PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

A Symmetrical Polyphase Network

We, STANDARD TELEPHONES AND CABLES LIMITED, a British Company, of STC House, 190 Strand, London W.C.2, England, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to symmetrical polyphase networks.

In order to understand the operation of the symmetrical polyphase networks according to the invention, the concept of negative frequency must be introduced. If a four-phase system is considered which has as shown in the drawing according to FIGURE 1 (A) voltages of V, −jV, −V, +jV applied to its four input terminals then the input signal can be called symmetrical since all voltages are equal in magnitude and spaced apart by steps of 90°, and of say positive sequence since, conventionally, all vectors rotate anticlockwise and the voltage on path 1 leads that on path 2 by 90°, and similarly, the voltage on path 2 leads that on path 3 etc. If now the vectors rotate the opposite way i.e. as shown in the drawing according to FIGURE 1 (B) the system is still symmetrical but is now of negative sequence since the voltage on path 1 lags the voltage on path 2 by 90° instead of leading as before.

Considering the voltage on path 1 it can be seen from the drawing according to FIGURE 2 that this voltage is $V \sin \omega t$ i.e. the projection of the vector 1 on to the imaginary axis when it is being rotated anticlockwise. When the sequence of vectors is reversed, $-V \sin \omega t$ will be observed. Since $-\sin \omega t = \sin(-\omega t)$ it can be said that, on one phase, positive sequence represents positive ω and negative sequence represents negative ω. Thus where positive and negative frequencies are hereinafter referred to with reference to the characteristics of a single phase network it means positive and negative sequence respectively in a polyphase network containing N phases of the single phase network.

The invention provides a symmetrical polyphase network including two or more polyphase network sections connected in cascade which each include a first impedance in each one of its N-phases connected between the input and output terminals thereof, the input of each one of said N-phases being connected to the output of an adjacent phase via a second impedance having a different phase angle to said first impedance.

The foregoing and other features according to the invention will be better understood from the following description with reference to the accompanying drawings, in which:—

FIGURES 1 (A) and 1 (B) respectively illustrate positive and negative sequence four phase vector diagrams.

FIGURE 2 illustrates a positive sequence four phase vector diagram.

FIGURE 3 shows the circuit diagram of a network section of a symmetrical four phase network according to the invention.

FIGURE 4 illustrates attenuation characteristics for the network shown in the drawing according to FIGURE 3,

FIGURE 5 illustrates attenuation characteristics for a symmetrical polyphase network which includes four network sections of the type shown in the drawing according to FIGURE 3 connected in cascade,

FIGURE 6 shows the circuit diagram of a network section of a symmetrical three phase network according to the invention,

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FIGURE 7 shows the ω plane pole-zero plot for a passive symmetrical polyphase network according to the invention.

FIGURE 8 shows the circuit diagram of two of the symmetrical four phase network sections according to FIGURE 3 connected in cascade via a four phase 1 to j impedance transformer,

FIGURES 9 (A) and (B) show frequency response curves for an N-path frequency translation system having low pass filters connected in each of the N-paths thereof.

FIGURES 10 (A) and (B) show frequency response curves for an N-path frequency translation system which utilizes the symmetrical polyphase networks according to the invention,

FIGURES 11 (A) to (C) show vector diagrams, and

FIGURE 12 shows the circuit diagram of a two phase quadrative modulator network.

It is well known in the art that it is possible to build passive R-C all-pass networks and to construct two such networks with a phase difference at their outputs of approximately 90° with a bandwidth determined by the network complexity.

A single network section of the symmetrical polyphase network according to the invention which performs exactly the same function as the two separate R.C networks and which is very much less sensitive to component tolerances is of the type shown in the drawing according to FIGURE 3. When two or more of these network sections are provided they are connected in cascade.

Referring to FIGURE 3, a four phase network section together with typical voltages and currents associated with each phase is shown therein and includes a resistance R in each of the four phases which is connected between the input and output terminals of the phase with which it is associated. The input of each phase connected to the output of an adjacent leading phase via a capacitance C.

The chain matrix for each one of the phases of this four phase network section is:—

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} \frac{1+j\omega CR}{1-\omega CR} & \frac{R}{1-\omega CR} \\ \frac{2j\omega C}{1-\omega CR} & \frac{1+j\omega CR}{1-\omega CR} \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \quad \cdots\cdots(1)$$

From this matrix it can be seen that a transmission zero occurs at $\omega=1/CR$. The insertion loss for a single phase takes the form shown by the chain dotted line 1 in the drawing according to FIGURE 4.

It should be noted that the input of each phase of the network according to FIGURE 3 may be connected via a capacitance to the output of an adjacent lagging phase instead of an adjacent leading phase in which case the chain matrix (1) would become: —

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} \frac{1+j\omega CR}{1+\omega CR} & \frac{R}{1+\omega CR} \\ \frac{2j\omega C}{1+\omega CR} & \frac{1+j\omega CR}{1+\omega CR} \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \quad \cdots\cdots(2)$$

It can therefore be seen from this matrix that a transmission zero will occur at $\omega=-1/CR$ and the insertion loss for a single phase will take the form shown by the dotted line 2 in the drawing according to FIGURE 4.

In each of the symmetrical polyphase network sections outlined in the preceding paragraphs, the capacitance C and resistance R may be interchanged. This interchange results in a reversal of the attenuation characteristics about zero frequency and introduces a phase shift through the network section of 90°. For example, the chain matrix (1) for the network section of FIGURE 3 becomes:—

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} \frac{1+j\omega CR}{j(1+\omega CR)} & \frac{R}{j(1+\omega CR)} \\ \frac{2j\omega C}{j(1+\omega CR)} & \frac{1+j\omega CR}{j(1+\omega CR)} \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \quad \cdots\cdots(3)$$

when the capacitance and resistance are interchanged.

The characteristic from a single network section is not be very desirable for most applications and in particular where it is necessary to be able to regulate the attenuation characteristics to a desired form and it is therefore necessary to use two or more sections connected in cascade. For example, the attenuation characteristic shown in the drawing according to FIGURE 5 may be required in which case it would be necessary to provide four of the network sections connected in cascade, the transmission zeros which occur in the lower side band at

$$\omega_1=-1/C_1R_1,\ \omega_2=-1/C_2R_2, \omega_3=-1/C_3R_3 \text{ and } \omega_4=-1/C_4R_4$$

are each associated with a separate one of the four phases.

The combined value of the circuit elements associated with each network section fixes the position of the transmission zero associated with that particular network section and the shape of the pass band section of the attenuation characteristics shown in FIGURE 5 may be varied by causing a variation of the value of the circuit elements associated with any one of the network section whilst maintaining the combined value of these elements. By this means the average attenuation level for the pass band may be varied as desired to suit a particular requirement. There will of course be a corresponding change in the minimum levels i.e. the levels 3 shown in FIGURE 5, for the attenuation characteristic between the transmission zeros thereby resulting in a variation of the average attenuation level for the stop band section of the attenuation characteristics.

A synthesis procedure which may be used to determine the characteristics of a plurality of cascade network sections involves multiplying the matrices of these sections together in order to determine the overall transfer function in terms of the elements i.e. the resistance and capacitances associated with each network section. The transfer function of the cascade network sections plus quadrature modulation is then equated to the transfer function of the equivalent two all-pass networks plus quadrature modulation.

By equating coefficient of powers of ω the element values of the symmetrical polyphase network can be determined and the desired characteristic obtained.

Utilization of this synthesis procedure enables symmetrical polyphase networks having up to four cascade network sections to be designed quite easily. Beyond four sections the algebra begins to become arduous although there is no limit, theroetically, to the network complexity. It has been found advantageous in view of this problem to utilize a computer to determine the values of the elements of the various network sections which give the desired insertion loss characteristics.

Symmetrical polyphase networks with other than four phases are slightly more complex, the circuit diagram of a three phase network scetion is shown by way of example in the drawing according to FIGURE 6. This three phase network section which may be utilized for example to provide three phase 50Hz for an electric motor is basically the same as the network section according to FIGURE 3 except the voltages associated with each phase are different and a resistance R/2 is connected is series with the capacitance C between the input of each phase and the output of an adjacent leading phase. It should be noted that the modifications and applications outlined in preceding paragraphs for the circuit diagram according to FIGURE 3 also apply to this circuit arrangement for example, four of the network sections according to FIGURE 6 when connected in cascade would have the attenuation characteristic shown in FIGURES of the drawings.

The voltages associated with each phase are respectively V, hV and h^2V where

$$h=-\tfrac{1}{2}+j\sqrt{3/2} \qquad (4)$$

$$h^2=-\tfrac{1}{2}-j\sqrt{3/2} \qquad (5)$$

$$h^3=1 \qquad (6)$$

and $$h+h^2+h^3=0 \qquad (7)$$

Also $$\omega 00=\frac{2}{\sqrt{3^{RC}}} \qquad (8)$$

The main requirement for the symmetrical polyphase network according to the invention is that each network section must include a first impedance in each of the phases connected between the input and output terminals thereof and and the input of each phase must be connected to an adjacent phase i.e. leading or lagging via another impedance having a different phase angle to the first impedance.

The passive symmetrical polyphase networks outlined in the preceding paragraphs are restricted by their passivity to transfer functions with transmission poles on the imaginary axis of their ω plane pole—zero plot and tranmission zeros on the real axis of this plot as shown in the drawing according to FIGURE 7.

For some types of functions the transmission poles are not, generally, on the imaginary axis. One method of realising such functions is to interpose N-phase 1 to j impedance transformers of a type as outlined in our co-pending patent application No. 27161/68 (Serial No. 1174709) at one or more points in the cascade of network sections as shown in the drawing according to FIGURE 8 for example wherein a four phase 1 to j impedance transformer 4 is interposed between two four phase network sections of the type shown in the drawing according to FIGURE 3.

Further freedom of pole position may be obtained by using negative impedance converters of inverters in addition to the N-phase 1 to j impedance transformers which would be interposed between each phase of a network section and a corresponding phase of an N-phase 1 to j impedance transformer.

The symmetrical polyphase networks outlined in the preceding paragraphs have a particular but not necessarily an exclusive application in the N-path frequency translation system outlined in British Patent Specification No. 1,098,250 and also in single sideband generation in a manner similar but superior to conventional quadrature modulation.

The transfer function of the N-path frequency translation system is defined by

$$V_0(p)=K\,.\,H(p-p_1).\ V_1(p-p_1+P_2)$$

where K is constant.

$H(p)$ is the transfer function of the network(s) in the N paths

$P_1=j2\pi f_1$

$p_2=j2\pi f_2$

f_1 is the input switching rate

f_2 is the output switching rate

It can be seen that the transfer function $H(p)$ is shifted along the real frequency axis by an amount f_1. Normally, in the N path filter system where $p_1=p_2$, this would result in a band pass characteristic symmetrical about the frequency f_1. If low pass filters are connected in the N paths the resultant characteristic will be that of a shifted low pass filter (including that at negative frequencies which is the mirror image of the positive frequency response). This is shown in the drawing according to FIGURES 9 (A) and (B). Symmetrical characteristics are often very wasteful when modulation processes are involved. In such cases much more attenuation is needed on one side of the pass band than the other. By using the symmetrical polyphase networks according to the invention the characteristic can be made to fit the requirement more efficiently. Also, it is no longer necessary for the switching or carrier frequency to be at midband. FIGURES 10 (A) and (B) illustrate this by way of example.

The symmetrical polyphase networks according to the invention may also be used for splitting a single phase into N phases.

According to the theory of symmetrical components any unbalanced system of N vectors can be represented as the sum of N symmetrical vector systems. If for example a two-phase (quadrature) system is considered with an input of V on one phase only then this is equivalent to applying two opposite sequence two phase signals simultaneously as shown in the drawings according to FIGURES 11 (A) to (C). If the transfer function of the system is $H(p)$ to the vector system according to FIGURE 11 (B) then it will be $H(-p)$ to the vector system according to FIGURE 11 (C). FIGURE 12 shows a two phase system with an input on one phase only which includes a two-phase network 10 having the input V_1 for one phase thereof i.e. phase 1 connected to a voltage source V and the input V_2 for the other phase thereof i.e. phase 2 connected to earth potential i.e. $V_2=0$. The voltage output V_3 of phase 1 is connected via a modulator 7 and a summation unit 9 to the output and the voltage output V_4 of phase 2 is connected via a modulator 8 and the summation unit 9 to the output.

At the output of phase 1 therefore

$$V_3=\frac{V}{2}(H(p)+H(-p))$$

and on phase 2

$$V_4=j\frac{V}{2}(H(p)-H(-p))$$

If quadrature modulation is then applied to V_3 and V_4 as shown in FIGURE 12 the resultant output is

$$V_{O(p)}=\frac{V(p\pm p_c)}{2}\Big[H(p)+H(-p)\pm j(jH(p)-jH(-p))\Big]$$

$$=H(p)\,V(p-p_c)+H(-p)\,V(p+p_c)$$

The effect is as if the modulation was done first, followed by a normal type of filter with the response $H(p+p_c)$. For this purpose the characteristic of the polyphase network would be as shown in FIGURE 10. The lower side band would then be suppressed while the upper sideband $V(p+p_c)$ would be passed. It should be noted that a two phase version of the network according to the invention cannot be realized in a practical form but this basic method can be employed for any number of phases and can therefore be adapted for the symmetrical polyphase networks according to the invention.

It should also be noted that it is possible to use the network of FIGURE 12 without modulators simply as a circuit to provide a two phase output from a single phase input. This is provided the network offers sufficient attenuation to negative sequence inputs and passes positive sequence inputs. FIGURE 11 shows a suitable characteristic. In a similar manner it is possible to generate an N phase output from a single phase input.

It should be noted that FIGURES 9 to 12 of our present patent application relate to subject-matter similar to the subject-matter outlined in our co-pending patent application No. 27161/68 in relation to 1174709) in relation to FIGURE 29 to 32.

WHAT WE CLAIM IS:—

1. A symmetrical polyphase network including two or more polyphase network sections connected in cascade which each include a first impedance in each one of its N-phases connected between the input and output terminals thereof, the input of each one of said N-phases being connected to the output of an adjacent phase via a second impedance having a different phase angle to said first impedance.

2. A symmetrical polyphase network as claimed in claim 1 wherein said adjacent phase is a leading phase.

3. A symmetrical polyphase network as claimed in claim 1 wherein said adjacent phase is a lagging phase.

4. A symmetrical polyphase network as claimed in any one of the preceding claims wherein when N is equal to four said first impedance is provided by either a first resistance or a first capacitance.

5. A symmetrical polyphase network as claimed in claim 4 wherein said second impedance is provided by a second capacitance when said first impedance is provided by a first resistance.

6. A symmetrical polyphase network as claimed in claim 4 wherein said second impedance is provided by a second resistance when said first impedance is provided by a first capacitance.

7. A symmetrical polyphase network as claimed in any one of the claims 1 to 3 wherein when N is equal to three said first impedance is provided by either a first resistance or a first capacitance connected in series with a second resistance.

8. A symmetrical polyphase network as claimed in claim 7 wherein said second impedance is provided by a second capacitance connected in series with a third resistance when said first impedance is provided by a first resistance.

9. A symmetrical polyphase network as claimed in claim 7 wherein said second impedance is provided by a third resistance when said first impedance is provided by a first capacitance connected in series with a second resistance.

10. A symmetrical polyphase network as claimed in any one of the preceding claims which also includes at least one N-phase 1 to j impedance tranformer, each one of which is interposed between a separate two of said cascaded polyphase network sections.

11. A symmetrical polyphase network as claimed in claim 10 which also includes negative impedance converters or inverters interposed between each phase of any one of said N-phase 1 to j impedance transformers and corresponding phases of a polyphase network section.

12. A symmetrical polyphase network substantially as hereinbefore described with reference to FIGURES 1, 2, 3 and 5 of the accompanying drawings.

13. A symmetrical polyphase network substantially as hereinbefore described with reference to FIGURES 1, 2, 5 and 6 of the accompanying drawings.

14. A symmetrical polyphase network substantially as hereinbefore described with reference to FIGURES 7 and 8 of the accompanying drawings.

15. An N-path frequency translation system which utilizes a symmetrical polyphase network as claimed in any one of the preceding claims.

16. An N-path frequency translation system which utilizes a symmetrical polyphase network as claimed in any one of the claims 1 to 14 substantially as herein-before described with reference to FIGURES 9 and 10 of the accompanying drawings.

17. A single side band generator which includes the symmetrical polyphase network as claimed in any one of the claims 1 to 14.

18. A phase splitting system which utilizes a symmetrical polyphase network as claimed in any one of the claims 1 to 14.

19. A polyphase modulator which utilizes a symmetrical polyphase network as claimed in any one of the claims 1 to 14, wherein the output of each phase of the symmetrical polyphase network is modulated before being applied to a summation unit, the output of which is the output of said polyphase modulator.

20. A polyphase modulator which utilizes a symmetrical polyphase network as claimed in any one of the claims 1 to 14 substantially as hereinbefore described with reference to FIGURES 11 and 12 of the accompanying drawings.

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Chartered Patent Agent
For the Applicants

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Fig. 1.

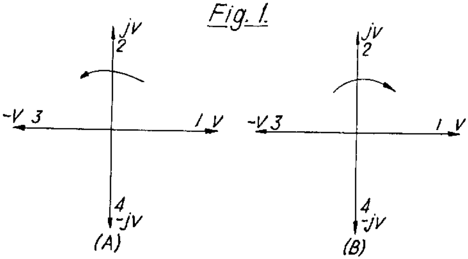


Fig. 2.

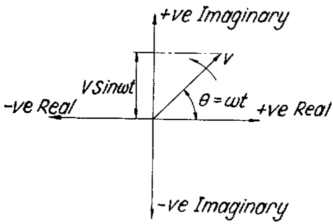


Fig. 11.

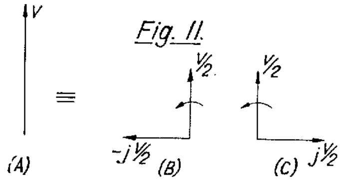
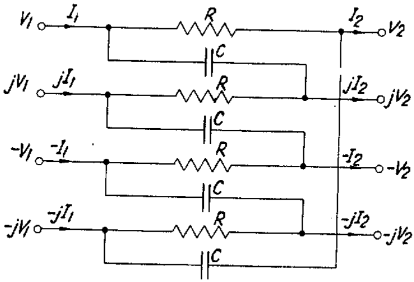


Fig. 3.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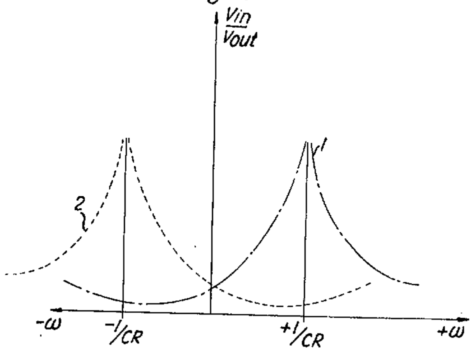
I1
R
C
I2
V2
jV1
jI1
jI2
jV2
-V1
-I1
-I2
-V2
-jV1
-jI1
-jI2
-jV2

Fig. 4.


Vin
Vout
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2
-ω
-1/CR
+1/CR
+ω

Fig. 6.

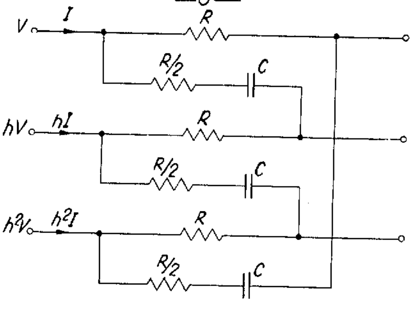
V
I
R
R/2
C
hV
hI
R
R/2
C
h^2V
h^2I
R
R/2
C

Fig. 7.

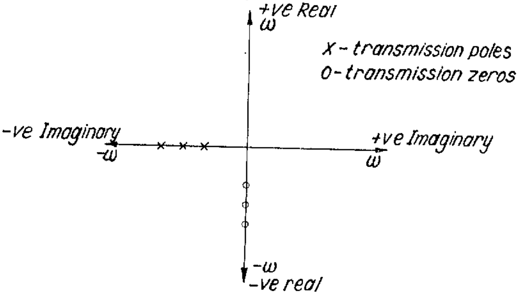
+ve Real
ω
X - transmission poles
O - transmission zeros
-ve Imaginary
-ω
+ve Imaginary
ω
-ω
-ve real

Fig. 8.

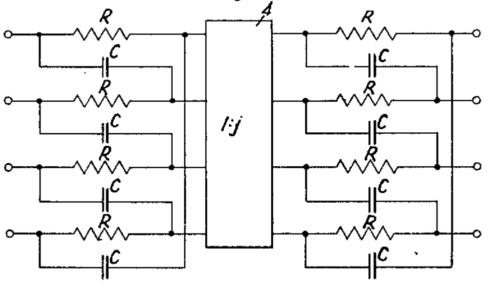

Fig. 5.

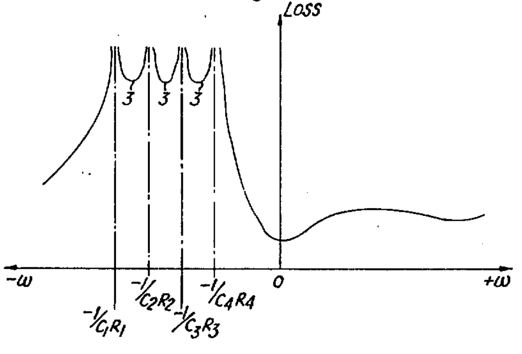

Fig. 9.

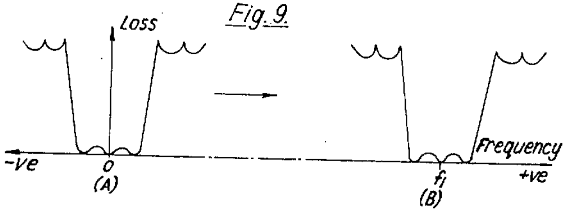

Fig. 10.

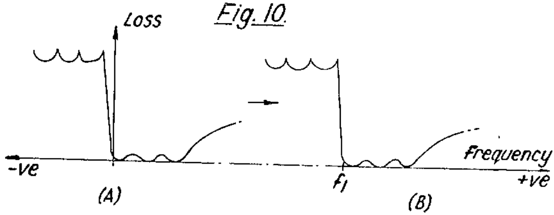

Fig. 12.