

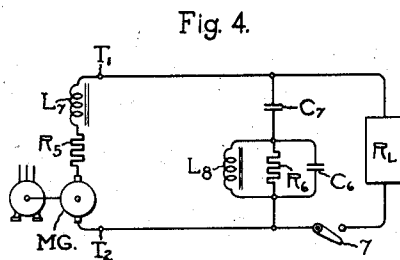
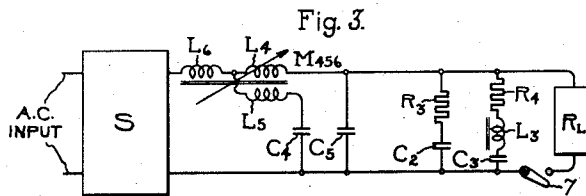
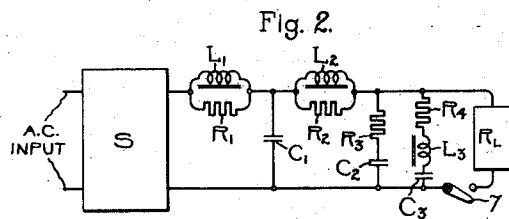
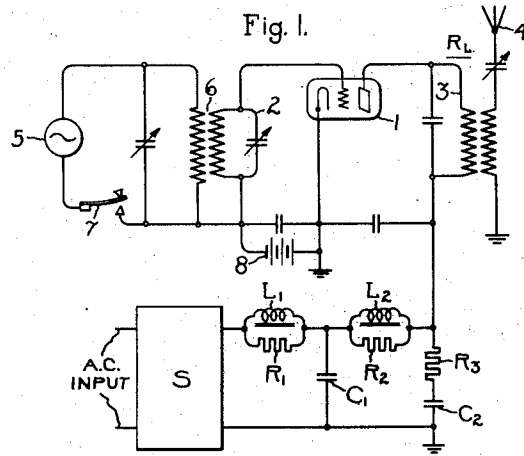
April 16, 1935.

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1,998,325

UNIFORM IMPEDANCE FILTER

Filed Aug. 23, 1933



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UNITED STATES PATENT OFFICE

1,998,325

UNIFORM IMPEDANCE FILTER

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tion of New York

Application August 23, 1933, Serial No. 686,421

7 Claims. (CL 178-44)

My invention relates to filter circuits, particu-
larly to filter circuits employed in connection with
keyed or modulated-load circuits of radio trans-
mitters or the like, and its principal object is the
provision of a filter system characterized by uni-
form impedance and adapted to ensure square-
wave keying in radio transmitters or similar ap-
paratus but without the disadvantages heretofore
encountered in the use of such filter circuits for
radio transmitter or like uses.

In keyed radio transmitters or the like it is
desirable, or practically necessary, that the filter
circuits be such that the keying is absolutely
square-wave, i. e., that the load current supplied
from the generator be zero when the keying
means or switch is open, and that the load cur-
rent rise instantaneously to its final steady value
as the keying means is closed and then drop in-
stantly to zero as soon as the keying means is
reopened.

Such filter circuits, employed for example in
connection with the keying means of transmitters,
have been proposed heretofore but these circuits
have been characterized by several disadvantages.
Either the action of the filter circuits in suppress-
ing the ripple voltage of the generator supplying
current to the load circuit has been relatively
poor, or the efficiency of the system comprising
generator, filter and load has been low.

In accordance with my present invention these
difficulties and others heretofore encountered in
the use of the filter circuits employed in keyed
radio transmitter systems or the like are obviated
by the provision of special shunt filter elements
associated with systems of this or similar char-
acter.

It will be understood, however, that my inven-
tion is not limited to use as an improvement upon
or an addition to the above-named or other sys-
tems heretofore proposed. On the contrary my
invention may be employed in connection with
any type of ripple suppressing circuit between the
current source and the special filter elements pro-
vided in accordance with my invention. Particu-
larly these special filter elements in accordance
with my invention may be employed to great ad-
vantage in combination with special types of rip-
ple suppressing filters for tuning out the main
ripple from the supply current and for absorbing
harmonics of the supply current ripple.

My invention will be better understood from the
following description when considered in connec-
tion with the accompanying drawing and its scope
will be pointed out in the appended claims.

Referring to the drawing:

Fig. 1 is a diagrammatic representation of an
embodiment of my invention incorporating a cur-
rent supply and filter system for a keyed radio
transmitter, and having shunt elements in ac-
cordanance with the invention.

Fig. 2 is a diagrammatic representation of an
embodiment of my invention identical with that
of Fig. 1 but including further special circuit ele-
ments whereby the operation of the system of Fig.
1 is improved.

Fig. 3 is a diagrammatic representation of an
embodiment of my invention in which are com-
bined ripple suppressing circuits hereinabove
mentioned and special shunt filter elements of the
type illustrated in the embodiment of my inven-
tion shown in Fig. 2.

Fig. 4 is a circuit diagram illustrating a fur-
ther embodiment of my invention.

It is known that in practically all conventional
circuits composed of a generator of current of
given frequencies followed by a filter which sup-
presses all but a certain band of the frequencies
produced by the generator and which is con-
nected to a load, the impedance presented by
the filter and generator to changes in the load
circuit caused by changes in the load impedance
or by other means such as variation of a voltage
in series with the load, varies for different rates
of change of the load current, the impedance,
or the load "modulation" voltage. In other
words, the filter and generator combined im-
pedance varies with the frequency of the load
modulation.

This variation of filter and generator combined
impedance makes it impossible for the load cur-
rent to follow exactly the wave shape of the
modulating voltage, assuming the modulating
voltage to comprise a number of frequencies. In
consequence two undesirable effects arise, as fol-
lows:

(1) *Transient or complex wave distortion (some-
times known as "linear" distortion).*

A complex modulating voltage, such as that
produced by opening and closing a switch in
series with the load, or by speech modulation
of the load drawn by a transmitter, or by other
means, will not produce a load current exactly
proportional at every instant to that modulat-
ing voltage. Conversely, if some load charac-
teristic be chosen so that a load current of given
wave shape is drawn from the generator or source
through the filter, the voltage required to pro-
duce the modulation will not follow the same
wave shape as the load current. It is assumed
that the load current is flowing through a pure

resistance load, this latter assumption being justified in practically all cases under consideration for the reason that, if the load should be not resistive but reactive, the load current would not then follow the wave shape of the modulating voltage unless the reactance wave were tuned out at all frequencies by a special type of filter.

(2) *Loss of load modulation.*

Since the load is assumed to be purely resistive, any filter and current source impedance whatever will cause a loss of per cent load current variation for a given modulating voltage, whether this voltage is actually applied in series with the load, or whether this is the voltage applied by the modulating tubes in a transmitter modulator. This loss of per cent modulation will be a maximum at the frequency of modulation at which the filter and source combined impedance, presented to the equivalent modulation generator, is a maximum.

In accordance with my invention means are provided whereby the above undesirable effects are obviated and whereby the following objects are attained:

(1) Increase of the percentage load current modulation for a given modulating voltage by reduction of the combined current source and filter impedance over the modulating frequency band.

(2) Improvement of transient and complex wave fidelity of load current with respect to the modulating voltage. In this connection it can be shown that the transient response of the standard inductance-capacity or LC filter for broadcast transmitters is relatively poor. In order to improve transient and complex wave fidelity it is necessary to reduce the combined source and filter impedance to a value low with respect to the load resistance over the entire frequency band, i. e., from zero to infinity. Such reduction of the combined source and filter impedance automatically accomplishes also the above first-named purpose, i. e., increase of the percentage load current modulation for a given modulation voltage.

(3) Reduction of the filter k. v. a. as compared to the total k. v. a. employed in usual LC filters. Means will be described hereinafter whereby complete suppression of the main or fundamental ripple or undesired frequency is accomplished by special tuned circuits, the remaining ripple harmonics being absorbed in the usual manner, and, in addition, current source and filter impedances are suppressed, all of the foregoing being accomplished with much less k. v. a. than that ordinarily employed in the present usual filters.

In Fig. 1 of the drawing, I have shown therein for purposes of illustration, a radio telegraph transmitter of a conventional type, comprising an electron discharge amplifier 1 having a tuned grid circuit 2 and a tuned anode circuit 3, the latter being coupled to a suitable radiating system 4. A source of high frequency oscillations 5 is coupled by means of transformer 6 to the input circuit of the amplifier 1. The supply of oscillations from this source is arranged to be interrupted in accordance with telegraphic signals by means of key 7, or its equivalent. The amplifier 1 is provided with grid biasing potential from a voltage source indicated by the battery 3.

The amplifier 1 is further provided with anode potential from a current supply and filter means including shunt circuit elements in accordance with my invention. This current supply and fil-

ter system, shown for illustrative purposes in Fig. 1 and which is primarily for use in connection with mercury vapor rectifier or other low arc-drop rectifier devices, comprises a current source, indicated by the rectangle S and which is preferably a rectifier of the above-mentioned type having a smoothing condenser C₁ in parallel therewith, connected through a filter means to the keyed or modulated-load circuit indicated generally by R_L and including amplifier 1 and the radiating system 4 to which the amplifier is coupled.

In a low arc-drop current supply system such as indicated in Fig. 1 it is necessary to accomplish the main part of the filtering by providing a reactor L₁ between the rectifier or source S and the condenser C₁. The resistance and reactance regulation of the current source may usually be neglected in analyzing the characteristics of the filter, since these regulation constants are ordinarily very small compared to the other constants. A resistor R₁, which is equal to or greater than the reactance value of L₁ at the main ripple frequency, is provided in parallel with L₁. The presence of the resistor R₁ is desirable for several reasons, one being that voltage surges across the rectifier tubes are reduced under conditions of abnormal or irregular tube emission, another reason being that the tuned impedance of L₁ and C₁ is reduced at the modulation tuning frequency. From the standpoint of transient fidelity, R₁ tends to prevent low frequency oscillation when irregular load currents are drawn from the filter.

The filter circuit constituted by L₁R₁ and C₁ suppresses source ripple fairly well but is characterized by imperfect transient fidelity. To lower the initial rush of load current and to prevent the subsequent decay it is necessary to insert the reactor L₂. The wave shape then is badly sloped and, in addition, the surge voltages on L₂ are excessive under keyed load conditions. Resistor R₂ is therefore added to correct these deficiencies. This resistor R₂ permits an initial value of load current to be drawn instantaneously from the condenser C₁. By proper choice of L₂ and R₂ it is possible to obtain the best wave shape, the proper relation being to make R₂ equal to R_L (load resistance) and L₂ equal to

$$\frac{5}{C_1}$$

where C₁ is in microfarads and L₂ is in henries. R₂ reduces the voltage surges across L₂ to negligible values, if the latter relation be employed.

It can be shown, however, that it is impossible to obtain uniform filter impedance with the filtering circuit so far described in connection with the system illustrated in Fig. 1; because of the non-uniformity of filter impedance the transient wave shape would still be relatively poor.

In accordance with my invention the difficulties above set forth in connection with the filter circuit so far described in connection with Fig. 1 are overcome by the provision of impedance suppressing shunts, illustrated in Figs. 1 and 2, these shunts being provided for the purpose and with the effect of causing the filter impedance to be low with respect to the load resistance over the entire frequency band, from zero to infinity.

Considering first the filter circuit system illustrated in Fig. 1, the impedance suppressing shunt provided therein in accordance with my invention is constituted by a circuit branch R₃C₂ having resistor R₃ in series with condenser C₂. This circuit branch R₃C₂ is inserted for two reasons: 75

first, to remove the remaining slope in the wave front characterizing the above-described filter comprising $L_1R_1C_1L_2R_2$, and second, to prevent oscillations being set up by condenser C_1 and inductance L_2 . The latter oscillations appear, under keyed load conditions, if an attempt is made to steepen the wave front by reducing the resistance R_2 .

From the standpoint of filter impedance, the circuit branch R_3C_2 reduces the high frequency impedance to an asymptotic value equal to

$$\frac{R_3R_2}{R_3+R_2}$$

as the frequency increases. If it were not for this shunt branch, the high frequency impedance would approach asymptotically the value R_2 . Numerically, C_2 is equal approximately to $\frac{1}{5} C_1$. More capacity than this gives no greater improvement in wave shape, while a value less than this causes a sharp initial peak in the load current. Resistor R_3 should be made equal to $\frac{2}{3} R_2$. A value greater than this will cause a sloped wave front, while a lower value will cause a sharp initial peak in the load current.

Considering now the embodiment of my invention illustrated in Fig. 2, the remaining low-frequency oscillation, and peak of low-frequency impedance, still present in the output of the system of Fig. 1 may be eliminated by the utilization, together with shunt branch R_3C_2 , of a second type of shunt branch, shown in Fig. 2. Here $R_4L_3C_3$, having resistor R_4 , reactor L_3 and condenser C_3 in series, is a shunt broadly tuned to the frequency for which the filter shown in Fig. 1 has its peak impedance. This frequency will be very close to the frequency,

$$f_1 = \frac{1}{2\pi\sqrt{L_3C_3}}$$

Numerically, this condition makes the alternating k. v. a. of L_3 and C_3 equal to that of L_1 and C_1 . Reactor L_3 is not, however, required to carry direct current, which makes its k. v. a. rating, assuming 100% modulation of load current, approximately $\frac{1}{2}$ the rating of L_1 . The condenser voltage, being approximately 50% modulated, requires twice the k. v. a. rating of C_1 . The total k. v. a. of L_3C_3 is then 150% of the rating of L_1C_1 .

Resistor R_4 should be made approximately equal to R_2 . Higher values than this will raise the total filter impedance at low frequencies, while lower values will simply permit the shunt to tune with L_1 , L_2 and C_1 , thus merely displacing the frequency at which the peak impedance occurs.

In the best wave shape obtainable with the circuit of Fig. 2 there still is present a very low frequency oscillation of approximately 6% amplitude. It can be shown, however, that this remaining oscillation may be still further reduced, in case it becomes really necessary, by increasing the k. v. a. in the shunt $R_4L_3C_3$. The loss of load modulation in the circuit system illustrated in Fig. 2 is very low at any frequency.

From the foregoing analysis of the systems shown in Figs. 1 and 2, it will be understood that difficulties such as irregular filter impedance, low circuit efficiency, loss of load modulation, and transient or complex wave distortion, have been overcome by the provision of the uniform impedance filter circuits comprising the shunt circuit elements described in connection with Figs. 1 and 2.

It will appear further, from the foregoing, that irregular filter impedance, loss of load modulation, and transient or complex wave distortion are inseparably linked, and that to prevent both distortion and loss of load modulation the filter impedance must be reduced to a value low with respect to the load resistance, from zero to infinite frequency.

Reference will now be made more particularly to the employment of my invention in combination with special tuned circuits, hereinbefore mentioned, adapted to suppress the fundamental ripple, whereby large reduction of the filter k. v. a. compared to the total k. v. a. used in conventional LC filters may be effected.

Now it may be shown that the total additional k. v. a. required, in the system of Fig. 2, to reduce the filter impedance to a low value, in the manner above set forth in connection with the latter figure, is 178% referred to the total k. v. a. of L_1C_1 . This is apparently a relatively large value. Even more than this additional percentage of k. v. a. is permissible, however, by the employment, in combination with the hereinbefore described shunt circuits shown in Figs. 1 and 2, of apparatus which tunes out the main ripple and permits ordinary absorption filtering of harmonics of the main ripple, this apparatus replacing the conventional apparatus, such as the usual "brute force" filter, the purpose of which is to attempt to suppress, by absorption, all of the ripple frequencies including the fundamental.

Referring particularly to the embodiment of my invention illustrated in Fig. 3, shunt circuit elements as described in connection with Fig. 2 are shown in combination with a circuit system capable of accomplishing the above-mentioned result, i. e., tuning out of the main ripple and permitting ordinary absorption filtering of the harmonics of the main ripple. The system shown in Fig. 3 comprises a current source S such as a rectifier connected to and A. C. supply line and providing a direct current upon which are superimposed ripple components including a main ripple and harmonics thereof.

Current from the source S of Fig. 3 is supplied to a modulated-load circuit R_L , which may be similar to the load circuit R_L of Fig. 1, through a ripple-suppressing means including a transformer having a winding L_4 in series between source S and load R_L and a winding L_5 in series with a condenser C_4 , the latter winding and condenser being in parallel with the load R_L . The ripple-suppressing and harmonic absorbing circuits further include a condenser C_5 in parallel with the load circuit R_L .

In the operation of the ripple-suppression and harmonic absorption system so far described in connection with Fig. 3, the circuit L_5C_4 tunes to the fundamental ripple frequency and induces a back voltage in the circuit $L_4C_5R_L$, this voltage being of the correct phase and magnitude, by proper reactor design and condenser adjustment, to suppress completely the flow of fundamental ripple current in the load R_L . At the same time the branch or circuit L_4C_5 operates as a usual absorption filter for the harmonics of the main ripple frequency.

The ripple-suppressing and harmonic-absorbing circuit above described including elements L_4 , L_5 , C_4 and C_5 is characterized, however, by the disadvantage that the current in the branch circuit L_5C_4 is affected by the load, which may vary and thereby upset the required conditions for

zero load ripple. In order to overcome this disadvantage the reactive element L_6 is added in series with transformer winding L_4 and in inductive relation with windings L_4 and L_5 , the mutual inductance of L_6 , L_4 and L_5 being designated by the character M_{456} .

It will be apparent that the addition of the reactive element L_6 overcomes the tendency of the load current to upset the conditions producing zero fundamental ripple in the load. The reactance of L_6 , which is made equal to that of L_4 , is of sufficient value to ensure that the variation of the tuned impedance of L_5C_4 , due to variation of the coupled-in load impedance does not raise appreciably the fundamental ripple voltage across L_5C_4 , which is tuned slightly off resonance, on the capacitive side, to the fundamental frequency. These results in the system of Fig. 3 depend on fairly loose coupling of all of the inductive elements.

It can be shown that the ripple suppression and harmonic absorption circuits of Fig. 3 effect a saving of approximately 70% of the filter k. v. a. of the conventional "brute force" filter.

The ripple-suppression and harmonic-absorption circuits hereinabove described in connection with Fig. 3, and circuits similar thereto, will, however, be characterized by high impedance with respect to an equivalent modulation generator connected in series with the load. In order to make the source and filter impedance of ripple suppression and harmonic absorption systems such as above-described in connection with Fig. 3 low with respect to the load resistance over the entire frequency band, from zero to infinity, the systems which include these filter circuits are provided, in accordance with my invention, with impedance-suppressing shunts of the type hereinbefore described. In Fig. 3, for example, the ripple-suppression and harmonic-absorption filter circuits hereinabove described are shown as followed by impedance suppressing means including shunt circuit branch R_3C_2 of the type hereinbefore described in connection with Fig. 1 and a second shunt circuit branch $R_4L_3C_3$ of the type described in connection with Fig. 2.

In order to determine the net saving of k. v. a. effected by the combination of the ripple-suppression and harmonic-absorption circuits with the special shunt circuits, as illustrated in the system of Fig. 3, the k. v. a. ratings of the circuit elements required to suppress the modulation impedance of the filter system must be added. The net results in k. v. a. saving are explained hereinbelow as follows:

As set forth hereinbefore in connection with the embodiment of my invention illustrated in Fig. 2 the additional k. v. a. required by the elements L_2 , R_2 , R_3 , C_2 , R_4 , L_3 , C_3 of Fig. 2 is 178% of the k. v. a. of a standard LC filter tuning to a low frequency. Assuming first a system including a single phase full wave rectifier as current source, then if the filter incorporated in the latter system were tuned to the fundamental ripple, as in the filter included in the system of Fig. 3, the k. v. a. of this filter would be 14% of the rating of a conventional LC filter. The k. v. a. of the above-mentioned additional elements required for impedance suppression would then be $0.14 \times 178\% = 25\%$ of that of the conventional LC filter.

The total k. v. a., therefore, of the combined filter system including a single phase full wave rectifier, as compared to a conventional filter

system providing the same degree of ripple suppression in the modulated load circuit, is as follows:

K. v. a. of the ripple-suppression filter circuit... = 30% k. v. a. of LC filter.

K. v. a. of the impedance suppressing elements... = 25% k. v. a. of LC filter.

Total... = 55% of the k. v. a. of the conventional LC filter.

Assuming, second, a system including a three phase full wave rectifier, the k. v. a. required if the filter be tuned nearly to the fundamental ripple frequency is 8% of that of the conventional filter. The k. v. a. of the impedance suppressing elements in this latter system is then $0.08 \times 178\% = 14.3\%$, and the total k. v. a., for the same degree of ripple suppression, is $8\% + 14.3\% = 22.3\%$ of that of the system employing the conventional type of filter.

It may be shown, further, that in the case of certain other filters for systems including a three phase full wave rectifier, in which system a limit of 0.15% ripple has been set, the total k. v. a. for this degree of ripple suppression as well as for the provision of low filter impedance over the whole frequency spectrum is, when circuit arrangements in accordance with my invention such as illustrated in Fig. 3 are employed, only 15% of that of the rectifier filter of the conventional type.

Referring now particularly to the modification of my invention illustrated in Fig. 4, shunt circuit elements in accordance with the invention are shown as incorporated in a system comprising a source of current, motor-generator MG, providing a direct current upon which ripple frequencies are superimposed, the inductance and resistance regulation constants of the generator being designated by L_7 and R_5 . A modulated-load circuit R_L , which may be similar to that shown in Fig. 1, is arranged to be supplied with current from the current source terminals T_1T_2 .

In order to suppress a given ripple frequency in the current supplied from the current source terminals T_1T_2 a two-element shunt filter circuit constituted by an inductance L_8 and a condenser C_6 in parallel is provided which is connected in series with a condenser C_7 , the parallel circuit L_8C_6 and the condenser C_7 being connected in shunt with the load circuit R_L . To suppress the given ripple, the parallel element or circuit L_8C_6 is tuned nearly to the frequency of this ripple, on the inductive side of resonance, and then the whole shunt circuit constituted by L_8C_6 and condenser C_7 is tuned to present nearly zero impedance across this shunt, to the given ripple frequency.*

Now obviously the whole filter and generator circuit, so far described in connection with Fig. 4, presents zero impedance at zero and infinite frequencies to an equivalent modulation generator. This impedance rises to the tuned parallel impedance of $R_5L_7L_8C_6C_7$ at some intermediate frequency very near to the ripple frequency. In order to reduce the tuned impedance to a low value, the elements L_8 and C_6 are

shunted by a resistance R_6 . The tuned impedance then approaches the value

$$\frac{L_1}{R_6 C_1}$$

The elements R_6 , L_1 and C_1 obviously require only A. C. k. v. a. ratings.

It is to be understood that in systems arranged, in accordance with my present invention, for use in connection for example with radio transmitters, or like apparatus comprising a modulated load circuit, the keying or load modulating mechanism may comprise the modulation means including switch 1, as shown for example in detail in Fig. 1. It will be readily understood, however, that the actual keying, or load modulating, may be accomplished not only directly as shown in Fig. 1 but, in general, by any suitable means.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In combination, a source of direct current having a ripple component superimposed thereon, filter means to reduce said ripple component, a load circuit, means to modulate said load circuit over a band of frequencies, and a circuit in shunt with the load circuit and comprising a resistor and a condenser in series to reduce the impedance of said source and filter to a predetermined low and uniform value, from zero to infinite frequency of the modulating frequency band.

2. In combination, a source of direct current having ripple components superimposed thereon, filter means to reduce said ripple components, a load circuit, means to modulate said load circuit over a band of frequencies, and means to reduce the impedance of said source and filter to a low value, from zero to infinite frequency of said modulating frequency band, said last-named means comprising two circuits in shunt with the load circuit, one of said shunt circuits comprising a resistor and a condenser in series, the other of the shunt circuits being tuned to the frequency of the main ripple component of the direct current and comprising a resistor, a reactor and a condenser in series.

3. In combination, a source of direct current having superimposed thereon a main ripple component and harmonics of the main ripple, filter means tuned to the main ripple to suppress said main ripple and to absorb said harmonics, a load circuit, means to modulate said load circuit over a band of frequencies, and means to reduce the impedance of said source and filter to a value low with respect to the load resistance from zero to infinite frequency of said modulation band, said last-named means comprising a circuit having a resistor and condenser in series with each other and in shunt with the load circuit and a second circuit tuned to the frequency of said main ripple having a resistor, a reactor and a condenser in series with each other and in shunt with the load circuit.

4. In combination, a source of direct current having superimposed thereon a main ripple component and harmonics of the main ripple, a load circuit, means to modulate said load circuit over a band of frequencies, filter means interposed between the source and the load circuit comprising a transformer having one winding in series between the source and the load circuit and a second winding in series with a condenser, said second winding and condenser being connected in shunt with the load circuit, said filter means fur-

ther comprising a third winding of substantially the same reactance as that of the first-named winding and connected in series therewith, said second winding and said condenser being tuned slightly off resonance on the capacitive side to the frequency of said main ripple, said three windings being loosely coupled, and means to reduce the impedance of said source and said filter means to a value low with respect to the load resistance from zero to infinite frequency of said modulation band, said last-named means comprising two circuits each in shunt to the load circuit, one of said last-named shunt circuits including a resistor and a condenser in series, the other of said last-named circuits being tuned substantially to the frequency of said main ripple and including a resistor, a reactor and a condenser in series.

5. In combination, a source of direct current having ripple components superimposed thereon, a load circuit, means to modulate said load circuit over a band of frequencies, a filter circuit interposed between the source and the load circuit, said filter circuit comprising a condenser in shunt with the source and a reactor connected in series with the source and between the source and said condenser, said reactor having a resistor in shunt therewith, the resistance value of said resistor being at least equal to the reactance value of said reactor at the main ripple frequency, said filter circuit further comprising a second reactor connected in series with the source and between said condenser and the load circuit, said second reactor having a resistor in shunt therewith, the resistance value of said second-named resistor being substantially equal to that of said load circuit, the reactance value of said second-named reactor being equal substantially to five divided by the reactance value of said condenser in microfarads, and a filter impedance suppressing circuit in shunt with said load circuit comprising a resistor and a condenser in series, the reactance of said last-named condenser in microfarads being substantially equal to one-fifth the reactance of said first-named condenser, the resistance value of said last-named resistor being substantially equal to two-thirds the resistance value of said second-named resistor.

6. In combination, a source of direct current having ripple components superimposed thereon, a load circuit, means to modulate said load circuit over a band of frequencies, a filter circuit to reduce said ripple components comprising a condenser in shunt with the source and two reactors in series therewith, one of said reactors being connected between the source and said condenser and the second reactor being connected between the condenser and the load circuit, a resistor in shunt with said one of the reactors and having a resistance value at least equal to the reactance value of said one of the reactors, a resistor in shunt with said second reactor and having a resistance value substantially equal to that of the load circuit, the reactance value of said second reactor being substantially five divided by the reactance value of said condenser in microfarads, and two filter impedance suppressing circuits in shunt with the load circuit, one of said shunt circuits comprising in series a resistor having a resistance value substantially two-thirds of that of said second-named resistor and a condenser having a reactance in microfarads substantially equal to one-fifth the reactance of said first-named condenser, the second of said

shunt circuits being broadly tuned to the main ripple frequency and comprising in series a resistor having a resistance value substantially that of said second-named resistor, a reactor, and a condenser.

5 7. In combination, a source of direct current having superimposed thereon a main ripple component and harmonics of the main ripple, a load circuit, means to modulate said load circuit
10 over a band of frequencies, and means to suppress said main ripple and to absorb said harmonics and to reduce the impedance of said source and filter to a value low with respect to the load resistance from zero to infinite frequency of said

modulation band, said last-named means comprising a circuit in shunt with the load circuit, said shunt circuit comprising a condenser in series with an inductance, a condenser and a resistance connected in parallel, a parallel circuit element constituted by said inductance and said last-named condenser, said parallel circuit element being tuned first approximately to the frequency of said ripple and said parallel circuit element being tuned thereafter with said first-named condenser to cause said shunt circuit to present approximately zero impedance to said ripple frequency.

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