Dec. 5, 1939. L. C. PETERSON 2,181,909

NEGATIVE IMPEDANCE CIRCUIT

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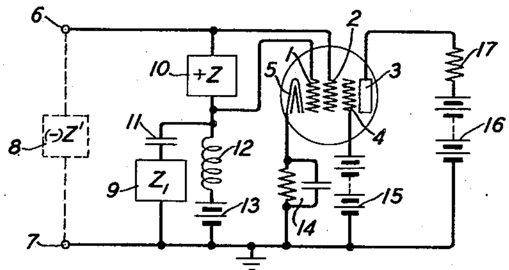

FIG. 1

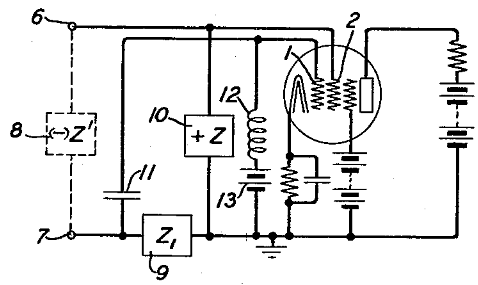

FIG. 2

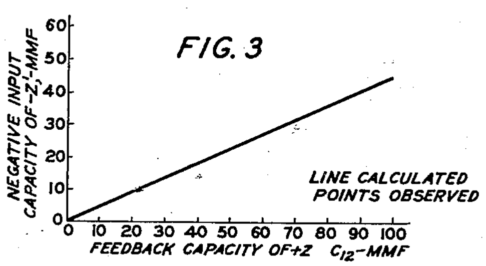

FIG. 3

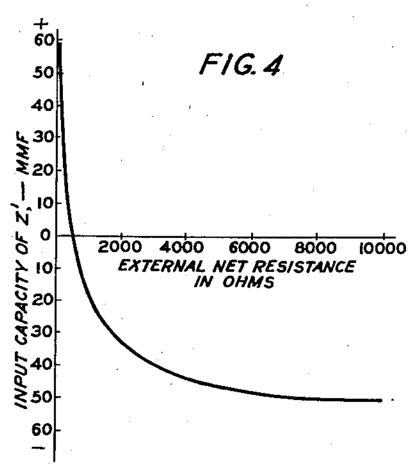

FIG. 4

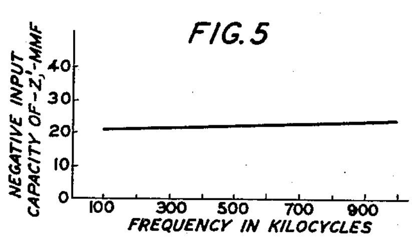

FIG. 5

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NEGATIVE IMPEDANCE CIRCUIT

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7 Claims. (Cl. 178—44)

The present invention relates to circuits for obtaining the negative of a given positive impedance.

A general object of the invention is the obtaining of a negative impedance by a simplified circuit and in a more direct manner than heretofore.

A feature of the invention comprises use of a tube exhibiting negative transconductance between certain of its elements for enabling the negative of a given positive impedance to be obtained between proper terminals.

More specifically the invention will be disclosed as employing a tube with a control grid and a second grid, positively biased, and with the given positive impedance and the terminals between which the negative of the given positive impedance is to be produced, properly associated with respect to each other and the two grid circuits.

The invention will be more fully understood from the following detailed description and accompanying drawing in which Figs. 1 and 2 show typical circuit diagrams embodying the invention, Fig. 1 illustrating the shunt type and Fig. 2 the series type, and Figs. 3 to 5 show curves illustrating the results obtained with the invention in typical examples.

Referring to Fig. 1, a space discharge tube is shown having positive (space charge) grid **1**, also referred to as net, control grid **2**, anode **3**, screen grid **4** and cathode **5**. Anode **3** is shown connected through a resistance **17** to anode battery **16**. This resistance is not essential. Battery **15** supplies positive voltage to screen grid **4**. Battery **13** supplies positive voltage through choke coil **12** to net **1**, the alternating current circuit branch from net to cathode being through blocking condenser **11** and an impedance **9** of value Z_1 to be discussed later. An impedance **10** of value $+Z$ (to be discussed later) is connected between control grid and net. Terminals **6** and **7**, between which the negative of impedance $+Z$ is developed, are connected respectively to control grid and cathode. The negative impedance $-Z'$ is indicated by dotted lines as present between terminals **6** and **7**. The usual resistance-capacity combination for biasing the control grid negatively is shown at **14**. This figure represents the shunt type of connection.

It is necessary in order to practice the invention to have a tube which exhibits an amplification constant numerically greater than unity from control grid **2** to net **1**. Stated conversely, the amplification from net **1** to control grid **2** is negative and numerically greater than one. Using subscripts to identify the grids, and the order of subscripts to denote direction in which the quantity is taken

$$\mu_{12}<-1 \tag{1}$$

Applicant has observed from tests made on a large number of tubes that certain type tubes meet this condition, examples being Western Electric 7575—F and 291A and R. C. A. 6A7 types.

In Fig. 1 it is assumed that the plate **3** is sufficiently well shielded by screen grid **4** from the control grid so that its influence on the control grid and net can be neglected. It is also assumed that the control grid is at all times negative with respect to the cathode. Then the impedance relation can be written

$$Z'=\frac{Z+\dfrac{Z_1R_1}{Z_1+R_1}}{1+\mu_{12}\dfrac{Z_1}{Z_1+R_1}} \tag{2}$$

where R_1 is the internal alternating current resistance of the net to cathode path. In those tubes in which Equation (1) obtains, the numerator of (2) being positive, the denominator is negative if

$$\frac{Z_1}{Z_1+R_1}$$

is substantially unity as can readily be the case by making Z_1 very large compared to R_1. Moreover, when Z_1 is very large compared to R_1 the fraction

$$\frac{Z_1R_1}{Z_1+R_1}$$

is at least as small as R_1 and will be designated for brevity as R_1'. Then expression (2) may be rewritten as

$$Z'=\frac{Z}{1+\mu_{12}\dfrac{Z_1}{Z_1+R_1}}+\frac{R_1'}{1+\mu_{12}\dfrac{Z_1}{Z_1+R_1}} \tag{3}$$

which means that Z' is negative, and is proportional to Z and includes a small negative resistance component, or denoting

$$\frac{1}{1+\mu_{12}\dfrac{Z_1}{Z_1+R_1}} \text{ as } -k, \tag{4}$$

$$Z'=-k(Z+R_1'). \tag{5}$$

Thus, the negative impedance $(-)Z'$ can be made very closely proportional to the negative of the given positive impedance Z according as R_1' is negligibly small in comparison with Z. This is true whether Z is a resistance or some other impedance such as a reactance or a network including reactances with or without resistances.

Referring to Fig. 2 which represents the series type of connection, the same reference characters represent the same elements as in Fig. 1. It will be noted that in Fig. 2 the impedance 10 which is the given positive impedance is connected from control grid to cathode. The impedance Z_1 is connected from net to cathode but is serially included with terminals 6 and 7 between control grid and cathode. The impedance equation for this figure may be written as

$$Z'=Z\left(1+\mu_{12}\frac{Z_1}{Z_1+R_1}\right)+\frac{Z_1R_1}{Z_1+R_1} \qquad (6)$$

As in the shunt case (Fig. 1), the requirements for Z' to be negative are that $\mu_{12}<-1$ and $Z_1>>R_1$. It will be noted that the second term is always positive in this case, so that the negative impedance (−)Z' includes a small positive resistance component numerically equal to the small negative resistance component found to be present in the shunt arrangement (Fig. 1).

Fig. 3 shows a graph of calculated values (line) and observed values (points), obtained for a circuit similar to that of Fig. 1 for the case in which Z was a simple capacity and where the tube parameters at the chosen operating point were:

$$\mu_{12}=-1.5$$
$$R_1=300 \text{ ohms}$$

In this case Z_1 was 10,000 ohms. The capacity used for +Z was a variable condenser the value of which could be read directly. A switch was used to short circuit Z_1 and the total capacity from control grid to cathode was determined when a relatively large fixed capacity was connected across terminals 6 and 7. This capacity was easily found since the value of the adjustable capacity at +Z was known. Then when the switch was opened, putting Z_1 in circuit, the capacity between terminals 6 and 7, now smaller than before, was measured. The difference was the capacity component of −Z' as given in Fig. 3 for various values of +Z. It is seen that as to this capacity relation, |Z'| is very nearly equal to

$$\frac{Z}{1-|\mu_{12}|}$$

as expected.

The dependence of the negative capacity upon the external net-to-cathode resistance Z_1, using the same circuit constants as in Fig. 3 but with a fixed capacity of 98.9 mmf. for +Z, is shown in Fig. 4. With Z_1=500 ohms the positive shunt tube capacity is just annulled and with increasing resistance at Z_1 the component of the capacity across 6 and 7 due to the feed-back action between the two grids becomes increasingly negative, approaching an asymptotic value for quite large values of Z_1.

The independence of frequency of the negative capacity is shown by Fig. 5. For this curve, the same circuit was used as for the other graphs except that +Z had the value 40.6 mmf.

Applicant has also determined that the negative impedance obtained with this experimental circuit exhibits practically perfect stability as regards variable plate voltage; a high degree of stability as regards changes in cathode heating current, screen voltage and control grid bias. All of these stabilities were greater than that for net potential variations so that greater care should be taken in maintaining the voltage of source 13 constant than is necessary in the case of the other voltages. Where batteries are shown in the figures, it is to be understood that other suitable sources may be used including any of those customarily used in the vacuum tube art.

What is claimed is:

1. A circuit for producing across a pair of terminals the negative of a given positive impedance comprising a space discharge device having a cathode, an anode, a control grid and a second grid, said device exhibiting gain from said control grid to the second grid, means to make the control grid negative and the second grid and anode each positive with reference to the cathode, means connecting in a series circuit said pair of terminals, said given positive impedance and a second impedance large compared to the internal impedance between the cathode and second grid and of the same sign as said internal impedance in such manner that the drop of potential across said second impedance is impressed between said cathode and second grid, said control grid being connected to one of said pair of terminals and to one terminal of said given positive impedance.

2. A circuit according to claim 1 in which said given positive impedance is connected between said control grid and said second grid.

3. A circuit according to claim 1 in which said given positive impedance is connected between said control grid and cathode.

4. In combination, a space discharge device having a cathode, an anode, a negatively biased control grid and a positively biased grid located between the cathode and control grid, external circuit connections for said device, the external circuit impedance between the positive grid and cathode being very large compared with the internal impedance between the positive grid and cathode, said device having negative gain from the positive grid to the negative grid numerically greater than unity, a positive impedance connected between said two grids and terminals between which the negative of said positive impedance is produced by said device, said terminals being connected to said negative grid and cathode.

5. In combination, a space discharge device having a cathode, a first grid next to the cathode with means for applying a steady positive potential thereto, a second grid beyond the first grid with means for applying a steady negative potential thereto, an anode beyond said second grid, means for applying positive potential to said anode, external circuit connections to said cathode and grids, the external circuit impedance between said first grid and cathode being very large compared to the internal impedance between the same elements, said device having negative gain from the first grid to the second grid numerically greater than unity, a positive impedance, terminals therefor, a negative impedance having as a component the negative of said positive impedance, terminals for said negative impedance, the terminals of one of said two last-mentioned impedances being connected between said two grids and the terminals of the other of said two last-mentioned impedances being connected between said second grid and cathode.

6. A circuit for producing between a pair of terminals an impedance Z, comprising a space discharge device having a cathode, an anode, a negative grid and a positive grid, said tube exhibiting gain from the negative to the positive grid, an impedance Z coupling said grids, the

internal impedance between the positive grid and cathode being R_1, said circuit possessing an external impedance of value Z_1 between the positive grid and cathode, in which

$$Z' = -k(Z + R_1')$$

$-k$ having the value

$$\frac{1}{1 + \mu_{12}\frac{Z_1}{Z_1 + R_1}}$$

μ_{12} being the amplification factor from the positive grid to the negative grid and being negative in sign and numerically greater than unity, R_1' having the value

$$\frac{Z_1 R_1}{Z_1 + R_1}$$

and Z_1 being very large compared to R_1.

7. A circuit for producing between a pair of terminals an impedance Z', comprising a space discharge device having a cathode, an anode, a negative grid and a positive grid, said tube exhibiting gain from the negative grid to the positive grid, an impedance Z connected between the negative grid and cathode, said pair of terminals being the external circuit terminals of said two grids, said circuit possessing an external impedance of value Z_1 between said positive grid and cathode, Z_1 being very large compared to R_1 the internal space impedance between the positive grid and cathode, in which

$$Z' = Z\left(1 + \mu_{12}\frac{Z_1}{Z_1 + R_1}\right) + \frac{Z_1 R_1}{Z_1 + R_1}$$

μ_{12} being the gain from the positive grid to the negative grid and being negative in sign and numerically large compared to unity.

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