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J. OSWALD

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ADJUSTABLE CORRECTING NETWORKS

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2 Sheets-Sheet 1

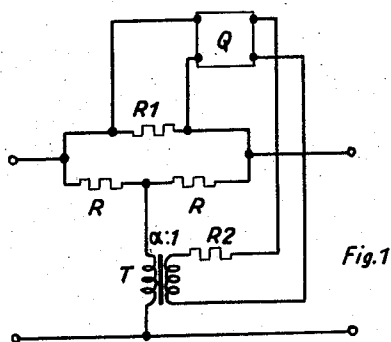


Fig. 1

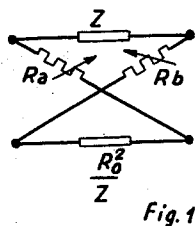


Fig. 1'

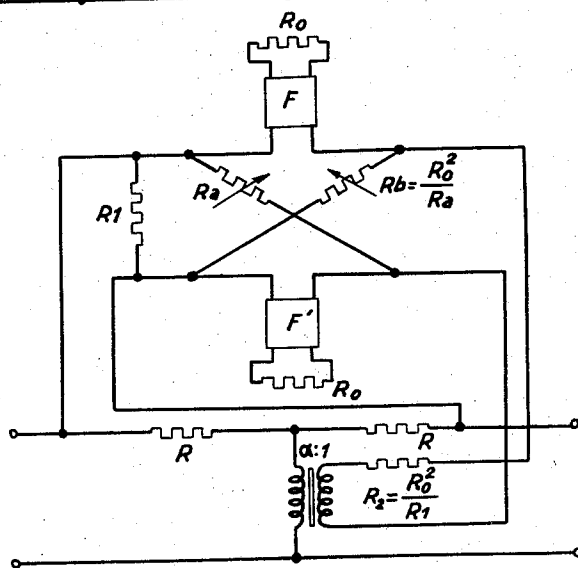


Fig. 2

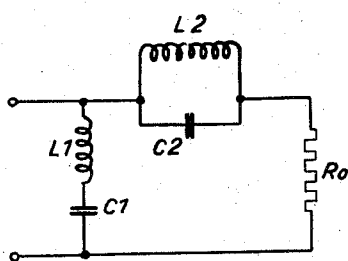


Fig. 3

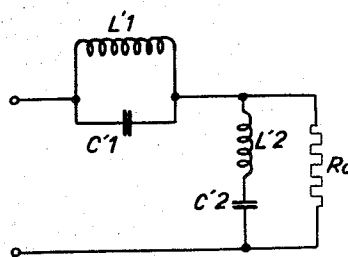


Fig. 4

INVENTOR
JACQUES OSWALD
BY *Paul M. Craig, Jr.*
ATTORNEY

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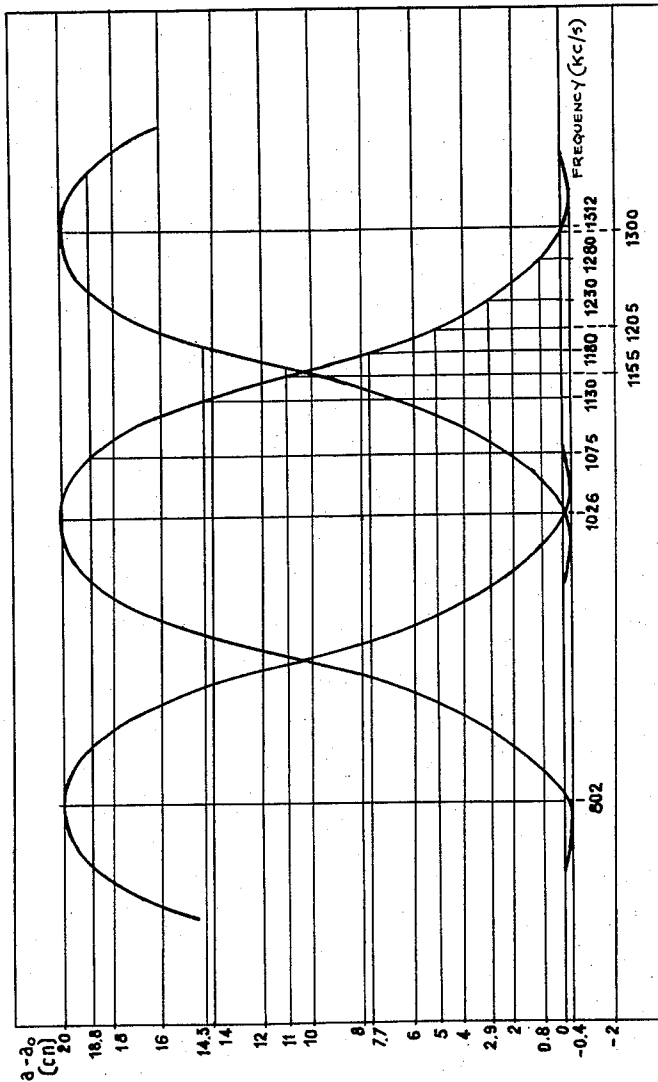


Fig. 5

INVENTOR

JACQUES OSWALD

BY *Paul M. Craig, Jr.*
ATTORNEY

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ADJUSTABLE CORRECTING NETWORKS

Jacques Oswald, Versailles, France, assignor to Compagnie Industrielle des Telephones, Paris, France, a French corporation

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In copending application Serial Number 559,965, filed January 18, 1956, is disclosed a correcting network with adjustable attenuation and constant impedance, comprising a cut-all lattice type network, of which two opposite branches are formed of two resistances R_a , R_b , variable in such a way that their product remains constantly equal to the square of the characteristic impedance R_0^2 of the network, and of which the two other branches are formed by fixed impedances Z and Z' , of which the product is equal to R_0^2 for all the frequencies.

In said copending application the case has been specially in which the fixed impedances are reactances. In this case, the curve of the attenuation caused by the correcting network, as a function of the frequency of the voltage applied thereto, comprises a certain number of pivot points, corresponding to privileged frequencies for which the attenuation does not depend on the adjustment of the resistances of the correcting network.

There is, however, no frequency range in which the attenuation remains constant.

Now, it is nevertheless highly desirable to produce correcting networks of which the attenuation remains constant (equal to a fixed reference value), for all the frequencies comprised outside a certain band, while for the frequencies comprised inside said band, the attenuation varies according to a given function of the frequency, dependent upon a parameter.

By placing such correcting networks in series, each ensuring a given variation of attenuation in the frequency band to which it belongs, it would then be possible to obtain a desired attenuation in the whole of the bands constituting the range in which the correction is to be effected.

In the following an explanation will be given of how such a result can be obtained, in accordance with the present invention, reference being had to the drawings in which:

Figure 1 illustrates a correcting network of the type described in the aforementioned co-pending application; Figure 1' is a lattice-type network of the type useful at Q in Figure 1;

Figure 2 is a schematic illustration of a correcting network according to the present invention;

Figures 3 and 4 are filter networks utilized in connection with the circuit of Figure 2; and

Figure 5 is a curve of attenuation versus frequency for one example of the present invention.

First of all the structure and properties of the correcting network with constant impedance according to the above-mentioned patent application will be recalled.

In one of its embodiments, this correcting network, of characteristic impedance R , consists of a bridged-T (Fig. 1) of which the horizontal branches are each composed of a resistance R , of which the "bridge" arm is composed of a resistance R_1 in parallel on the input terminals of a cut-all antimetric network Q, and of which the vertical branch consists of the secondary winding of a transformer T of which the primary winding is connected in series

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with a resistance R_2 on the output terminals of the network Q.

The cut-all network, represented in Fig. 1', is an anti-metric lattice-type network of which two opposite branches are resistances R_a , R_b , adjustable in such a way that their product remains equal to a fixed value R_0^2 , the two other opposite branches having respectively impedances

$$Z' = \frac{R_0^2}{Z}$$

R_0 is the characteristic impedance of the network, linked to R and R_1 by the relation

$$(1) \quad R_0^2 = \frac{R R_1^2}{R + R_1}$$

For this correcting network, the resistance R_2 and the transformation ratio α of the transformer T (ratio of the number of turns of the secondary winding to that of the primary winding) are respectively determined by:

$$(2) \quad R_1 R_2 = R_0^2$$

$$(3) \quad \alpha^2 = \frac{R^2}{R_0^2}$$

It is now proposed to obtain a correcting network of which the effect is limited to a certain frequency domain, i.e. to one or more frequency zones for which it gives an attenuation variable in accordance with an imposed law, while outside this zone or zones, its attenuation is reduced to a fixed reference value.

The correcting network according to the present invention, which makes it possible to achieve this result, is characterised in this, that the impedances of the two fixed branches of the cut-all network are respectively composed of the input impedances of two inverted filters, i.e. filters such that the impedance matrix of the one is equal, within the factor R_0^2 , to the admittance matrix of the other, the output terminals of said filters being closed on resistances equal to R_0 , the elements of these filters being determined in such a way that in order to obtain that the adjustment of the correcting network affects the attenuation caused by the latter only in a certain frequency band, while in the external band or bands said attenuation remains substantially constant and independent of this adjustment, said filters admit said band as attenuated band and the external band or bands as pass-bands.

Fig. 2 represents schematically a correcting network constituted in this way. It has been shown in the patent application cited above (Formulae 4 and 14) that the transfer exponent θ of a correcting network according to said patent is given by the relation:

$$(4) \quad \text{Tanh} \frac{\theta - a_0}{2} = \rho \frac{Z - R_0}{Z + R_0} \tanh \frac{a_0}{2}$$

in which the factor ρ is equal to:

$$(5) \quad \rho = \frac{R_a - R_0}{R_a + R_0}$$

and in which a_0 designates the attenuation of the correcting network for $\rho=0$, i.e. for $R_a=R_b=R_0$, this attenuation being, at all the frequencies equal to:

$$\text{Log} \frac{R_1}{R_0} = \frac{1}{2} \log \left(1 + \frac{R_1}{R} \right)$$

Now it is known that, for the frequencies comprised in the bands in which the composite attenuation of the filter is negligible, the effective input impedance of the filter is substantially equal to the impedance connected to its output terminals; the second factor of the right hand side of (4) is therefore very close to zero and consequently θ is substantially identical with a_0 ; the correcting network therefore only introduces a constant at-

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tenuation. In the attenuated bands, on the other hand, the effective impedance is variable, and consequently also the attenuation introduced by the correcting network.

The mathematical relations will now be established which the elements of the correcting network according to the invention have to satisfy.

For this purpose, the effective reflection exponent $\Gamma_r = A_r + jB_r$ of the filter F will be introduced, having an effective input impedance Z bound to Γ_r by the relation:

$$(6) \quad \frac{Z - R_0}{Z + R_0} = e^{-\Gamma_r}$$

or

$$(7) \quad Z = R_0 \coth \frac{\Gamma_r}{2}$$

while, in the above-mentioned patent, the impedance Z was defined by:

$$(8) \quad Z = R_0 \coth \Gamma$$

The transfer exponent of the correcting network will therefore be obtained by substituting

$$\frac{\Gamma_r}{2}$$

for Γ in Formula 4, which gives:

$$(9) \quad \tanh \frac{\theta - a_0}{2} = \rho e^{-\Gamma_r} \tanh \frac{a_0}{2} = \mu e^{-\Gamma_r}$$

by putting

$$(10) \quad \mu = \rho \tanh \frac{a_0}{2}$$

it follows that:

$$(11) \quad \theta - a_0 = \log \frac{1 + \mu e^{-\Gamma_r}}{1 - \mu e^{-\Gamma_r}}$$

and, by separating the real and imaginary parts, we find, designating by a the attenuation of the correcting network.

$$(12) \quad \tanh (a - a_0) = \frac{2\mu e - A_r}{1 + \mu^2 e - 2A_r} \cos B_r$$

This Formula 12 makes it possible to specify the behaviour of the correcting network.

In the pass-bands, the reflection attenuation A_r is very high, so that a remains practically equal to a_0 . It should be noted that the obtaining of a constant attenuation equal to a fixed value independent of the adjustment of the corrector, outside the frequency band in which the correcting network can act, constitutes an indubitably exclusive advantage of the type of correcting network according to the invention: in the Bode correctors, in effect, attenuations are obtained in the pass band of the filters which certainly remain substantially constant, but which depend on the resistances connected to the terminals of these filters, i.e. on the adjustment of the correcting network.

In the attenuated bands, A_r is negligible, the effective impedance then being very close to a reactance, so that

$$\left| \frac{Z - R_0}{Z + R_0} \right|$$

is substantially equal to 1; it follows that:

$$(12') \quad \tanh (a - a_0) = \frac{2\mu}{1 + \mu^2} \cos B_r$$

The curve of the attenuation produced by the corrector, as a function of the frequency of the voltage applied thereto, therefore has pivot points, independent of the adjustment of the correcting network, for the frequencies corresponding to

$$(13) \quad B_r = (2h + 1) \frac{\pi}{2}$$

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(h being any whole number) for which the input impedance Z of the filters is equal to $\pm jR_0$ and this curve shows maxima variations for all the adjustments of the corrector, at frequencies corresponding to:

$$(14) \quad B_r = h\pi$$

for which the impedance Z shows a zero or a pole.

In the attenuated bands, for the frequencies sufficiently far from the cut-off frequency, the input impedance Z of the filters differs little from their image impedance W_1 , regarded from their input terminals; the pivot points of the attenuation curve therefore substantially correspond to the frequencies for which the image impedance of the filters assumes the values $\pm jR_0$.

On the other hand, for the frequencies for which the variation of attenuation is maximum, the image impedance W_1 of the filters shows the same singularity (zero or pole) as their effective input impedance Z; these frequencies are therefore defined strictly by the poles or zeros of the image impedance.

In the vicinity of the cut-off frequencies of the filters, Γ_r must be determined by the formula:

$$(15) \quad e^{\Gamma_r} = \frac{W^2 + R_0^2 + qR_0(W_1 - W_2)}{W^2 - R_0^2 - qR_0(W_1 - W_2)}$$

in which W_2 designates the second image impedance of the filters, W their characteristic impedance ($W^2 = W_1 W_2$) and q their attenuation function.

According to whether it is desired to obtain an equalizer operating for frequencies lower than a given frequency, or higher than a given frequency, or comprised between two given frequencies, low-pass filters or band-cut filters will be chosen for the filters F and F'.

The determination of the elements of the corrector network is thus reduced to that of a filter of which the reflection exponent assumes given values for given frequencies; this is a well-known problem which can be solved by a method of approximation.

It is obvious that instead of the bridged-T arrangement, the equivalent differential arrangement described in the above-mentioned patent application can be used.

By way of example, a correcting device has been carried out for a wide frequency band, comprised between 300 kc./s. and 12,000 kc./s. This device comprises, in series, sixteen elementary correcting units $S_1, S_2, \dots, S_p, \dots, S_{16}$, of which the attenuation curves are identical, to the nearest translation, in a logarithmic scale of frequencies, and of which the middle frequencies (frequencies of maximum attenuation) are regularly distributed in said scale, that of the first elementary corrector being equal to 300 kc./s., that of the p th being to

$$\left(\frac{12,000}{300} \right)^{\frac{p-1}{15}} \text{ kc./s.}$$

and that of the sixteenth to 12,000 kc./s. The ratio of the middle frequencies of two adjacent elementary correctors is thus equal to 1.279; these frequencies are respectively 802 kc./s., 1026 kc./s. and 1312 kc./s. for the 5th, 6th and 7th correctors. The filters F and F' forming the opposite branches of the cut-all network are band-cut filters, of inverse impedances, of which the diagrams are given in Figs. 3 and 4 respectively.

By replacing $\cos B_r$ by 1 and μ by

$$(12'') \quad \tanh \left(\rho - \tanh \frac{a_0}{2} \right)$$

in (12'), which constitutes a permissible approximation, we obtain:

$$\tanh (a - a_0) \simeq \tanh \left(2\rho \tanh \frac{a_0}{2} \right) \simeq \tanh (\rho a_0)$$

hence

$$a - a_0 \simeq \rho a_0$$

By choosing for a_0 a value of 0.25 neper, the mean

characteristic impedance R_0 of the cut-all network is equal to $R/2$, that is to say to 37.5 ohms if the correcting network is adapted to impedances of 75 ohms.

For the corrector S_6 of which the middle frequency is $f_6=1026$ kc./s., and which operates in a frequency band substantially limited by the middle frequencies of the adjacent correctors, the elements have been chosen thus:

$$\begin{aligned} L_1 &= 9.75 \mu\text{h.} & L'_1 &= 3.50 \mu\text{h.} \\ L_2 &= 1.75 \mu\text{h.} & L'_2 &= 19.5 \mu\text{h.} \\ C_1 &= 2440 \text{ pf.} & C'_1 &= 6775 \text{ pf.} \\ C_2 &= 13,550 \text{ pf.} & C'_2 &= 1220 \text{ pf.} \end{aligned}$$

The measurements of attenuation carried out on this corrector gave the results shown in the following table, in which f/f_6 designates the ratio of the frequency f , of the voltage applied to the correcting network, to the frequency f_6 on which it is centred, and in which $a-a_0$ is the difference between the attenuation " a " caused by the network for the frequency f and the attenuation " a_0 " which it produces substantially for all the frequencies outside its operating band.

f/f_6 or f_6/f	$a-a_0$ (Centin nebers)
1	20
1.05	18.8
1.1	14.3
1.125	11
1.15	7.7
1.175	5
1.2	2.9
1.245	0.8
1.265	0
1.30	-0.4
1.35	-0.1

Fig. 5 represents the attenuation curves of the 5th, 6th and 7th correctors for $\rho=0.8$; of course the adjustment of each corrector is independent, so that the ordinates of each curve of deviation can be multiplied separately by a positive or negative factor comprised between (-1) and $(+1)$, if 0.8 be allowed as absolute maximum value of ρ , and between (-1.25) and $(+1.25)$ if this value be raised to 1.

In the event that the correcting network according to the invention is used in a system of telecommunication by cable, comprising amplifiers and equalisers, it makes it possible to correct with great accuracy the deviations of attenuation due to systematic and uncertain imperfections of said amplifiers and equalisers.

The correcting networks according to the present invention can be carried out with great economy: in the example just described, each correcting network comprises in addition to the capacitors of which the cost is relatively low, four inductances and one transformer; which is substantially equivalent, from the point of view of cost, to five inductances. The total cost of the correcting device comprising sixteen elementary correcting networks is therefore of the order of the cost of eighty inductances, that is, substantially less than that of equivalent correctors of the well-known type.

What I claim is:

1. In a transmitting line an attenuation-correcting network comprising a main bridged-T four-terminal network including two horizontal branches each comprising a resistance equal to R , a vertical branch including the primary winding of a transformer, and a bridge branch including the input circuit of a cut-all antimetric auxiliary four-terminal network having a mean characteristic impedance R_0 , the output circuit of said auxiliary four-terminal network being connected to the secondary winding of said transformer, said auxiliary four-terminal network being a lattice-type network and comprising a first pair of opposite branches comprising resistances adapted to be varied while maintaining their product equal to R_0^2 , and a second pair of opposite branches including fixed impedances of which the product is also

equal to R_0^2 , wherein said fixed impedances include respectively the input circuit of two filters of which the output circuits are each connected, respectively, to a resistance R_0 , said filters being adapted to have a non-zero composite attenuation throughout the domain of correction and a negligible composite attenuation outside said domain, whereby said attenuation-correcting network only affects the effective attenuation in a definite frequency band.

2. In a transmitting line an attenuation correcting network comprising a main bridged-T four-terminal network including two horizontal branches, one vertical branch and one bridge branch, each of said horizontal branches including a resistance equal to the value of the constant characteristic impedance of the line, and at least one cut-all antimetric auxiliary four-terminal network, the input thereof being inserted in said bridge branch and the output thereof being coupled with said vertical branch, said auxiliary four-terminal network being a lattice-type network and having a mean characteristic impedance R_0 and comprising a first pair of opposite branches having resistances which are adapted to vary while maintaining their product equal to R_0^2 and a second pair of opposite branches including fixed impedances of which the product is also equal to R_0^2 ; wherein said fixed impedances include the input circuits of two filters of which the output circuits are connected each to a respective resistance of R_0 value, said filters being adapted to have a non-zero composite attenuation in a certain frequency band, and a negligible composite attenuation outside said frequency band whereby said attenuation-correcting network only affects the produced attenuation throughout a domain of correction including said frequency band.

3. In a transmitting line a plurality of attenuation-correcting networks inserted therein, said attenuation-correcting networks being series connected in said transmitting line, wherein each of said attenuation-correcting networks comprises a main bridged-T four-terminal network including two horizontal branches one vertical branch and one bridge branch, each of said horizontal branches including a resistance equal to the value of the line constant characteristic impedance, cut-all antimetric auxiliary four-terminal networks being associated respectively with each of said main bridged-T four-terminal networks, each auxiliary network being a lattice-type network and having input and output circuits; wherein the input circuit of each auxiliary four-terminal network is inserted in the bridge branch of the associated main four-terminal network, the output circuit of the same being coupled with the corresponding vertical branch; wherein each of said auxiliary four-terminal networks has a corresponding mean characteristic impedance and comprises a first pair of opposite branches having resistances which are adapted to vary while maintaining their product equal to the square value of said corresponding mean characteristic impedance and a second pair of opposite branches including fixed impedances of which the product is also equal to the square value of said corresponding mean characteristic impedance; wherein said fixed impedances include the input circuits of two filters, the output circuits of said filters being connected each to a respective resistance of value equal to said corresponding mean characteristic impedance and said filters in each of said attenuation-correcting networks being adapted to have a non-zero composite attenuation within corresponding given frequency band and a negligible composite attenuation outside said corresponding frequency band whereby each of said attenuation-correcting networks can be adjusted independently so as to define a zone of correction for said plurality of attenuation-correcting networks which includes the various corresponding frequency bands.

4. In a transmitting line an attenuation-correcting network comprising a main T network including two hori-

zontal branches and a vertical branch, at least one cut-all antimetric auxiliary four-terminal network having a mean characteristic impedance R_0 , the input circuit of said auxiliary four-terminal network being coupled with each of said horizontal branches, and the output circuit of said auxiliary four-terminal network including said vertical branch, said vertical branch having a resistance value which is in relation with the line constant characteristic impedance, said auxiliary four-terminal network being a lattice-type network comprising a first pair of opposite branches including resistances which can be made to vary while maintaining their product equal to R_0^2 , and a second pair of opposite branches including fixed impedances of which the product is also equal to

R_0^2 , wherein said fixed impedances include respectively the input circuit of two filters of which the output circuits are each connected, respectively, to a resistance R_0 , said filters being adapted to have a non-zero composite attenuation throughout the domain of correction and a negligible composite attenuation outside said domain, whereby said attenuation-correcting network only affects the effective attenuation in a definite frequency band.

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