July 21, 1931. M. M. DOLMAGE 1,815,838

NEGATIVE CAPACITY DEVICE

Filed June 27, 1929

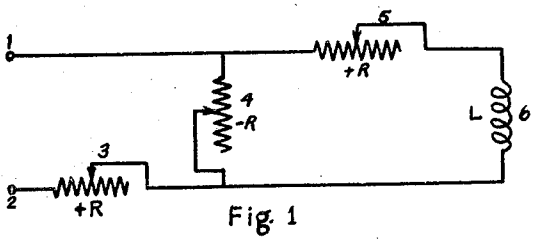


Fig. 1

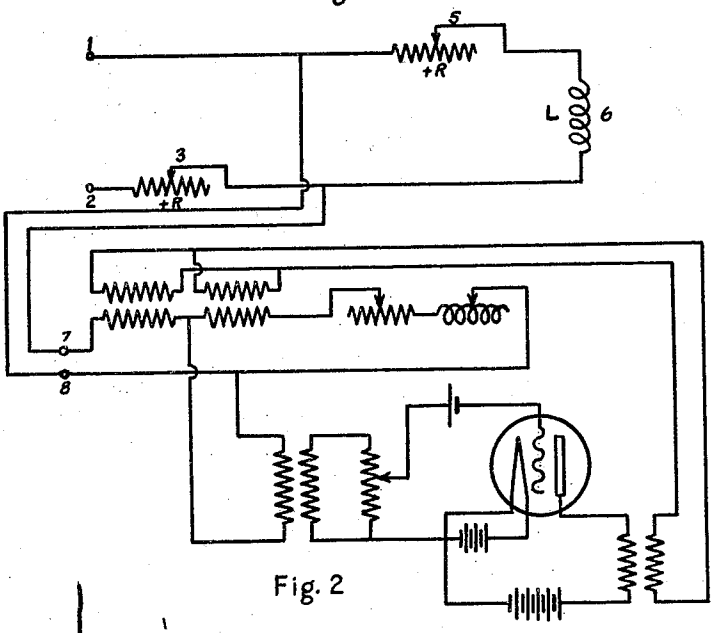


Fig. 2

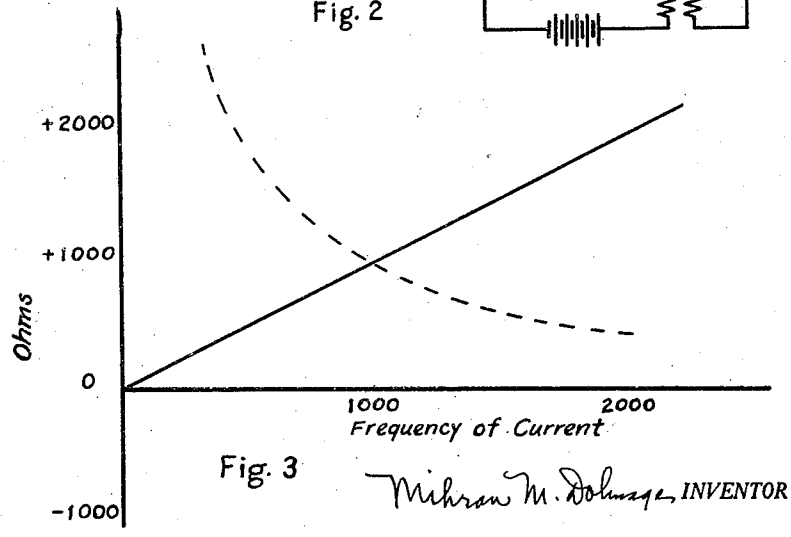


Fig. 3

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UNITED STATES PATENT OFFICE

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NEGATIVE CAPACITY DEVICE

Application filed June 27, 1929. Serial No. 374,084.

This invention relates to a new combination in the electrical art, a negative capacity.

Where, in an electrical circuit or a transmission line, a single frequency alternating current is involved, it is well known that the opposition offered to the flow of electrical current by a condenser in the electrical circuit or by a capacity in the transmission line may be offset by an inductance. The relief thus obtained may be partial or complete depending on the relative dimensions of the inductance and the condenser.

To make this point perfectly clear consider a circuit containing in series a condenser of capacity C, an inductance L, a resistance R, and a generator having an electro-motive force equal to E sin pt. In such a circuit the reactance of the condenser is equal to

$$\frac{1}{pC}.$$

The reactance of the inductance L is pL. These two reactances being in phase opposition, the total net reactance of the circuit is given by

$$(1)\quad \text{Reactance} = pL - \frac{1}{pC}$$

Clearly then there is a frequency for which the two reactances, the capacity reactance and the inductive reactance, are equal to each other and the resulting total net reactance is zero.

Where, however, a number of frequencies have to be transmitted simultaneously, which is the general case in signalling circuits, both wire and wireless, the difficulty immediately arises that if the signalling circuit is tuned to some one frequency, all other frequencies are adversely affected. As an instance, in wireless receiving at the present stage of the art it is necessary to have recourse to so called "loose tuning" to avoid the undue reduction of either the main carrier wave or the modulated carrier wave or both.

This invention relates to the discovery of a method for obtaining what can be properly called a "negative" capacity. Full disclosure is made herein of the means required to carry out the method. Essentially, according to my definition of it, a negative capacity is a device which, in its effect, when interposed in an electrical circuit, is the exact counterpart of an ordinary capacity for the entire range of frequencies from practically zero to practically infinity. The reactance of such a device may be expressed by the relation

$$(2)\quad \text{Reactance} = +\frac{1}{pC}$$

the corresponding expression for the reactance of an ordinary capacity being

$$(3)\quad \text{Reactance} = -\frac{1}{pC}$$

Assuming such a negative capacity ($-$C) to have been wired in series with an ordinary condenser ($+$C) in an electrical circuit wherein acts an electromotive force of frequency

$$\frac{p}{2\pi},$$

it follows immediately that the net reactance in this circuit would be equal to

$$(4)\quad \frac{1}{pC} - \frac{1}{pC} = 0$$

Hence in such a circuit, if a number of electromotive forces having different frequencies (instead of a single frequency electromotive force) were active, the reactance of the circuit would be nil for all frequencies and there would be no discrimination as between different frequencies. To put this in another way, we would have realized a distortionless circuit. This is obviously true since relation (4) holds regardless of p. The practical importance in signalling work of a negative

capacity, having the characteristics hereinabove outlined, is too evident to require comment.

It should be understood, of course, that instead of complete neutralization of the negative reactance of the capacity, we may arrange for partial neutralization if we so desire. The "relative" neutralization in such a case will be the same for all frequencies. If, for instance, we wish 50% neutralization of the negative reactance

$$\left(-\frac{1}{pC}\right)$$

of the capacity C in an electrical circuit, then the combination of the negative reactance of the given capacity and of the positive reactance of the negative capacity device will be

$$\left(-\frac{1}{2pC}\right).$$

It is necessary and sufficient, in order to realize the above purpose, that the value of the negative capacity be equal to

$$+\frac{1}{2pC}.$$

The reactance of the series combination is thus given by

$$(5) \quad -\frac{1}{pC}+\frac{1}{2pC}=-\frac{1}{2pC}$$

The important point to note is this, that: while neutralization of capacity reactance is also possible through the use of ordinary inductance, such neutralization is not equally effective at all frequencies. If it is 100% at some one frequency, so that for that frequency the net reactance is zero, it will be only 25% for half of that frequency. This is evident since, if series inductance is used for neutralization purposes, the net reactance of the circuit is given by Formula (1) hereinabove. If, as stated, for some definite frequency

$$\left(\frac{p_o}{2\pi}\right)$$

the above reactance is equal to zero, then:

$$p_oL=\frac{1}{p_oC}$$

Now, for half the above frequency, the second term in equation (1), which term expresses capacity reactance in ohms, is twice as large, while the first term which expresses the reactance of the inductance coil, is only one-half in value. Assume that for the original frequency, the positive reactance (pL) is 1,000 ohms and the negative reactance of the capacity is −1,000 ohms. The series combination of the above will have a reactance which would be 0 ohms. The negative reactance for one-half frequency is evidently −2,000 ohms, while the reactance of the inductance is only +500 ohms. The net reactance of the series combination is −2,000+500, or −1,500 ohms. The neutralization which was 100% for the frequency as originally assumed is now only 25% for one-half of that frequency. The opposition offered to the flow of current through an electrical circuit containing a condenser and inductance coil would be, as shown above, 0 ohms for the neutralization frequency. It is −1,500 ohms for one-half frequency.

This brief description gives a clear idea of the "distortion" that is produced when capacity reactance is used in series with an inductance when a number of different frequencies are to be transmitted simultaneously over any given electrical circuit. In commercial practice, this situation is of common ocurrence, for instance, in the case of telephone circuits where speech frequencies varying between a few hundred cycles and 5,000 cycles are transmitted over the same circuit. If such an electrical circuit contains a series condenser, the use of an inductance in series in relation thereto would be absolutely valueless, as it would introduce intolerable distortion. The above brief description also gives an idea of the great value of the negative capacity device such as disclosed hereunder, since neutralization is in the same proportion for all frequencies when a negative capacity device is used to balance out, in whole or in part, a capacity wired in an electrical circuit.

The discussion given above for series neutralization of the reactance of a capacity by means of "negative" capacity as compared to similar neutralization by means of an inductance coil, also holds true for parallel neutralization, or parallel use of a negative capacity with an ordinary capacity.

The method I have discovered to realize the object of this invention is, briefly, to use in parallel with a negative resistance a combination comprising an ordinary positive resistance having the same absolute ohmic value as the negative resistance, in series with an inductance. The value of this inductance is to be chosen in accordance with the rules indicated below.

The novel features of my invention are pointed out in the appended claims. The invention itself will be best understood by reference to the drawings and the discussion given herein below.

Figure 1 of the drawings shows the general idea underlying the use of my method. Figure 2 shows a particular method of carrying out my invention using as a negative resistance the type of circuit and apparatus covered in U. S. A. Patent No. 1,606,350, granted to me. Figure 3 shows in dotted line the reactance in ohms of the "negative" capacity device discovered by me in function of frequency. As a matter of interest, the corresponding reactance of an ordinary inductance coil is shown in full line. It will be seen, at a glance, how different the two are.

In the case of the "negative" capacity of the present specifications, the absolute value of this reactance decreases as the frequency increases, while for an ordinary inductance the opposite trend holds, as shown on said Figure 3. Furthermore, the reactance variation of the device disclosed hereunder is inversely proportional to the frequency, while in the case of an ordinary inductance the reactance is directly proportional to the frequency.

The arrangement of apparatus connected across terminals 1 and 2 represents a "negative" capacity within the meaning of the word as defined previously. Element 3 is an ordinary resistance. Element 4 is a negative resistance. It may be of any type known to the art. In parallel with this element are wired, in series combination, a resistance (element 5) and an inductance (element 6).

Figure 2 shows a preferred form of negative resistance for element 4 of Figure 1 of the drawings. It is represented by the combination of apparatus connected to terminals 7 and 8. This type of negative resistance has been disclosed in U. S. A. Patent 1,606,350, granted to me.

To show how effectively the combination shown realizes the requirements for a negative capacity, as defined above, consider the mathematical expression for the parallel combination of elements 4, 5 and 6. Using the usual imaginary notation, the expression is given by

$$(6)\quad \frac{-R(R+jpL)}{-R+R+jpL}=\frac{-R(R+jpL)}{+jpL}$$

where j is the usual imaginary factor

$$\sqrt{-1}.$$

Bearing in mind that $j^2=-1$, we obtain, after multiplying the numerator and denominator of the above factor by $(-j)$

$$(7)\quad \frac{+jR(R+jpL)}{pL}$$

Developing fully the real and imaginary terms of the above gives the following relation

$$\text{Parallel impedance}=+\frac{jR^2}{pL}-R=-R+j\frac{R^2}{pL}$$

The first item of the above expression is a negative resistance. The second or imaginary term represents a positive reactance, and is of opposite sign to the negative reactance of an ordinary capacity. Furtherfore, it can be written in the form

$$+j\frac{1}{p\frac{L}{R^2}}.$$

It is seen from the expression as just written that the reactance of this new device is inversely proportional to (p) and therefore inversely proportional to the frequency of the current transmitted through it, just as in the case of the reactance of an ordinary capacity. But, it has the opposite sign $(+)$ instead of the minus $(-)$ as hereinabove assumed for the reactance of an ordinary capacity. Now (R) and (L) in the above expression are anything we choose. We can, therefore, if we wish to secure a "negative" capacity of predetermined value $(-C)$, so choose the above values (R) and (L) that

$$(8)\quad C=\frac{L}{R^2}$$

We can secure, therefore, the value of the element (6) of the drawings from fundamental Equation (8). It should be noted that (R) is still determinate and may be best chosen so as to secure convenient or practical values for the reactance (L) required to realize the predetermined positive reactance for the negative capacity device.

Once we have fixed the value of (L), as just described, we can write as follows the value of the parallel impedance of elements (4), (5), and (6).

$$(9)\quad \text{Parallel impedance}=-R+j\frac{1}{pC}$$

The combination of element 3 (series positive resistance R) with the parallel impedance of elements 4, 5 and 6 as just written has an an impedance equal to

$$(10)\quad +R-R+j\frac{1}{pC}=+j\frac{1}{pC}$$

The impedance of the combination of apparatus connected to terminals (1) and (2) of the drawings, is therefore given by

$$+\left(\frac{1}{pC}\right),$$

a negative capacity in the true sense of the term. This entirely new device in the art, no matter what the frequency factor (p) acts exactly like a capacity, so far as frequency variation is concerned, but otherwise is in exact phase opposition. If in any electric circuit, we have a condenser having a capacity C, the combination of apparatus indicated on Figure 1 of the drawings used in series with the condenser C will wipe out completely the reactive effect of this condenser regardless of the frequency of the current which may be transmitted through such a circuit.

A very valuable advantage of the arrangement shown on the drawings is the ease with which the value of the negative capacity may be changed. To obtain a change it is sufficient to change the value of the resistance elements shown on Figure 1 or Figure 2, without changing the inductance element. All the resistance elements must be changed the same amount. If the various resistance elements are changed by the same percentage,

say 10%, the capacity will have changed in accordance with the square of such change, or 21%. This will be clear by reference to Formula (8). Or we may leave the resistance elements alone, and change only the value of inductance (6). In this case the variation of the value of the negative capacity is directly proportional to the variation in the value of the inductance of element (6).

I claim:

1. An automatic device having reactance characteristics of opposite sign to that of a capacity, such reactance varying inversely with frequency.

2. A two terminal electrical network consisting of a negative resistance, in parallel with a combination of a resistance and an inductance in series relation, said parallel arrangement being wired in series with a resistance.

3. An automatic device having reactance characteristics of opposite sign to that of a capacity, such reactance varying inversely with frequency, with additional means for varying the value of said reactance in equal proportion for all frequencies.

4. In an electrical network containing a condenser, automatic means for the partial neutralization of said condenser to the flow of current through said network, equally effective for all frequencies.

5. In an electrical network for the simultaneous transmission of a band of frequencies, containing a condenser, automatic means for the complete neutralization of said condenser to the flow of current through said network, equally effective for all frequencies.

6. In an electrical circuit containing a condenser, automatic means for neutralizing the effect of said condenser to the flow of current through said circuit, such means being equally effective at all frequencies.

In testimony whereof I affix my signature.

MIHRAN M. DOLMAGE.