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P. H. CRAIG

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SYSTEM FOR SUPPRESSING INTERFERING CURRENTS

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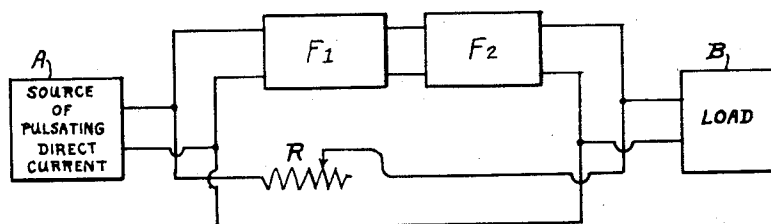


Fig. 1

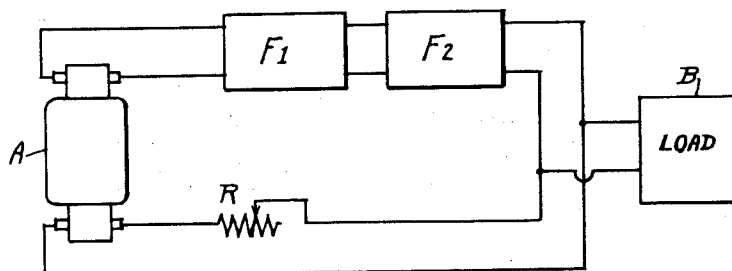


Fig. 2

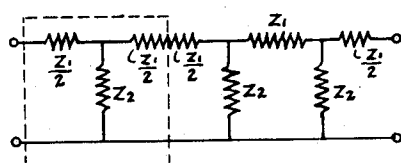


Fig. 3

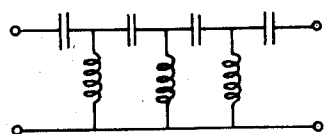


Fig. 5

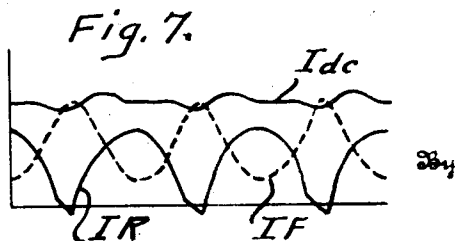


Fig. 7.

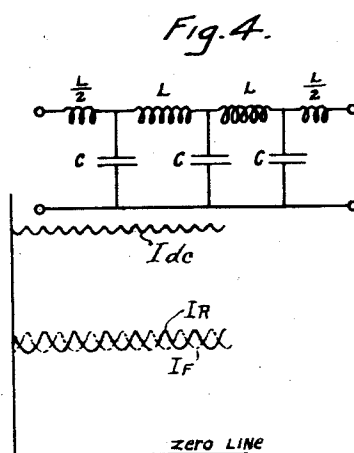


Fig. 6

Inventor

Palmer H. Craig  
Ralph B. Stewart

Attorney

## UNITED STATES PATENT OFFICE

PALMER HUNT CRAIG, OF CINCINNATI, OHIO

## SYSTEM FOR SUPPRESSING INTERFERING CURRENTS

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My invention relates to circuit arrangements for suppressing the "ripple" or alternating current component in a pulsating direct current supply source.

My invention also involves a novel method of suppressing the ripple in a source of pulsating direct current.

My invention is particularly useful in suppressing commutator ripples in circuits supplied with direct current from a commutator generator. It may also be used to suppress the ripple in the output circuit of an alternating current rectifier system.

An object of my invention is to devise a circuit network which when interposed between a source of pulsating direct current and its load will substantially eliminate the ripple current in the load circuit.

A further object of my invention is to devise a circuit network interposed between a source of pulsating direct current and its load by which current is supplied to the load over a plurality of paths, and the ripple current in one path is retarded (or advanced) in phase by 180 degrees with respect to the ripple current in another path.

My invention is illustrated in the accompanying drawing in which:

Figure 1 shows the invention applied to a single source of pulsating direct current;

Figure 2 shows the invention applied to a direct current generator having two commutators;

Figure 3 is a diagram of a filter employed in the explanation of the operation of my invention;

Figures 4 and 5 show different forms of filters which may be employed in my invention;

Figure 6 shows the relation between the currents in the two supply paths and the load current where the source of supply is a commutator generator;

Figure 7 shows the relation between the various currents where the source of supply is an alternating current rectifier.

Referring to Figure 1, A indicates a source of pulsating direct current, and B indicates a load which is to be supplied with steady di-

rect current from source A. The source A is connected to the load B by two parallel paths, one of which includes filter sections F1 and F2 connected in cascade, and the other path includes a variable resistance R. Filter sections F1 and F2 comprise a filter of the "ladder" type, that is, a filter made up of recurring sections of series and shunt impedances. Filter networks of this type possess the property of producing a phase displacement in alternating currents transmitted by the filter, and the phase displacement is proportional to the number of sections embodied in the filter.

The phase shift produced by a ladder filter may be determined in accordance with the following mathematical formulæ:

Referring to Figure 3, there is shown a general circuit diagram for a filter of the ladder type in which the series impedances are indicated by the reference characters Z1 and the shunt impedances are represented by the characters Z2. The portion of the filter included in the dotted square is known as a filter "section." In a uniform filter network of this kind, the propagation constant  $\gamma$  is given by the following equation:

$$\cosh \gamma = 1 + \frac{Z_1}{2Z_2}$$

Where Z1 and Z2 are pure reactances,

$$\gamma = \alpha + j\beta$$

Where  $\alpha$  = attenuation constant per section  
 $\beta$  = phase shift per section (radians)

Within a pass band,  $\alpha = 0$  and  $\beta \neq 0$

Within a stop band,  $\alpha \neq 0$  and  $\beta = 0$

Hence for phase shift purposes, the frequency in use lies within a pass band of the filter.

For a low-pass filter shown in Figure 4,

$$Z_1 = j\omega L, \text{ and } Z_2 = \frac{1}{j\omega C}$$

$$\cosh \gamma = 1 + \frac{j\omega L}{\frac{1}{j\omega C}} = 1 - \frac{1}{2}\omega^2 LC$$

$$\cosh \gamma = \cosh \alpha \cos \beta + j \sinh \alpha \sin \beta$$

Since  $\cosh \gamma$  is real, the last term vanishes and,  $\cosh \gamma = \cosh \alpha \cos \beta$ .

For the pass band,  $\alpha = 0$ , and  $\cosh \alpha = 1$ .

Therefore  $\cosh \gamma = \cos \beta = 1 - \frac{1}{2}\omega^2 LC$ .

5  $\omega = 2\pi f$ , where  $f$  is the frequency of the ripple.

By proper choice of the product  $LC$ ,  $\beta$ , or the phase shift per section, may be made any angle desired from 0 to 180°. The values of  
10  $L$  and  $C$  are not quite arbitrary, however, since to avoid reflection the characteristic impedance of the filter should match the equivalent load resistance. This requires that

$$15 \quad \frac{L}{C} = R^2$$

where  $R$  is the equivalent load resistance.

The pulsating current delivered by source  $A$  may be considered as comprising a steady  
20 direct current and an alternating current, or ripple, superimposed upon the steady current. In accordance with the foregoing design principles, I include sufficient sections in the filter to produce a total phase displacement  
25 of 180° in the ripple current transmitted over the upper path to the load. Since the lower path includes simply a pure resistance  $R$ , the phase of the ripple current transmitted over this path remains unchanged. Accord-  
30 ingly, if resistance  $R$  is adjusted until the amplitude of the ripple current supplied over the lower path is the same as that over the upper path, the two currents will combine at the load terminals in opposite phase relation  
35 and will neutralize each other.

The filter inserted in the upper conducting path may be formed in two section  $F1$  and  $F2$  as shown, each producing one-half the total phase shift, or a single filter section of proper  
40 design may be employed to produce the desired phase shift. It will be understood, of course, that more than two filter sections may be employed, each producing a proportional fraction of the total desired phase shift.

45 I prefer to use low-pass filters of the type shown in Figure 4, but it will be understood that high-pass filters of the type shown in Figure 5 may be employed if desired. In case  
50 filters of the type shown in Figure 5 are used, only the ripple current will be transmitted over the path including the filters, and both direct and ripple current will be transmitted over the lower path.

55 The source  $A$  may be any source of pulsating current, such as a commutator type generator, or a source of rectified alternating current.

60 In Figure 2 I have shown my invention applied to a commutator type of generator provided with a commutator at each end of the armature. In this case the ripples produced by the two commutators are of the same frequency and are synchronous. The operation  
65 of the arrangement shown in Figure 2 will

be apparent from the description of the operation of Figure 1.

In Figure 6, I have shown the current relations existing in the circuit of Figure 1. The solid line  $IR$  indicates the current transmitted over the lower path through resistance  $R$ , and the dotted line  $IF$  indicates the current transmitted through the filter path. It will be seen that the two ripple currents superposed upon these two supply currents are opposite in phase and substantially neutralize each other. The resultant load current is shown by the line  $I_{dc}$ , which is the sum of lines  $IR$  and  $IF$ , and it will be seen that the resultant ripple in the load circuit is of higher frequency and greatly reduced amplitude.

Figure 7 shows the current relations existing in the circuit when the source of supply is a full-wave alternating current rectifier.

85 It will be apparent to one skilled in the art that the filter inserted in the upper path connecting the source  $A$  with the load  $B$  is equivalent to a long transmission line having an effective length greater than the lower path  
90 by one-half wave length of the ripple current. It will also be understood that filters may be inserted in both paths, but one path must contain a greater number of filter sections in order to produce a relative phase  
95 shift of 180 degrees.

The ripple current may not always be a simple harmonic current, but may be a complex wave made up of a fundamental and several harmonics. It will be understood that  
100 where I refer to a phase shift of 180° or to a half-wave length of the ripple current, this has reference to the most predominant component of the ripple. Where the ripple is very complex, and this is probably the usual  
105 case, the phase-shift required may not be exactly 180°, but will be of such magnitude as to reduce the interference to a minimum.

The physical embodiment of my invention may vary in many details without departing  
110 from the spirit of the invention.

What I claim is:

1. In combination, a source of pulsating direct current, a load circuit, a circuit connecting said source and load, a second circuit  
115 connecting said source and load, a filter network in one of said circuits for causing a relative phase shift of 180 degrees between the ripple currents in the two connecting circuits.

120 2. In combination, a source of pulsating direct current, a load circuit, two parallel circuits connecting said load to said source, one of said connecting circuits having an effective length greater than the other connecting circuit by one-half wave length of the ripple current from said source.

125 3. In combination, a source of direct current containing a ripple current, a load, two direct current supply circuits connecting said  
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load to said source, means for producing a relative phase shift of 180 degrees between the ripple currents transmitted over the two connecting circuits, and means to equalize the amplitude of the two ripple currents.

4. The method of suppressing the ripple current in a load circuit supplied from a source of pulsating direct current which consists in, supplying current to the load over two parallel paths one of which has an effective length greater than the other by one-half wave length of the ripple current, and equalizing the amplitudes of the two ripple currents transmitted.

5. The method of suppressing the ripple current in a load circuit supplied from a source of pulsating direct current which consists in, supplying the pulsating direct current to the load over two parallel paths, and causing a relative phase shift of 180 degrees between the ripple currents in the two paths.

6. In combination, a source of direct current containing a ripple current, a load, two direct current supply circuits connecting said load to said source, means for producing a relative phase shift of 180 degrees between the ripple currents transmitted over the two connecting circuits.

7. In combination, a source of pulsating direct current, a load circuit, two parallel circuits connecting said load to said source, and a filter network comprising recurring sections of series and shunt impedances connected in one of said circuits for causing a relative phase shift of 180 degrees between the ripple currents in the two connecting circuits.

8. In combination, a source of direct current containing a ripple current, a load, a direct current supply circuit connecting said load to said source, and a second circuit connected between said load and said source independently of said supply circuit for supplying a ripple current to said load to substantially balance the ripple current supplied by said direct current supply circuit.

In witness whereof I affix my signature.

PALMER HUNT CRAIG.

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