June 5, 1928. 1,672,056

J. R. CARSON

# TRANSLATING CIRCUIT

Filed Dec. 22, 1924

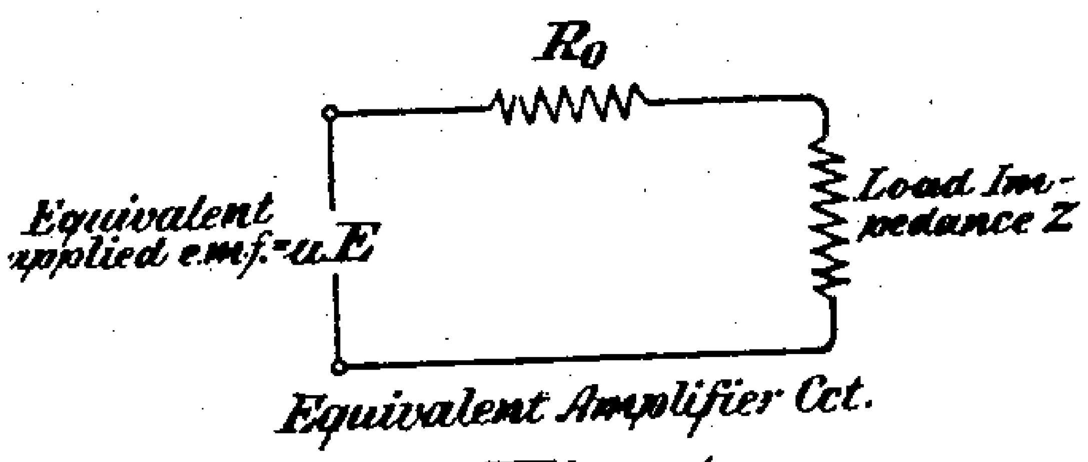


Fig. 1

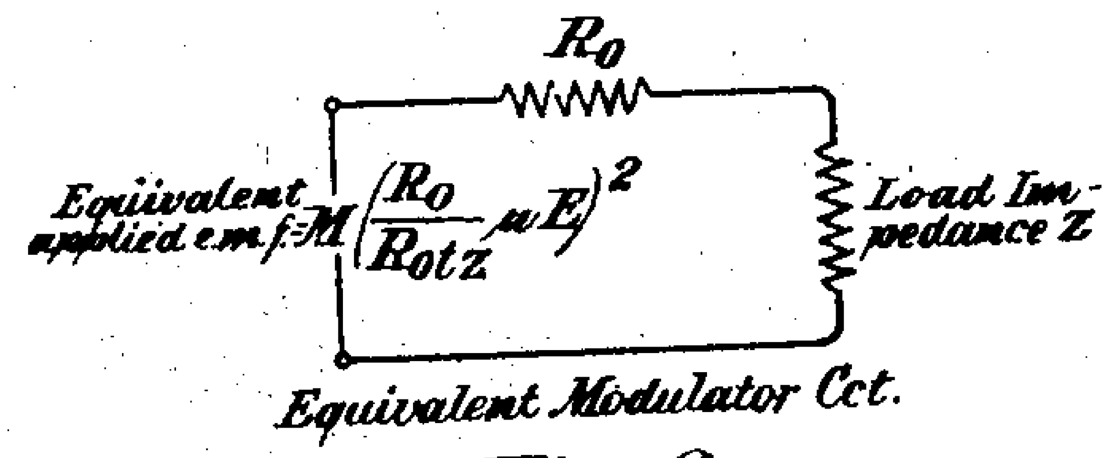


Fig. 2

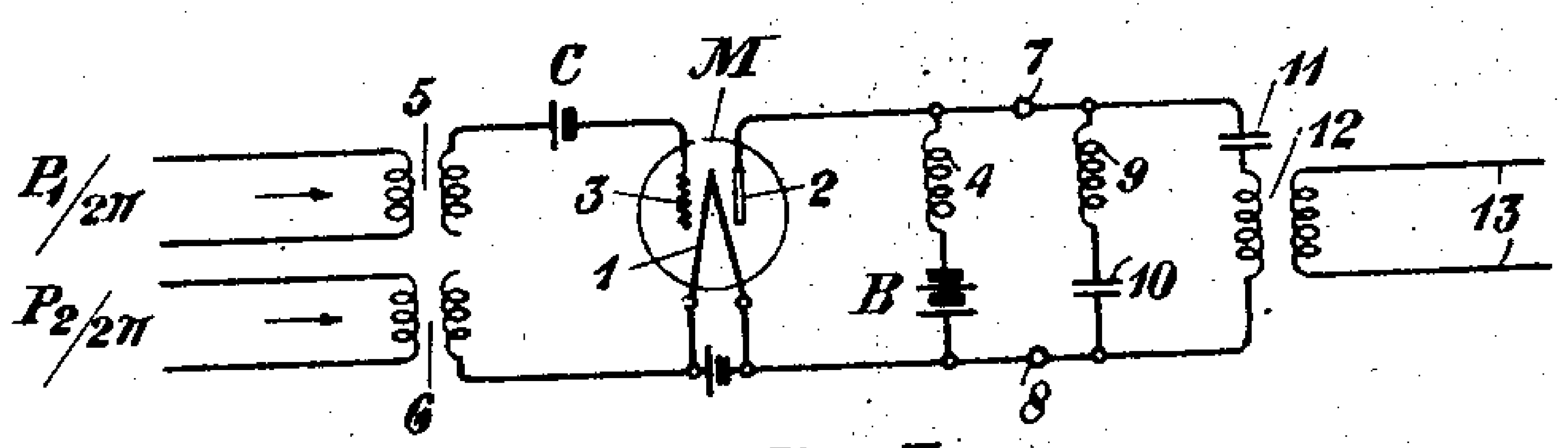


Fig. 3

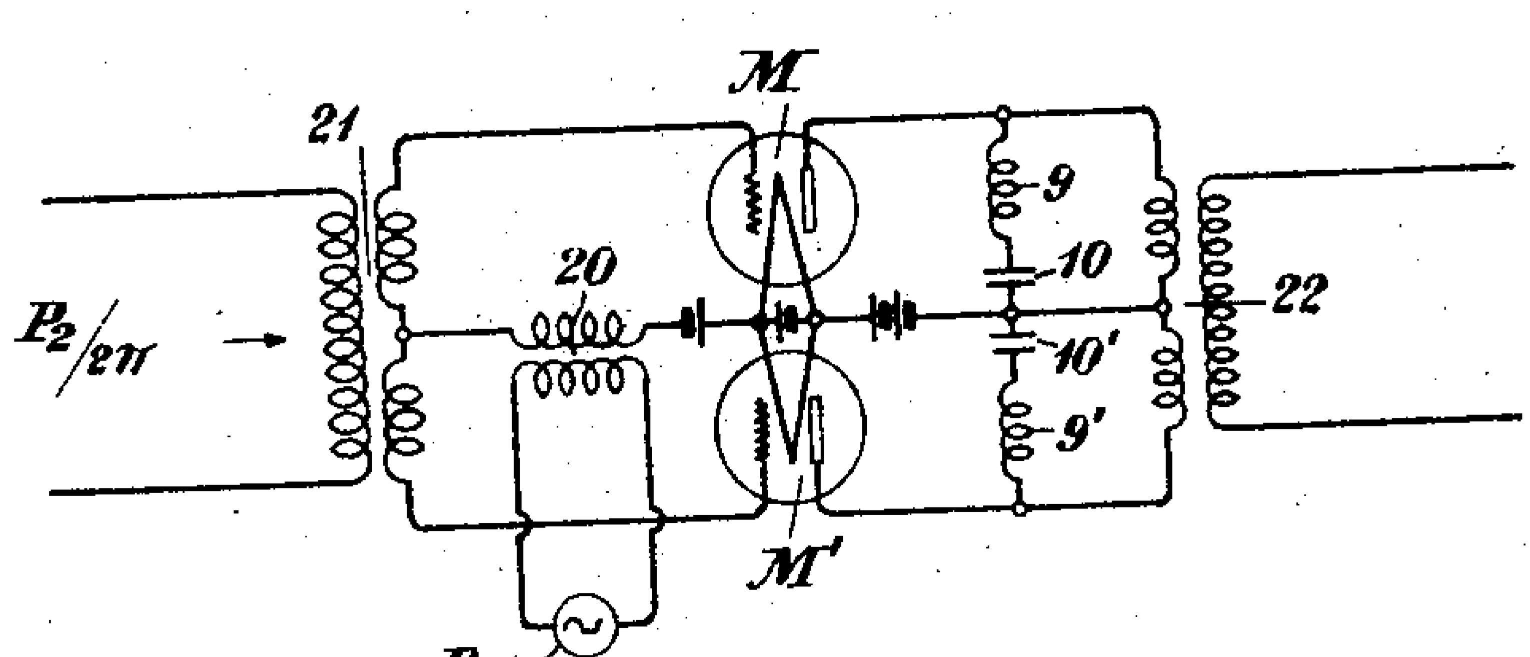


Fig. 4

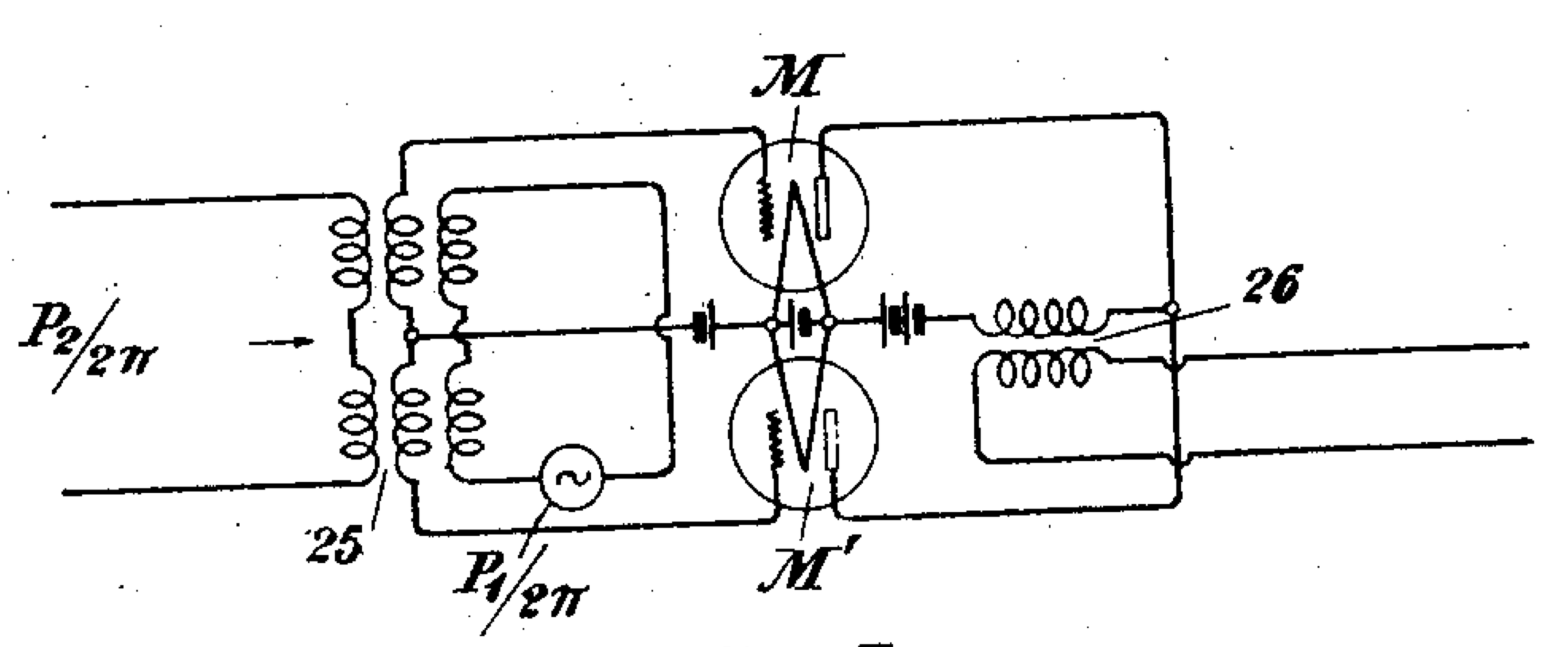


Fig. 5

INVENTOR
J. R. Carson
BY
[signature]
ATTORNEY

Patented June 5, 1928. **1,672,056**

# UNITED STATES PATENT OFFICE.

JOHN R. CARSON, OF SCARSDALE, NEW YORK, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

## TRANSLATING CIRCUIT.

Application filed December 22, 1924. Serial No. 757,548.

This invention relates to translating devices and more particularly to translating devices in the nature of modulators or detectors.

In my United States Patent 1,448,702, of March 13, 1923, I have described a circuit arrangement for increasing the output energy of a modulator or detector, preferably of the vacuum tube type. In my said patent it is shown that if the impedance of the load circuit in the output of a modulator be made substantially zero at the signal frequency, the output modulated energy will be increased 57 per cent. This result is accomplished by arranging a by-pass across the output circuit of the modulator, said by-pass being tuned or otherwise made selective so that it acts practically as a short circuit for the signal frequency. The same principle applies to a detector except that in this case the received modulated current modulates the carrier current to produce the low frequency signal and therefore the load impedance should be substantially zero at the frequency of the received modulated current.

I have discovered that the modulated energy may be increased 273 per cent over that of an ordinary modulator if the impedance of the load circuit be made substantially zero at both the signal frequency and the carrier frequency, in the case of the modulator. In the case of the detector, the same result may be accomplished by making the load circuit impedance substantially zero at the carrier frequency and the received side band of the frequency.

The arrangements by which these results may be obtained will be clearly understood from the following description when read in connection with the accompanying drawings, Figures 1 and 2 of which are schematic diagrams indicating the electrical equivalents of certain types of vacuum tube circuits, Fig. 3 of which is a diagram of a circuit arrangement of a vacuum tube modulator (or a detector) operating in accordance with the principles of my Patent 1,448,702, already referred to, while Figs. 4 and 5 are diagrams of two circuit arrangements of vacuum tube modulators (or detectors) embodying the principles of the present invention.

It is a well known fact that if an electromotive force E is impressed on the input circuit of a three-element vacuum tube amplifier of amplification constant $\mu$ and an external or load impedance $z$, its behavior as an amplifier may be correctly described by postulating an electromotive force $\mu E$ impressed on the load impedance $z$ through a resistance $R_0$, where $R_0$ is the "internal resistance" of the tube, and is given by the formula

$$\frac{1}{R_0}=\frac{\partial I}{\partial E_b} \quad (1)$$

I being the plate current and $E_b$ being the steady plate-filament potential difference. (See articles by H. J. van der Bijl in the Physical Review of September, 1918, and in The Proceedings of the Institute of Radio Engineers of April, 1919, as well as an article by John R. Carson in The Proceedings of the Institute of Radio Engineers of April, 1919).

This law has led to the concept of the equivalent circuit of the vacuum tube amplifier, indicated schematically in Fig. 1, and has been a very valuable aid in interpreting the behavior of amplifiers of this character and in designing the associated circuits. It may also be shown that a vacuum tube, when functioning as a modulator, may be represented by an "equivalent circuit" of almost equal simplicity. The equivalent modulator circuit may be inferred at once from the following theorem:

If a voltage E is impressed on the input terminals of a three-element vacuum tube feeding into a load impedance $z$, the operation of the device as a modulator may be correctly described by postulating an E. M. F.

$$M\left(\frac{\mu R_0}{R_0+z}E\right)^2 \quad (2)$$

impressed on the load impedance $z$ through a resistance $R_0$. In equation (2) M is the modulation factor, a physical parameter of the tube, and is given by the equation

$$M=\left(\frac{1}{2R_0}\right)\cdot\left(\frac{\partial R_0}{\partial E_b}\right) \quad (3)$$

The equivalent circuit is shown schematically in Fig. 2.

The law formulated by this theorem and the character of the approximations involved are easily deduced from the treatment of the problem developed in an article by John R. Carson in The Proceedings of the Institute of Radio Engineers of June, 1921, and for full details of the solution reference may be had to said article.

In my Patent 1,448,702, it is shown that the modulated output current, i. e., the currents in the output of the modulators commonly known as the upper and lower side waves, may be expressed:

$$\left(M(\mu R_0)^2 \frac{E_1 E_2}{Z(p_1)\cdot Z(p_2)}\right)\cdot\left(\frac{1}{Z(p_1-p_2)}\right) \quad (4)$$

$$\left(M(\mu R_0)^2 \frac{E_1 E_2}{Z(p_1)\cdot Z(p_2)}\right)\cdot\left(\frac{1}{Z(p_1+p_2)}\right) \quad (5)$$

Expression (4) is the expression for the current of frequency

$$\frac{(p_1-p_2)}{2\pi}$$

and expression (5) is the expression for the current of frequency

$$\frac{(p_1+p_2)}{2\pi}$$

In these expressions $E_1$ and $E_2$ are respectively the E. M. F. of the carrier wave and the E. M. F. of the signal wave applied to the modulator; and $Z(p_1)$, $Z(p_2)$, $Z(p_1-p_2)$ and $Z(p_1+p_2)$ represent respectively the impedances at the carrier frequency, signal frequency, lower side frequency, and upper side frequency.

Suppose now that by proper design of an ordinary modulating arrangement, the load impedance acts like a pure resistance R at the frequencies corresponding to $p_1$, $p_2$, $(p_1-p_2)$, and $(p_1+p_2)$. It is at once apparent, by substituting $R_0+R$ for Z in equations (4) and (5), that the modulated currents expressed by each of said equations will be proportional to

$$\frac{R_0^2}{(R_0+R)^3} \quad (6)$$

and the modulated energy $W_1$ delivered to the load impedance will consequently be proportional to

$$\frac{RR_0^4}{(R_0+R)^6} \quad (7)$$

This expression is a maximum when

$$R=\frac{R_0}{5}$$

and when this condition is satisfied, becomes

$$\frac{\left(\frac{5}{6}\right)^6}{5R_0} \quad (8)$$

Let us now assume that the modulating arrangement be so designed that the load impedance acts like a pure resistance R at the frequencies corresponding to $p_1$, $(p_1-p_2)$, and $(p_1+p_2)$, but acts like a short circuit to currents of the signal frequency $\frac{p_2}{2\pi}$. This condition may be practically realized when the carrier frequency is sufficiently large as compared with the signal frequency. In this case the term $Z(p_2)$ becomes $R_0$ instead of $R_0+R$, as in the preceding case, and consequently the modulated currents are proportional to

$$\frac{R_0}{(R_0+R)^2} \quad (9)$$

and the modulated energy $W_2$ is proportional to

$$\frac{RR_0^2}{(R_0+R)^4} \quad (10)$$

This expression is a maximum when

$$R=\frac{R_0}{3}$$

and when this condition is satisfied, becomes

$$\frac{\left(\frac{3}{4}\right)^4}{3R_0} \quad (11)$$

A comparison of equations (8) and (11) shows that for the same applied electromotive forces the modulated energy outputs $W_1$ and $W_2$ are related by

$$\frac{W_1}{W_2}=\left(\frac{3}{5}\right)\left(\frac{4}{3}\right)^4\left(\frac{5}{6}\right)^6=0.635 \text{ or } W_2=1.575\ W_1. \quad (12)$$

It follows at once that a proper design of the associated circuits to satisfy the condition laid down in the second case results in a gain of 57 per cent in the available modulated energy, as compared with the first arrangement. Another immediate deduction from formulas (4) and (5) is that, although we are concerned only in transmitting radio or high frequency modulated currents, it is necessary to provide a low impedance path in the output circuit for the low frequency signaling currents $\frac{(p_2)}{2\pi}$; otherwise, a serious loss in the modulated energy results.

As a result of the deductions above stated, the vacuum tube modulator circuit, illustrated in Fig. 3 and embodying the invention of my Patent 1,448,702, was produced. This modulator conforms to the requirements above outlined by having a shunt circuit including inductance 9 and capacity 10 bridged across its output circuit. The bridge thus formed constitutes a by-pass of substantially zero impedance at the signal frequency. The load impedance at the signal frequency may be thus made substantially negligible.

In accordance with the present invention I propose to still further increase the output energy of the modulators by making the load impedance substantially zero at both signal and carrier frequency. The principle by which this result is accomplished will now be explained.

Suppose by proper design the load impedance be made to act like a pure resistance at frequencies $(p_1-p_2)$ and $(p_1+p_2)$ but acts as a short circuit at the signal frequency $p_2$, and furthermore acts as a short circuit at the carrier frequency $p_1$. In this case the term $Z(p_2)$ of expressions (4) and (5) becomes $R_0$ instead of $R_0+R$ and the term $Z(p_1)$ also becomes $R_0$. Consequently, the modulated currents (side frequencies) will be proportional to

$$\frac{1}{R_0+R} \quad (13)$$

and the modulated energy $W_3$ is proportional to

$$\frac{R}{(R_0+R)^2} \quad (14)$$

This expression is a maximum when $R=R_0$ and when this condition is satisfied becomes

$$\frac{1}{4(R_0)} \quad (15)$$

A comparison of (8) and (15) shows that for the same applied electromotive forces the modulated energy outputs $W_1$ and $W_3$ are related by

$$\frac{W_3}{W_1}=\left(\frac{5}{4}\right)\left(\frac{6}{5}\right)^6$$

or $W_3=3.73\ W_1$.

It follows at once from these deductions that if the circuits be so designed that the load impedance at both the carrier frequency and the signal frequency is substantially zero, the modulated output energy will be 273 per cent greater than in the case of an ordinary modulator. While it is readily possible to reduce the load impedance at the signal frequency to substantially zero by the use of a tuned by-pass, as described in my previous patent, the reduction of the load impedance at the carrier frequency cannot be accomplished practically by this means, for the carrier frequency is so close to the side frequency resulting from modulation that the side frequency or modulated energy would be by-passed as well as the unmodulated carrier component. In accordance with the present invention I propose to accomplish the result of reducing the load impedance to substantially zero at the carrier frequency by the employment of a duplex modulator (or detector), so arranged as to balance out the unmodulated carrier component.

Such a circuit is shown in Fig. 4, in which the modulator is shown as comprising two detecting tubes M and M′. The carrier frequency $\frac{p_1}{2\pi}$ is adapted to the common branch of the two grid circuits through a transformer 20 so that the potential of carrier frequency is applied to the two tubes symmetrically. The signal frequency $\frac{p_2}{2\pi}$ is applied to the grids of the two tubes differentially through the transformer 21. The load circuit is connected to the output through a transformer 22, said transformer having its input windings divided so that one half is in the plate circuit of one tube and the other half in the plate circuit of the other tube. It will be apparent from the circuit arrangement of the output that if the carrier frequency alone is applied to the input, the current of this frequency flowing in the upper half of the input winding of transformer 22 will be opposed by a corresponding current flowing in the lower half of the winding from the other tube. Consequently, as regards the load circuit, the carrier frequency will be balanced out. The signal frequency being applied to the modulator tubes differentially will not be balanced out by this circuit as the signal currents flowing in the two output circuits will aid each other.

In order to render the impedance of the load circuit substantially zero at the signal frequency $\frac{p_2}{2\pi}$, I provide a by-pass comprising an inductance 9 and capacity 10 across the output circuit of the tube M and a similar by-pass comprising the inductance 9′ and capacity 10′ across the output circuit of the tube M′. These inductances and capacities are so chosen as to tune the by-passes to the signal frequency $\frac{p_2}{2\pi}$ with the result that the by-passes act substantially as short circuits at those frequencies and the load impedance therefore becomes zero at the signal frequency, as set forth in my Patent 1,448,702. It will also be clear that the balancing action of the two halves of the primary winding of transformer 22 with regard to the carrier frequency has the effect of rendering the impedance of the load circuit zero at that frequency.

At first thought, it might be assumed that balancing the circuit in the manner described would balance out not only the carrier frequency but also the modulated component or the so-called side frequencies, and that therefore the object of the invention would be defeated by rendering the output impedance zero at the side frequencies. I have shown, however, in my United States Patent 1,449,383, of March 27, 1923, that where the duplex modulator circuit is balanced for the purpose of suppressing the carrier, currents in the two output circuits of the duplex arrangement may each be expressed in terms of the input voltages as a Fourier series. The circuit may be connected to balance out either the even or the odd power terms of the series. It is also shown in said patent that the unmodulated carrier component appearing in the output circuit is a first power term while the side frequencies or sum and difference frequencies are derived from the second power term of the series. If, therefore, the circuit is so connected as to balance out the odd power term it will suppress the carrier, but the side frequency components being derived from the even power term will be mutual-aiding. It will be clear, therefore, that in the circuit of Fig. 4 the odd power term, including the unmodulated carrier, will be suppressed with respect to the transformer 22 but the side frequencies or sum and difference frequencies will not be suppressed. The transformer 22 may be so designed as to act substantially as a pure resistance at the side frequencies in a manner well known in the art and yet by reason of the balanced relation it will suppress the carrier frequency. Therefore, by this circuit we have a condition such that the load impedance Z will be substantially a pure resistance at the two side frequencies $p_1+p_2$ and $p_1-p_2$, but its impedance will be substantially zero by reason of the balanced arrangement at the carrier frequency $\frac{p_1}{2\pi}$ and will also be substantially zero at the signal frequency $\frac{p_2}{2\pi}$ by reason of the tuned shunts, previously described.

The circuit may be so balanced as to render the load impedance substantially zero at both the carrier and signal frequencies, thereby rendering it unnecessary to use the tuned by-pass circuits for the signal frequency if both the signal frequency and the carrier frequency are impressed upon the grid circuit in the same manner. It will be recalled that in Fig. 4 the signal frequency is impressed upon the grid circuits differentially, while the carrier frequency is applied symmetrically. In Fig. 5, however, I show an arrangement in which both the signal frequency $\frac{p_2}{2\pi}$ and the carrier frequency $\frac{p_1}{2\pi}$ are applied to the grids of the modulators M and M′ differentially through the windings of a transformer 25. The load circuit is connected to the common branch of the two output circuits through a transformer 26. The connection of the load is made to the common branch in this case because the frequencies to be balanced out are applied to the grid circuits differentially. If, on the other hand, both the signal and the carrier frequency were applied to the grid circuits symmetrically, the balance would be effected with respect to the output circuit by means of a transformer arrangement, such as shown at 22 in Fig. 4. In the present case, however, it will be apparent that the connection of the transformer 26 is such that odd power terms of the Fourier series will be balanced out. As both the signal frequency and the carrier frequency are first power terms and are applied to the modulating system in the same way, the components in the output circuit corresponding to both of these frequencies will be balanced out and hence the impedance of the load circuit will be substantially zero at both the signal frequency and the carrier frequency and yet it will act substantially as a pure resistance at the two side frequencies which are derived from a second power component.

While the preceding discussion pre-supposes the use of a vacuum tube as a modulator, the invention is equally applicable to the use of the tube as a detector, although in the latter case a slight functional modification of the arrangement would be involved.

It will also be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illustrated without departing from the spirit of the invention as defined in the following claims.

What is claimed is:

1. A modulating arrangement comprising a modulating device, means to impress a carrier frequency and a modulating signal frequency upon said device, a load circuit associated with said device, said load circuit being so designed that its impedance will be substantially zero at both the modulating signal frequency and the carrier frequency.

2. A modulating arrangement comprising a modulating device, means to impress a carrier frequency and a modulating signal frequency upon said device, a load circuit associated with said device, said load circuit being so designed that its impedance will be substantially zero at both the modulating

signal frequency and the carrier frequency and will act substantially as a pure resistance for the side frequency components.

3. A modulating arrangement comprising a vacuum tube modulator, means to impress a carrier frequency and a modulating signal frequency upon said modulator, and a load circuit for said modulator, said load circuit being so designed as to have substantially zero impedance for currents of signal frequency and of carrier frequency.

4. A modulating arrangement comprising a vacuum tube modulator, means to impress a carrier frequency and a modulating signal frequency upon said modulator, and a load circuit for said modulator, said load circuit being so designed as to have substantially zero impedance for currents of signal frequency and of carrier frequency and to have an impedance which acts substantially as a pure resistance for the side frequency components.

5. A modulating arrangement comprising a vacuum tube modulator having an input and an output circuit, means to impress a carrier frequency and a modulating signal frequency upon the input circuit, and a load circuit associated with said output circuit, said load circuit being so designed that its impedance will be substantially zero for currents of signal frequency and carrier frequency.

6. A modulating arrangement comprising a vacuum tube modulator having an input and an output circuit, means to impress a carrier frequency and a modulating signal frequency upon the input circuit, and a load circuit associated with said output circuit, said load circuit being so designed that its impedance will be substantially zero for currents of signal frequency and carrier frequency and will act substantially as a pure resistance for the side frequency components.

7. A modulating arrangement comprising modulating devices in a duplex arrangement, each having an input and an output circuit, means to impress a carrier frequency and a modulating signal frequency upon said input circuits, a load circuit so associated with said output circuits that the carrier frequency components in said output circuits will oppose each other with respect to the load circuit and the load circuit will offer substantially zero impedance to said frequency, and means to render the impedance of the load circuit substantially zero at the signal frequency.

8. A modulating arrangement comprising modulating devices in a duplex arrangement, each having an input and an output circuit, means to impress a carrier frequency and a modulating signal frequency upon said input circuits, a load circuit so associated with said output circuits that the carrier frequency components in said output circuits will oppose each other with respect to the load circuit and the load circuit will offer substantially zero impedance to said frequency, and means to render the impedance of the load circuit substantially zero at the signal frequency, while enabling said load circuit to act substantially as a pure resistance for the side frequency components.

9. A modulating arrangement comprising modulating devices in a duplex arrangement, each having an input and an output circuit, means to impress a carrier frequency and a modulating signal frequency upon said input circuits, a load circuit so associated with said output circuits that both the carrier frequency components and the signal frequency components in said output circuits will oppose each other with respect to said load circuit and the load circuit will offer substantially zero impedance to said frequencies.

10. A modulating arrangement comprising modulating devices in a duplex arrangement, each having an input and an output circuit, means to impress a carrier frequency and a modulating signal frequency upon said input circuits, a load circuit so associated with said output circuits that both the carrier frequency components and the signal frequency components in said output circuits will oppose each other with respect to said load circuit and the load circuit will offer substantially zero impedance to said frequencies, said load impedance acting substantially as a pure resistance for the side frequency components.

In testimony whereof, I have signed my name to this specification this 19th day of December, 1924.

JOHN R. CARSON.