

Let us see how well-defined characteristics can be applied to attenuator networks so that we can get the quantitative results we want for our own particular requirements.

Basic characteristics

Four-terminal networks may come in two formats: symmetrical, in which we can interchange the input and output terminals without affecting in any way the electrical characteristics of the circuit; and asymmetrical, in which this last condition does not hold. The simple attenuator of Fig. 1 is clearly asymmetrical. Each of the two formats may be balanced or unbalanced, definitions to which we shall revert later on.

Symmetrical systems have two fundamental characteristics that are essential to our understanding of their function in life: the characteristic impedance, symbolized Z_0 in the complex case, and the attenuation constant α. For purely resistive networks, we can talk about characteristic resistance, R_0, and attenuation factor N.

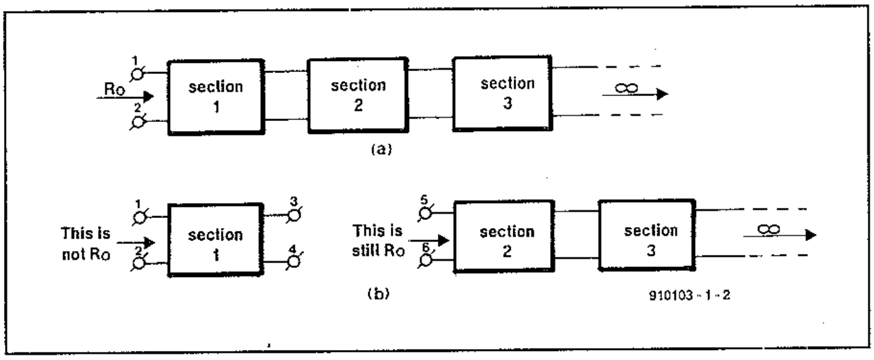

Fig. 2. Defining the characteristic resistance of a network.

Characteristic resistance

Let us use our imagination for a moment. Suppose we have a network made up of an infinite number of identical repetitive sections as in Fig. 2a. Each section contains a number of resistances, but how these are actually arranged is not important at this stage. Suffice it to say that the resistance measured at the input terminals, 1 and 2, will have a certain magnitude that will depend only on the nature and circuit arrangement of the individual sections. Suppose this resistance to be R_0.

Now, it might appear that we are getting into deep water by this approach: as the network is infinitely long, what chance do we have of calculating R_0 for a specific case where the contents of only one (or of a finite number) of the sections is known? Fortunately there is a way out of the impasse by a relatively simple dodge: suppose we remove the first section of the infinite chain as in Fig. 2b. The input resistance of the remainder of the array as measured at terminals 5 and 6 will be the same as that measured originally at terminals 1 and 2, because the infinite nature of the assembly is unaffected by removing the first section (or any finite number of sections, come to that); so we could still measure R_0. The input resistance of the section we have removed, however, is very unlikely to be R_0, but we can make it so in one of two ways: by replacing the rest of the infinite chain (not a very practical way to be sure), or by putting across terminals 3 and 4 a *single resistance* of a value equal to R_0.

Now, this second method gives us the clue we want: no matter how many finite sections we remove from the infinite chain, if we terminate them with a resistor of value R_0, the input resistance will also be equal to R_0 since these sections are effectively terminated by R_0 when reconnected to the rest of the infinite array. With this proper value of termination, that is, the characteristic resistance of each section, therefore, the input conditions are such that anything connected to the input terminals *cannot distinguish* between an infinite network or a finite network so terminated.

Hence, we can define the characteristic resistance, R_0, of an attenuator network: *any symmetrical network terminated in R_0 will have an input resistance also equal to R_0*. And this, of course, must also be true when working from output to input.

Attenuation factor

What about the attenuation constant, or the attenuation factor as it is more generally known for resistive networks? Well, this simply tells us the loss sustained in each section of a network. This loss may be expressed as a fraction of the input or as a reduction in decibels (dB); if the output is one-half the input, for example, the voltage (or current) attenuation is 6 dB.

Each section of an attenuator network will attenuate at identical rates, but the actual amount of attenuation is different as we proceed along the chain. Suppose, for instance, that we start off with unit input and lose half of this input in each section. The output of section 1 will be $^1/_2$ and this becomes the input to section 2. Here again, half the input is lost, so the output of section 2 will be $^1/_2 \times ^1/_2$ or $^1/_4$. After the following section, the output will be $^1/_4 \times ^1/_2 = ^1/_8$. Hence, the *amount* of loss differs for each section because the

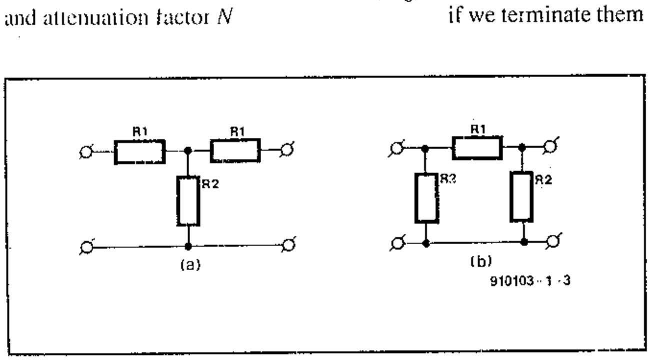

Fig. 3. The forms of the T-section and the π-section attenuators.

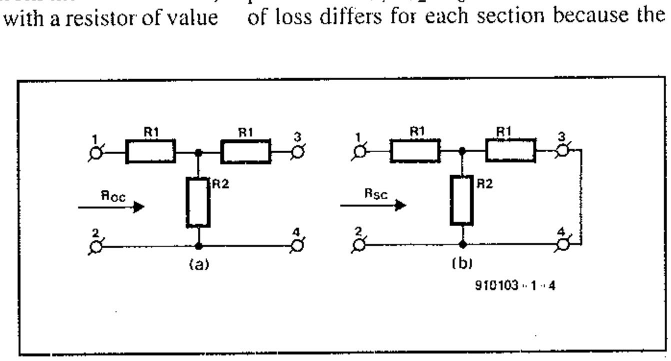

Fig. 4. Extreme termination conditions enable *Ro* to be calculated.

magnitude remaining to be attenuated at any stage is becoming progressively smaller. The *rate* of loss, however, remains constant.

For *n* sections, each reducing the input by some fraction *p*, the output will be p^n; if the attenuation is expressed in dB, *n* sections, each having a loss of *p* dB, will have an overall loss of *np* dB.

Finding R_o

Let us get down to the job of calculating the characteristic resistance of an attenuator section from a knowledge of its component parts.

The forms taken by individual sections of the general attenuator array are T-sections or π-sections; these are illustrated respectively in Fig. 3a and Fig. 3b. The T-section, as its configuration clearly implies, is made up of a divided series-arm and a central shunt-arm. Used between equal impedances, the section is symmetrical when the series-arm contains two equal resistances. The π-section, again as its form implies, consists of a single series-arm and two shunt-arms. This section is symmetrical when the shunt-arms are equal resistances. Both sections, though symmetrical in the way described, are unbalanced in the sense that the series-arm members are on one side of the section 'through' wires. It is essential not to get 'symmetry' confused with balance when talking about attenuator sections.

Working on the T-section for convenience (the π-section will lead us to exactly the same end-result), suppose we terminate the section at points 3 and 4 with the extreme conditions of, first, an open-circuit, and secondly, a short-circuit. Figures 4a and 4b show these cases. Clearly, in the first case, the input resistance seen at terminals 1 and 2 will be

$$R_{oc}=R_1+R_2.$$

and in the second case, it will be

$$R_{sc}=R_1+R_1R_2/(R_1+R_2)$$

Now, between these open-circuited and short-circuited conditions at the termination, there can be an infinite range of resistance values; as the termination changes through this range, the input resistance will change also. It seems reasonable, therefore, that there will be *some* value of the terminating resistance that will make the input resistance *also* equal to this value. This value

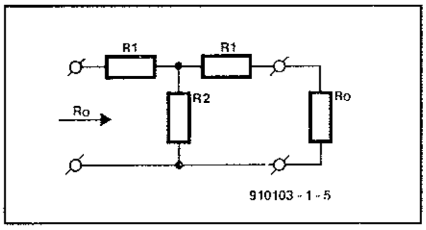

Fig. 5. A correctly terminated section.

must be in accordance with our earlier stated definition, the characteristic resistance of the attenuator section. So, from Fig. 5 we have

$$R_o=R_1+R_2(R_1+R_o)/(R_1+R_2+R_o)$$

Solving this for R_o, we get

$$R_o=\sqrt{(R_1^2+2R_1R_2)}$$

This enables us to find the characteristic resistance of a section from a knowledge of the resistor values making up the section.

We can now go one step further and find R_o without necessarily knowing the values of the elements used in a section. All we need to know is the input resistance (which can easily be measured) when the output terminals are either open-circuited or short-circuited. For, looking back a few lines, we have the product $R_{oc}R_{sc}$ expressible as

$$R_{oc}R_{sc}=(R_1+R_2)[R_1+R_1R_2/(R_1+R_2)]$$

and multiplying this out, we get

$$R_{oc}R_{sc}=R_1^2+2R_1R_2$$

The right-hand side of this is R_o^2, so that

$$R_o=\sqrt{(R_{oc}R_{sc})},$$

which provides us with a very neat way of calculating the characteristic resistance of any section.

Cascaded sections

Although a single section will operate successfully as an attenuator, it is usual to have a number of sections in cascade or tandem so that a range of attenuation is provided. Once the R_o of a particular section has been found, another section may be added to it without affecting the overall characteristic resistance. For, if in Fig. 6a section A is terminated correctly by R_o, an identical section connected in place of R_o will in turn correctly terminate A, since section A will be unable to distinguish between the presence of section B or the presence of a single terminating resistor equal in value to R_o.

It is plain that no matter how many such sections are wired in cascade, the input resistance will remain at R_o. What will change as we progress along the chain is the total attenuation: each section will introduce the same attenuation, but the desired overall attenuation can be achieved by using the required number of sections.

Finding the attenuation

Knowing the characteristic resistance of a circuit into which an attenuator is to be inserted, the problem of design boils down to finding suitable values for R_1 and R_2, given R_o and the required attenuation.

A desired value of R_o can be obtained with numerous combinations of R_1 and R_2; looking at Fig. 7, for instance, both sections shown have a characteristic resistance of 30 Ω (check on this for yourself!) but the network on the right will provide a greater degree of attenuation than the one on the left.

As we have already mentioned, the attenuation may be expressed as a fraction, that is, as a ratio of output voltage (U_o) to input voltage (U_i). Expressed in decibels

$$\text{attenuation}=20\log(U_i/U_o)$$

If the ratio of the input power P_i and the output power P_o is taken

$$\text{attenuation}=10\log(P_i/P_o) \quad [\text{dB}]$$

$$=20\log\sqrt{(P_i/P_o)} \quad [\text{dB}].$$

whence $U_i/U_o=\sqrt{(P_i/P_o)}=N$, the attenuation factor. Notice that with this notation the attenuation is expressed as a whole number, not a proper fraction. This often makes calculations easier.

In next month's concluding part of this article we shall see how the attenuation can be provided and how practical attenuators can be built to suit a variety of occasions.

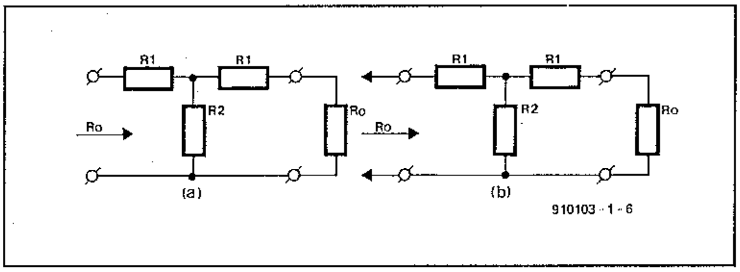

Fig. 6. How sections can be cascaded.

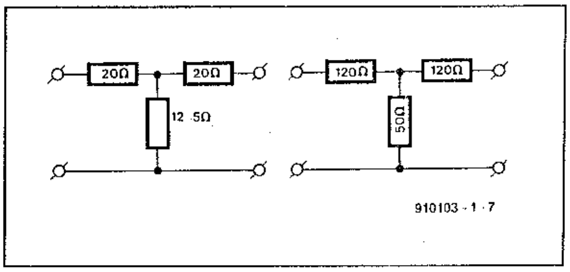

Fig. 7. Networks with identical R_o but different attenuations.

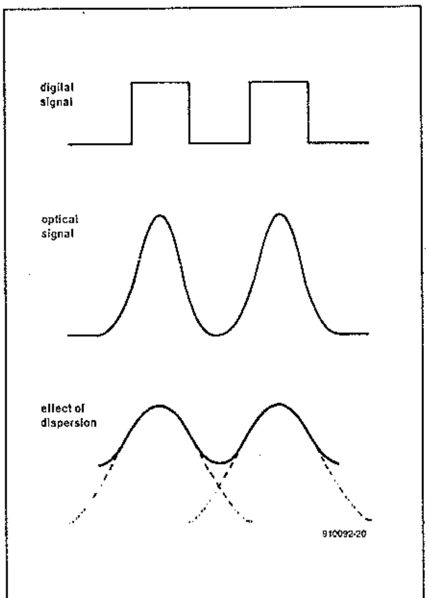

Fig. 10. Effects of dispersion on digital signal bandwidth: a) original data signal; b) light pulse inputto fiber system; c) dispersed light pulses overlapped.

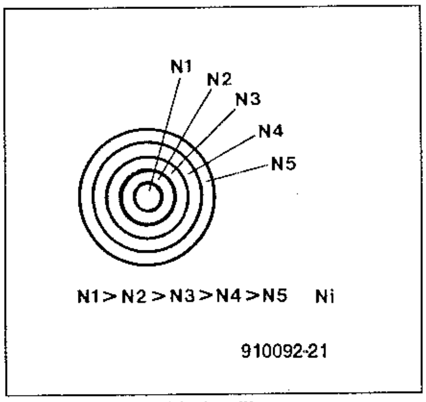

Fig. 11. Graded index fiber.

modes and eventually the cable becomes monomodal; If the core gets down to 3 to 5 microns then only the HE_{11} mode becomes available. The critical diameter required for monomodal operation is:

$$D_{crit} = \frac{2.4\lambda}{\pi\,[NA]} \qquad [15]$$

Because the monomodal cable potentially reduces the number of available modes, it also reduces intermodal dispersion. Thus the monomode fiber is capable of extremely high data rates or analogue bandwidths.

Next month ...

In the second and final instalment of this article we will take a look at losses in fiber optic systems fiber optic communications and some of the basic driver and receiver circuits needed to make fiber optics work. ❑

Reference:

1 "Optical-fibre communication" *Elektor Electronics* February 1991

CORRECTIONS

Wattmeter

April 1991, p. 32-35

With reference the circuit diagram Fig. 1 the right-hand terminal of the lower section of switch S2 should be connected to the circuit ground. This point is indicated by a dot.

In the adjustment procedure given on page 35 the references to presets P4 and P5 have been transposed. Contrary to what is stated P4 sets the VY offset, and P5 the VX offset. The functions of the presets are shown correctly in the circuit diagram, Fig. 1.

To improve the accuracy of the instrument, connect R5 direct to the circuit ground instead of junction R6-R7. Finally, all circuit board tracks carrying mains current must be strengthened with 2.5-mm^2 cross-sectional area solid copper wire if currents higher than about 5 A are measured.

80C32/8052 Single-board computer

May 1991, p. 17-23

When a CPU type 8031 or 8052AH-BASIC is used, IC1, IC2, IC3, and IC8-IC12 must be 74HCT types. Jumper B is erroneously reffered to as B12 in the text under "On-board EPROM programmer". Contrary to what is stated, this jumper must be fitted only when an EPROM is to be programmed — for all other use of the SBC it must be removed. Also note that jumper B may only be fitted when the programming LED is out.

Sequential control

July/August 1991, p. 61

Motor M should be a d.c. type, not an a.c. type as shown in the circuit diagram.

Digital phase meter

June 1991, p. 32-39

In Fig. 5 the switch between input 'A' and IC1 should be identified 'S1', and that between input 'B' and IC2 'S2'. Switch S4 is an on/off type, not a push-button as shown in the diagram. Capacitors C3 and C6 are shown with the wrong polarity. The component overlay of the relevant printed-circuit board (Fig. 8) is all right.

Universal NiCd battery charger

June 1991, p. 14-19

The parts list on page 19 should be corrected to read

C7 = 2200µF 25V

When difficult to obtain, the BYW29/100 (D5) may be replaced by the BY229 which is rated at 6 A.

The text under the heading 'Calibration' should be replaced by:

4. Connect a multimeter between points G and H on the board and adjust P1 until the measured voltage is 1 V lower than the voltage on the battery terminals.

MIDI program changer

April 1991, p. 14-17

The contents of the EPROM should be modified as follows:

address	data
OOBC	E5
00C7	80
00C8	CB
00C9	F5
00CA	7B
00CB	12
00CC	00
00CD	D2
00CE	C2
00CF	02
00D0	80
00D1	C2

Readers who have obtained the EPROM ready-programmed through the Readers Services may return it to obtain an update.

Electronic exposure timer

March 1991, p. 31-35

Please add to the parts list on page 32:
C16 = 33 pF

Augmented A-matrices

May 1991, p. 42-43

The drawing below was erroneously omitted in the left-hand bottom corner of page 43.