June 24, 1930. H. WHITTLE 1,767,951

TRANSMISSION CIRCUITS

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Fig.1

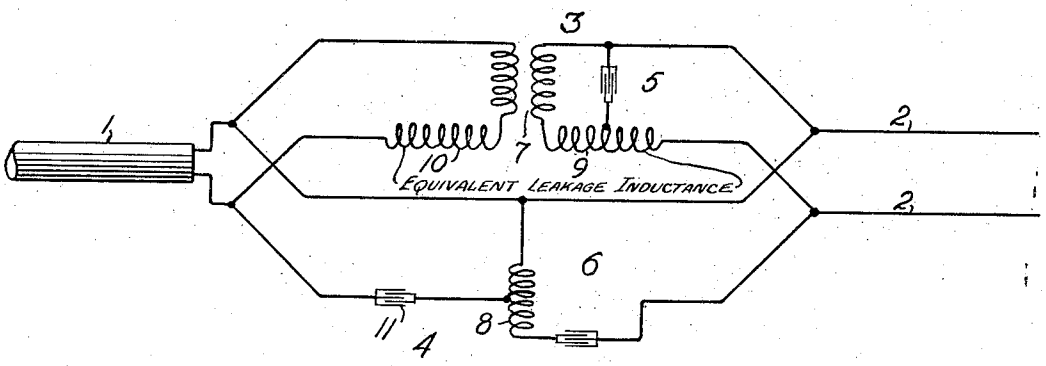
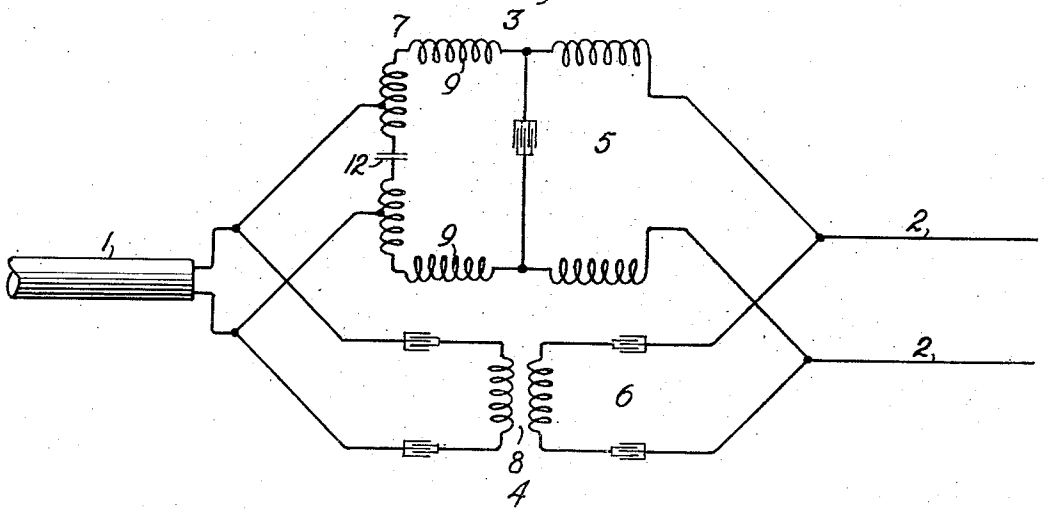


Fig.2



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Fig. 3.

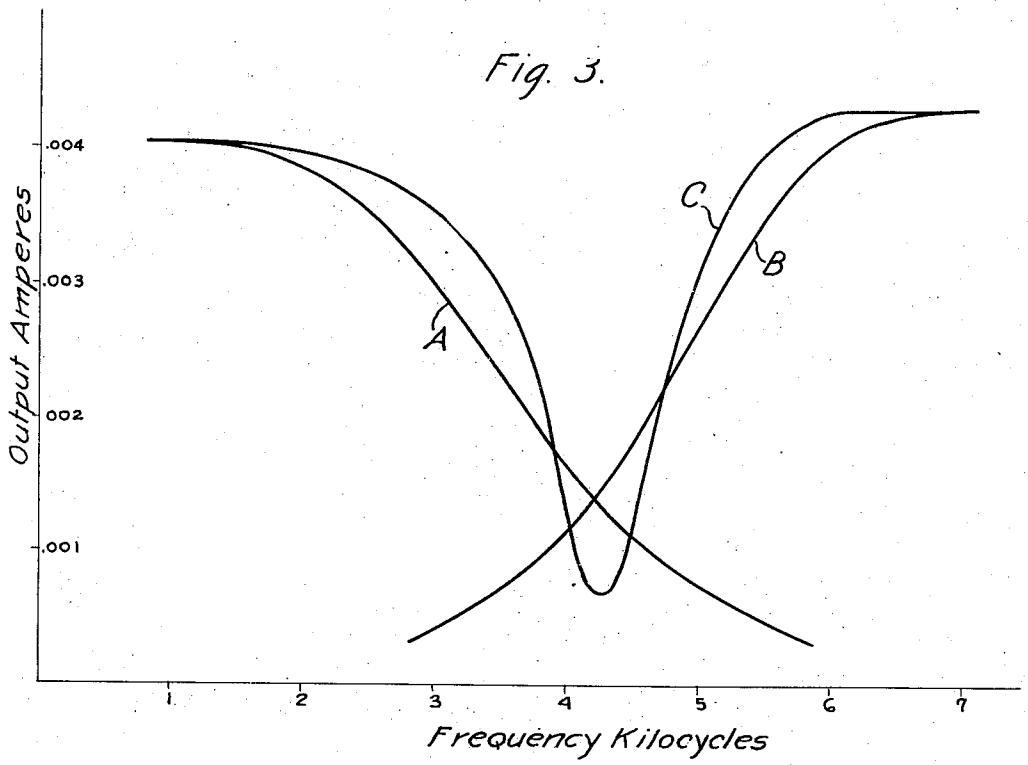
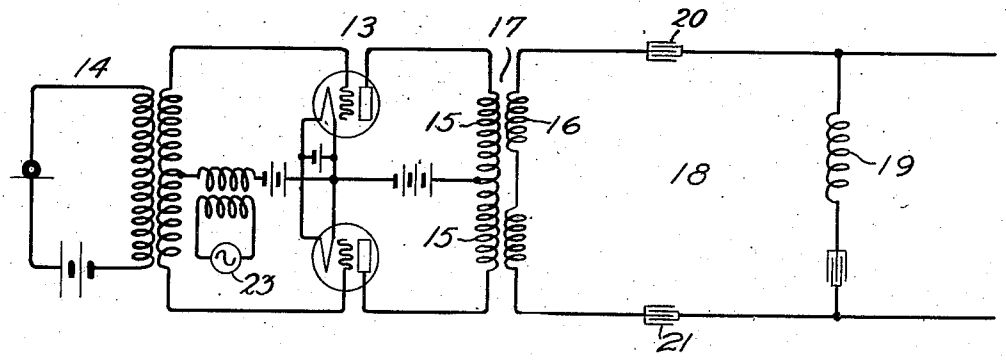


Fig. 4.



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Patented June 24, 1930 1,767,951

UNITED STATES PATENT OFFICE

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TRANSMISSION CIRCUITS

Application filed February 1, 1923. Serial No. 616,259.

This invention relates to transmission circuits and particularly to coupling means for line sections having different impedance characteristics.

An object of the invention is to couple line sections of different impedance characteristics, in such manner as to result in greater efficiency of energy transfer, lower cost, and greater simplicity of circuit than by the methods of the prior art. A specific object is to terminate a filter network in a combination in which a filter is connected to a line through a transformer in an improved manner. A feature of one species of connection is the provision of a conducting path for Morse or other direct currents. Another object is to connect a balanced modulator with an output filter in such manner that, while the proper impedance for the transmitted currents is provided, the connection will have low impedance for the modulating frequency components impressed on the modulator.

It is well known that a maximum transfer of energy between two interconnected circuits occurs when the impedance of one of the circuits matches the impedance of the other. Whenever the impedances are unequal, transition or reflection losses take place which cause a considerable reduction in the effective transmission therebetween. A common example of a means for equalizing the impedances of interconnected circuits is a transformer inserted between the lines, use being made of the well-known principle that an impedance may be effectively transferred from the primary to the secondary of a transformer by multiplying the impedance in the primary circuit by substantially the square of the voltage ratio (ratio of secondary to primary turns), or vice versa. An illustration of the use of this principle is the conventional treatment of a transformer as a circuit element, in which the transformer is simulated by an "equivalent" simple impedance. This "equivalent" impedance is used in the familiar Kapp vector diagram for showing the voltage regulation of a transformer as explained, for example, in chapter 24 of Karapetoff's Experimental Electrical Engineering, vol. 2, second edition, 1911. In utilizing this principle for the purpose of coupling circuits of different impedance characteristics, it is necessary only to use a transformer having a transformation ratio equal to the square root of the impedance ratio of the circuits including the impedances of the transformer windings.

In an actual case, the two lines may be a cable and an open wire line and the ratio of their impedances may vary with the frequency of the current transmitted. In order that a coupling arrangement of the kind described may be equally effective for all frequencies, the single transformer of the coupling arrangement explained above would have to be replaced by a parallel arrangement of as many transformers as there are frequencies, each transformer having characteristics individual to a particular frequency. In a practical case, a compromise may be effected by dividing the transmitted frequency band into two or more parts by means of filter circuits and inserting in each part a transformer having characteristics appropriate to the mean frequency of the currents transmitted therethrough.

Applicant's invention, in a generic sense, is an improvement over the arrangement described in that an improved method of relating the filters to the transformers is used. In prior arrangements the transformer is functionally independent of the filter and the arrangement for relating these two elements is, in general, the same as that for connecting filters to other circuits. In applicant's invention the transformer combines its function as such with that of a terminating element of a filter, with a consequent reduction in the number of impedance elements required and therefore a substantial reduction of the variation of the energy transmitted through the junction of the filter and the connected circuits at different frequencies. The utilization of an impedance of the transformer to supply the impedance of a filter element is accomplished in various ways, depending upon the particular type of filter concerned. In the case of a low pass filter, such as might be used for the voice frequency path, or channel, of the coupling, the leakage induc-

tance of a two-winding transformer is made to serve as a series terminating inductance for the filter, the equivalent shunt impedance of the transformer which is effectively in shunt to the filter being sufficiently large as determined by proper transformer design so as not to affect the selective characteristics of the filter. In alternative forms of the invention in which a high pass filter is used (this type of filter being characterized by series capacity and shunt inductance), the leakage inductance of the transformer is made negligible and the equivalent shunt impedance of the transformer as measured between the points at which the filter is connected, whether the transformer is an auto-transformer or a two winding transformer, constitutes the terminating shunt element of the filter. In each of these modifications, as well as in the others to be mentioned, the ratio of the transformer is made to conform with the necessities occasioned by the unequal impedances of the two interconnected circuits.

In another modification of the invention similar to that first described, the low pass filter is given a series termination, but in this case the final series impedance element is not principally supplied by the transformer. An auto-transformer having high impedance is connected across the terminating series element of the filter. This arrangement provides a conducting path between the interconnected lines so that the system may be used for direct current Morse transmission.

In a modification of a somewhat different character, a transformer impedance is used as the terminating impedance of a filter in an arrangement for coupling a modulating device with a high pass filter which is designed to provide a low impedance filter for the modulating frequency components. The equivalent shunt impedance of the transformer as measured across the secondary constitutes the terminating shunt element of the filter which is preferably given a full shunt termination, the equivalent impedance as measured across the primary, (the impedance at the primary looking in the direction of the filter) being made great enough to match the internal impedance of the modulator tube for the frequencies desired to be transmitted.

This invention will be better understood by reference to the following detailed description taken in connection with the accompanying drawing in which Fig. 1 illustrates one coupling arrangement of the invention embodying two distinct means for utilizing the transformer inductance as the terminating element of a filter; Fig. 2 shows a modification of the arrangement of Fig. 1 in which a different arrangement for relating the transformers to the filters is employed; Fig. 3 illustrates diagrammatically the operation of the system of Figs. 1 or 2; and Fig. 4 illustrates an application of the generic principle of the invention to a combination of a modulator and its output circuit.

Considering the system of Fig. 1, a coupling arrangement is used to connect a cable line 1 with an open wire line 2. To aid in an understanding the invention values approximating those found in practice will be assigned to the various quantities concerned. Accordingly, the open wire line may have an impedance of 600 ohms for all frequencies included in the range of the usual carrier frequencies as well as the frequencies used for voice and other methods of low frequency, signaling. 30,000 cycles may, in this instance, be assumed as the upper limit of the frequencies to be considered. The impedance of the cable varies with frequency, being substantially the same as that of the open wire line for frequencies of approximately 135 cycles and decreasing to approximately 140 ohms at the frequency of 30,000 cycles. The advantage of using an individual coupling transformer and channel for each of the frequencies transmitted is approximated by dividing the transmitted frequency band into two portions, and transmitting the currents of the lower frequency, characteristic of voice and telegraphic signaling, through branch or channel 3 and the currents of higher frequency, through branch 4. In order to separate the frequencies and constrain them to follow the paths indicated, the low and high pass filters 5 and 6, respectively, are used. A transformer is used in each branch to equalize the impedances of the interconnected lines for the mean frequency of the currents transmitted therethrough.

Equality is indicated when the impedances looking in either direction from the terminals of the primary of the transformer are equal or, as would naturally follow from the previous adjustment, when the impedances, looking in either direction from the terminals of the secondary, are equal. The equalization is effected by making the transformer ratio in either case equal to the square root of the ratio of the interconnected impedances for the mean frequency of the currents transmitted therethrough. Proper selection of the transformer ratio accordingly insures the avoidance of reflection and transition losses at the junction comprised by the transformer. The problem remains of terminating the filters and connecting them to the open wire line and to the transformers so that losses are avoided at these junction points.

Considering this problem generally, without reference to a particular branch of the present coupling arrangement or to a particular type of filter, except that some modification of the usual iterative or periodic filter circuit illustrated by the Campbell Patents No. 1,227,113 and No. 1,227,114, issued May 22, 1917, will be assumed, it may be said that

this type of filter comprises a plurality of serially arranged sections which are similar to each other and each of which consists of a series or line impedance and a shunt impedance. For purposes of section design such a filter is conveniently assumed to have infinite extension in either direction. In such an infinite filter the impedance, looking in the direction of the infinite extension, is the same for all corresponding points of the filter. This impedance is known as the characteristic impedance of the filter measured at that type of cross section. For practical purposes, of course, a filter must be given finite dimensions. In order to provide for the combination of a finite filter with a load circuit connected to either end without transition or reflection losses such a combination must be made to be the equivalent of an infinite filter, the load circuit, accordingly, replacing the infinitely extending portion of the filter. Since the load impedance is fixed this requires the proper choice of filter. If the filter is properly designed relatively to the connected load it may have a full shunt or a full series at either end, these terms denoting, respectively, that a whole shunt section element or a whole series section element is used to terminate the filter. If the filter is terminated in the middle of a series element the termination is mid-series, if a terminating shunt impedance has a magnitude twice that of the regular shunt impedance, the termination is mid-shunt.

The design of the filter terminations in the system of the invention is governed substantially by the considerations above, except as limited by the fact that, according to the essential novel principle of the invention, a transformer of proper ratio is used and the impedance of the transformer constitutes the terminating impedance element of the filter.

Considering branch 3 of Fig. 1 in detail, the filter 5 is of the conventional low pass type and may have many or few sections. Its connection with line 2 may be governed by the considerations above explained. An impedance of the transformer must constitute the terminating impedance of the low pass filter at that end, and any transformer impedance, from the inherent nature of the device, must be substantially inductive. Since the inductances of a low pass filter are the series elements, the filter termination must be of the series element type.

In order to enable the transformer to supply this impedance it is designed to have a large leakage inductance. A leakage inductance may, according to well known theory, be simulated by an equivalent inductance in series with the transformer windings, as shown by 9 and 10. Accordingly, by proper design of the transformer, the series terminating inductance of the filter may be supplied by the equivalent leakage inductance of the transformer at the filter side. Since an inductance may be effectively transferred from one winding of the transformer to the other, merely by multiplying by the square of the ratio of turns, it is immaterial whether all the leakage inductance is in one winding or whether part is in one and part in the other. If desired, a filter similar to 5 may be inserted at the left, instead of at the right of the transformer 7, or it may be duplicated at the left. In other words, the transformer may be effectively used at either end or at any part of a filter intermediate the ends. If used intermediate the ends the design of the two parts of the filter must, of course, be different to correspond with the impedances of the respective lines to which they are connected. In either case the ratio of the transformer is made such as to match the impedances of the two circuit combinations.

The complete equivalent circuit of the transformer comprises, in addition to the load and the series leakage impedances one of which is by the above indicated method of calculation transferred to the filter side, a shunt circuit connected between the two leakage impedances and carrying the magnetizing component of the primary current. The impedance of this shunt circuit is found to be, in accordance with the fundamental theory of transformer operation the mutual-inductance of the transformer multiplied by the ratio of the primary to secondary turns. For a transformer having zero leakage inductance this impedance is simply equal to the self inductance of the particular winding at whose terminals the calculations are chosen to be made. In the present case a transformer is used in which this equivalent shunt impedance is great as compared with the normal shunt impedance of a filter section and accordingly does not disturb the circuit relations in the filter connection.

Considering branch 4, a shunt termination at the filter end is required, since a high pass filter is used, in which type of filter the inductance elements occur in shunt. In the case of branch 4, as well as of branch 3, a full or a partial shunt termination may be used, the particular type of shunt termination affecting only the impedance of the filter-line combination and accordingly the ratio of transformation. The ration of transformation is fixed by the impedance ratio of the interconnected circuits, one or both of which consist of such a filter-line combination, as explained. The equivalent shunt impedance of the transformer determined as described in the paragraph above should be made that suitable for the terminating inductance of a shunt-terminated filter. Since the introduction of a series inductance into a high pass filter would disturb its normal function, the transformer should have negligible leakage and accordingly an auto-transformer 8, as

shown, is preferred. For this case the equivalent shunt impedance would equal the self-inductance of the transformer across the pair of terminals with reference to which the calculations are chosen to be made. Condenser 11 may be used as a blocking condenser only or as a portion of a second section of the filter, this section comprising the condenser 11 and the transformer. If the connections of branches 3 and 4 are designed as indicated the circuits may be used equally well for transmission in either direction.

The use of the coupling transformer to constitute an element of the filter results in a marked economy of impedance elements, as compared with the conventional arrangements in which the transformer and filter are functionally independent. For example, the use of the arrangement in branch 3 results in the saving of one coil, that in branch 4 in the saving of one coil or two coils, depending upon whether an auto-transformer or a two-winding transformer is replaced by this arrangement.

Although the arrangements in the branch circuits of Fig. 1 in general conform, as to the choice of elements, with most efficient practice, they may be varied in certain details, as shown for example in Fig. 2, in which similarly numbered elements have similar functions. In this figure the circuits of branch 4 differ from the corresponding circuits of Fig. 1 principally in the use of a two-winding transformer instead of an auto-transformer. Since the transformer is of the two-winding type special precautions should be taken to insure that there is negligible leakage. The circuit illustrated may be used, depending on the values of the capacities, either as a pair of connected filters or as a single filter. If the latter the condensers on one side of the transformer are used only as blocking condensers. Branch 3 of Fig. 2 differs essentially from that of Fig. 1 in that reliance is not had on the leakage inductance of the transformer to supply the series terminating inductance of the filter since an auto-transformer, which has no leakage inductance, is used. Elements 9 accordingly are inductances constituting the conventional terminating elements of the filter. Although the use of an auto transformer, as compared with a two-winding transformer, is attended by a lesser economy of circuit elements, since it cannot supply the series terminating inductance of the filter, it has the compensating advantage that by its use a conductive path is provided through the branch which, accordingly, permits of the coupling to be used for direct current Morse, as well as carrier and ordinary telephone communication, a feature not present in the system of Fig. 1. The condenser 12 functions as a blocking condenser to prevent a direct current short circuit. Since a series filter termination is used, the equivalent shunting impedance of the transformer, including the condenser 12, as measured at the terminating points of the filter (in this particular case it would be that of the combination of the self-inductance of the transformer and condenser), must be given a large value as compared with the impedance of the filter as measured at the same points, as in the similar case of branch 3 of Fig. 1 and for the same reason. Series inductances are shown on each side of the line instead of the simpler arrangement of Fig. 1.

Fig. 3 shows, for an actual case, the resultant effect in the system as a whole of a coupling arrangement of Figs. 1 or 2. If the filters in branches 3 and 4 are designed to attenuate substantially all currents except those in the voice and carrier frequency bands, respectively, graphs A and B represent the currents passed by these branches. Curve C shows the summation in the lines 1 and 2 of the currents in the branches. It is noted that although at most frequencies the ordinates of this curve are substantially equal to the sum of the ordinates of curves A and B, this is not true for a small portion of the range of each filter at the cut-off point. This results from a pronounced phase displacement between the component currents at this point, although there is a progressive change in phase with frequency and a similar but smaller interference effect at other points. It is to be noted that this results in a sharper cut-off in the resultant curve than in either of the component curves. If the cut-off frequencies are brought more closely together, so that curves A and B are closer together, the dip in curve C can be substantially eliminated so that its ordinates are substantially uniform.

Fig. 4 shows an application of a principle, quite similar to that illustrated in branches 4 of Figs. 1 and 2, in a combination comprising a balanced modulator working into a high pass filter having a sufficiently high frequency lower cut-off to eliminate the modulating component. In the arrangement shown there is provided, as will be explained later, a modulating system in which the unmodulated carrier component is suppressed and in which the output circuit may be given a low impedance for both of the components impressed on the input of the modulator. As is pointed out in U. S. Patent to Carson 1,672,056, issued June 5, 1928, this condition results in greatly increased efficiency.

The balanced modulator disclosed in the drawing is of the conventional type as disclosed, for example, in a paper by Colpitts and Blackwell, "Carrier current telephony and telegraphy", volume 40, No. 4 of the Journal of the A. I. E. E., page 314. By the arrangement shown, modulation of the carrier current from source 23 by current from voice or any other low frequency circuit

14 is attended by a suppression of the unmodulated carrier component in the output circuit. The suppression of this carrier frequency component results from the opposed effects of equal potentials induced in the secondary winding 16 of the three winding transformer 17 by the amplified high frequency currents from source 23 in primary 15. The opposition of potentials in primary 15 results from the mode of impressing potentials on the input circuits of the tubes from source 23, these potentials being equal and having the same phase. Currents of the modulating frequency from circuit 14 are not suppressed since potentials impressed from this circuit on the input circuits of the two tubes are of opposite phase, and accordingly the resultant potentials in the output circuits of the tubes, and hence in the secondary of transformers 17, are not opposed as in the case of the similar potentials derived from source 23. The currents of the side band frequencies partake of the character of the modulating currents, which constitute one of its two combination elements, and are accordingly not suppressed. This result is easily deduced from a consideration of the physics of the operation of the balanced modulator. The currents from circuit 14, by unsymmetrical super-position with the currents from source 23 on the input circuits of the tubes, destroy the balance established by the current from that source alone.

The transformer and its associated filter 18 is designed so that the equivalent shunt impedance has such a value as to constitute the transformer the shunt termination of the filter 18, and so that the impedance of the output circuit including the transformer and filter looking away from the modulator has the value, in proportion to the internal impedances of the tubes, which is demanded for efficient transmission of the selected components.

Since the inductances in a high pass filter are in the shunt rather than in the series, elements the transformer should have as little leakage as possible. The use of an auto transformer, as in branch 4 of Fig. 1, would insure zero leakage and this type of transformer could be used instead of the two-winding transformer illustrated. Consistent with the requirement that the equivalent shunt impedance must supply the shunt terminating impedance of the filter, that transformer, in a practical case, would be designed to have a much smaller equivalent shunt impedance than the more conventional designs of transformer that would otherwise be used to couple the filter with the modulator. With the usual values of tube and line impedances, a relatively large ratio of primary to secondary turns would also be required in order to effect the proper impedance matching.

Since the shunt terminating impedance of a high pass filter of the type illustrated is low for the usual modulating frequencies, there is provided a modulating system in which the output circuit has a low impedance for the modulating current with consequent increased efficiency of the system and without sacrifice of the efficiency which normally results from the proper relation between external and internal output impedance for the frequencies of the currents transmitted and with a marked economy of circuit elements.

The type of filter disclosed in Figs. 1 and 2 is denominated the "two-element" type, since as above explained each section consists of two elements, namely, one series element and one shunt element. The particular design of filter disclosed in Fig. 4 is varied from this type by the use of a resonant circuit 19 for the shunt circuit of one section.

A filter having its sections made up of this type of shunt circuit (having two elements) and a single series element is known as a "three-element" type. It also belongs to the class of filters shown and described in U. S. patent to Campbell 1,493,600, issued May 13, 1924 known as the "suppression type", which are characterized by the use of either resonant shunt circuits, resonant loops in the line or by the use of both these features. An advantage in the use of the three element suppression type of filter resides in the sharper cut-off that can be secured thereby as compared with the two element type. Since the terminating impedance at the modulator end is effectively an inductance and, therefore, the terminating shunt impedance of a two-element filter section, the filter, as a whole, can be considered as of the composite type having two part-sections one part-section of a conventional two-element type filter and the other part-section of the three-element suppression type, the condensers 20 and 21 each effectively comprising a series terminating capacity of each part-section. It is preferable to use a full shunt termination for this filter at the modulator end, in order to have the lowest possible impedance in the transformer secondary.

It is to be understood that this invention is not limited to the particular form of coupling means described above for interconnecting a telephone cable with an open wire line, since it will be apparent to those skilled in the art that the coupling means of this invention may be modified without departing in anywise from the spirit of this invention in adapting the coupling means to the interconnection of impedance devices of various types and different characteristics of impedance.

What is claimed is:

1. In combination, an input circuit, a transformer, a broad-band filter and a load circuit in series relation, the filter and load circuit having characteristics substantially equivalent to that of an infinite filter having identical sections, and an impedance of the transformer constituting the shunt terminating impedance of the filter.

2. In combination, two circuits of different impedance characteristics and a coupling means therebetween, said means comprising a non-unity ratio transformer and a broad-band filter, the impedance of the filter matching the impedance of its connected circuit, the impedance of the transformer, filter, and connected circuit matching the impedance of the other circuit, and an impedance of the transformer constituting the terminating impedance of the filter connected thereto.

3. A combined filter and a non-unity ratio transformer, an inductance of the transformer in effect forming part of the filter and the filter consisting of a line of negligible attenuation containing lumped impedances effectively in series with the line, and lumped impedances effectively in shunt across the line, said impedances having precomputed values dependent upon the upper limiting frequency and the lower limiting frequency of a range of frequencies it is desired to transmit without attenuation the values of said series and said shunt impedances being so proportioned that the filter transmits with practically negligible attenuation sinusoidal current of all frequencies between said two limiting frequencies while attenuating, and approximately extinguishing, current of neighboring frequencies lying outside of said limiting frequencies.

4. In combination, a non-unity ratio step-down transformer, a high pass filter, a load circuit connected to the filter at the end remote from the transformer and a circuit connected in energy transfer relation to the transformer, the equivalent shunt inductance as measured at the low winding of the transformer constituting the shunt terminating inductance of the filter, said inductance being low for frequencies below the cut-off frequency, and the impedance of the transformer filter, and load circuit substantially matching the impedance of said connected circuit.

5. In combination, a modulator, means for impressing a relatively low and a relatively high frequency wave thereon, and a combined non-unity ratio transformer and filter connected to the output circuit of said modulator, the filter having sections of different attenuation frequency characteristics but a common critical frequency and the same impedance frequency characteristic, and a reactance of the transformer in effect forming part of one section of the filter.

6. In combination, a modulator, means for impressing a relatively low and a relatively high frequency wave thereon, and a combined non-unity ratio transformer and multi-section filter connected to the output circuit of said modulator, the equivalent shunt inductance of the transformer as measured at the points at which it is connected to the filter in effect forming part of one section of the filter and the filter having its cut-off sharpened by the replacement of a section thereof by a section of different type whereby its attenuation characteristic is made steeper near its critical frequency.

7. In combination, a modulator, means for impressing a relatively low and a relatively high frequency wave thereon, and a combined non-unity ratio transformer and multi-section filter connected to the output circuit of said modulator, the equivalent shunt inductance of the transformer in effect forming part of one section of the filter and one section of the filter giving high attenuation over one frequency range and another section over another frequency range, whereby the multi-section filter gives high attenuation over both ranges.

8. In combination, a modulator, means for impressing a relatively low and a relatively high frequency wave thereon, and a combined non-unity transformer and filter connected to the output circuit of said modulator, the filter comprising two types of sections having a common finite critical frequency, an inductance of the transformer in effect forming part of one of said sections and one type of section giving high attenuation at a frequency remote from the critical frequency and another type of section giving high attenuation at a point near the critical frequency.

9. In combination, a modulator, means for impressing a relatively low and a relatively high frequency wave thereon, and a combined non-unity ratio transformer and multi-section filter connected to the output circuit of said modulator, an inductance of the transformer in effect forming part of one section of the filter, one section of the filter having maximum attenuation at zero frequency, and another section having maximum attenuation at a frequency near the cut-off frequency in the attenuation range.

10. In combination, a modulator, means for impressing a relatively low and a relatively high frequency wave thereon, and a combined transformer and multi-section filter connected to the output circuit of said modulator, one section of the filter having in effect a series arm comprising lumped capacity and a shunt arm comprising the inductance of the winding of the transformer connected thereto, and another section of the filter having, in effect, a series arm comprising lumped capacity and a shunt arm comprising lumped capacity and lumped induc-

tance tuned to the critical frequency of the filter.

11. In combination, a modulator, a high pass filter connected thereto for passing the modulated components and attenuating the modulating components, and a load circuit connected to the remote end of the filter, the filter having in effect series impedance comprising lumped capacity elements and a shunt terminating impedance comprising the equivalent shunt inductance of the transformer as measured at the points at which the filter is connected, said equivalent shunt inductance being low for the frequencies below the cut-off frequency and the impedance of said transformer, filter, and load circuit substantially matching the impedance of the modulator for the frequencies to be transmitted.

12. In combination, a modulator including an output transformer, a high pass filter for passing the modulated components and a load circuit, the ratio of the transformer being such that the impedance of the transformer, filter, and load circuit, is substantially equal to the internal impedance of the modulator at the frequencies of the currents transmitted therethrough, the filter comprising two types of sections having the same finite critical frequency, the equivalent shunt inductance of the transformer at the points at which the filter is connected in effect forming part of one of said sections, one type of section giving high attenuation at a frequency remote from the critical frequency and another type of section giving a high attenuation at a point near the critical frequency.

13. In combination, a balanced modulator including an output transformer, a load circuit, and a high pass filter for passing the modulated frequencies coupling said modulator and load circuit, said filter having a full shunt termination constituted by the equivalent shunt inductance of the transformer as measured at the points at which the filter is connected, and the impedance of the transformer, filter and load circuit substantially matching the impedance of said modulator at the frequencies of the current transmitted therethrough.

14. In combination, a modulator, means for impressing a relatively low and relatively high frequency wave thereon, a multi-section high pass filter, a transformer connecting the filter with the output circuit of said modulator, said filter having an end section of the two-element type with a full shunt termination and another section of the three-element suppression type, and a load circuit connected to the end of the filter remote from said two-element section, the equivalent shunt impedance of the transformer as measured at the points at which the filter is connected constituting the shunt terminating impedance of the filter and the transformer, filter and load circuit substantially matching the impedance of the modulator for the frequencies to be transmitted therethrough, said filter being designed to attenuate current of the modulating frequencies.

In witness whereof, I hereunto subscribe my name this 24th day of January, A. D. 1923.

HORACE WHITTLE.