April 7, 1931. F. CONRAD 1,799,974

MODULATION SYSTEM

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Fig. 1.

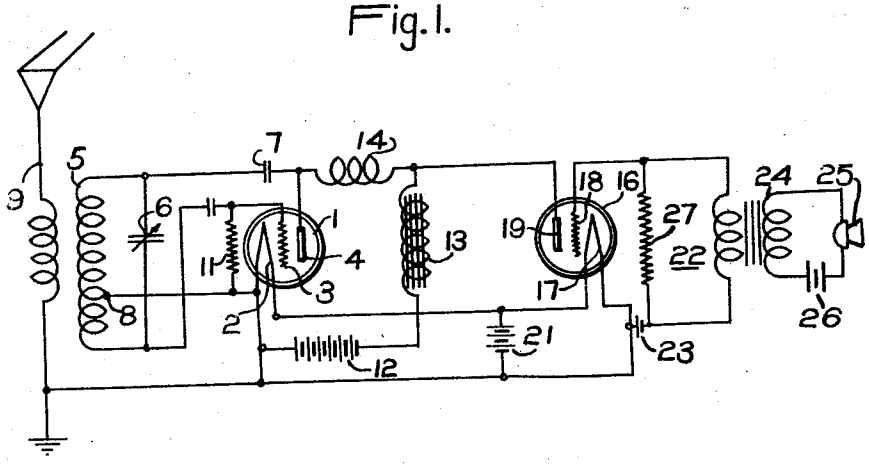

Fig. 2.

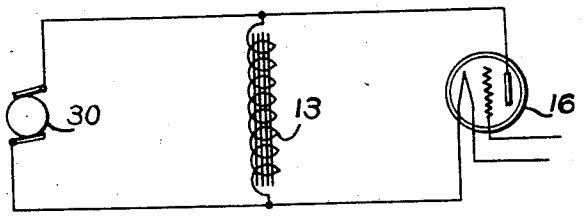

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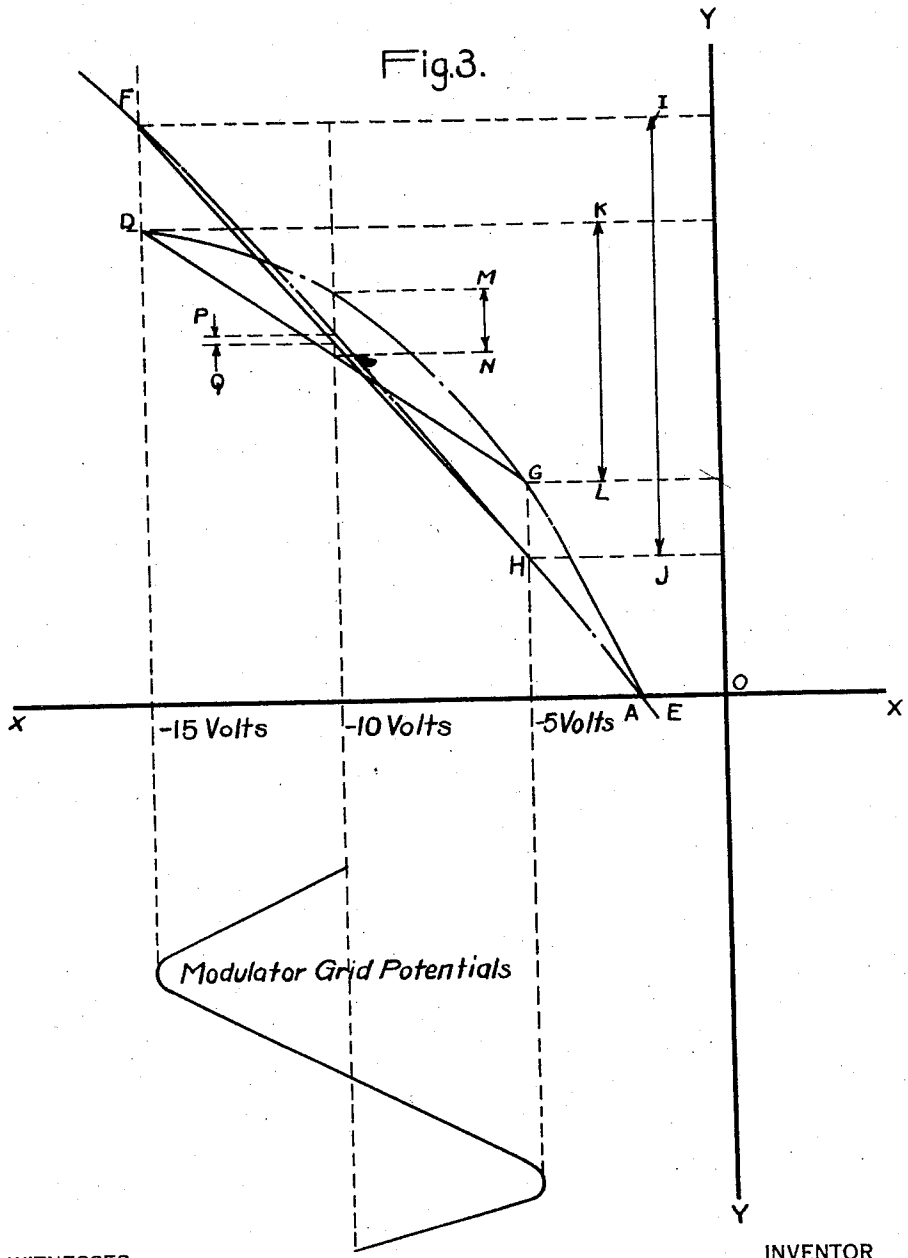
Fig.3.



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UNITED STATES PATENT OFFICE

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MODULATION SYSTEM

Application filed August 7, 1926. Serial No. 127,719.

My invention relates to modulation systems, and it has particular relation to systems now generally known as the constant-current type.

One object of my invention is to provide means whereby the modulated output of an oscillation generator may be truly representative of the modulating potentials.

Another object of my invention is to provide means for the prevention of distortion in modulation systems of the constant-current type.

The term "modulation" is descriptive of the method by which the amplitude of an oscillating high-frequency current is caused to vary in accordance with a signal. This variation in amplitude is sometimes accomplished by changing the grid potential of an oscillating thermionic tube in accordance with signal currents, or it may be obtained by varying the plate potential of the oscillating tube in accordance with signals. Perhaps the best known of the systems in which modulation is accomplished by varying plate potential is the constant-current system, origination of which is generally ascribed to Heising. In the latter system, an oscillating thermionic device and a modulating device are so connected that their plates are in parallel with reference to the plate-potential source, modulating being accomplished by diverting a greater or less amount of current from the oscillating tube in accordance with the signal being impressed upon the modulating tube.

Previous to my invention, no effort was made, insofar as I am aware, to have the impedance of the modulator tubes bear a definite relation to the impedance of the oscillator tubes. In general, it has been customary to use approximately the same number of tubes for modulation as for oscillation generation, with the result that the impedance of the modulator group was necessarily high. I have discovered that high modulator-impedance is one of the principal causes of distorted output, and, by my invention, I provide a modulator section having an impedance far below that of the oscillator section. Specifically, I prefer to employ either modulator tubes of extremely low impedance, or a number of modulator tubes considerable in excess of the number of oscillators.

For a complete understanding of my invention, and the underlying theory, reference is made to the accompanying drawings, and to the following description.

Figure 1 is a diagrammatic view, greatly simplified, of a constant-current modulating system,

Fig. 2 is a diagram illustrating the action of the modulator tube,

Fig. 3 is a set of curves illustrating the effect of both high and low modulator-tube impedances on the modulated output of the oscillation generator.

Referring to Fig. 1, a thermionic device 1, provided with a filament 2, a grid 3 and a plate 4, has associated therewith and oscillation circuit comprising an inductor 5 and a condenser 6. One end of the inductor 5 is connected to the grid 3 and the other end to the plate 4 through a condenser 7, while an intermediate point 8 is conductively connected to the filament 2. The oscillating circuit is inductively, or otherwise, coupled to the antenna 9. A grid leak 11 is usually employed to keep the grid of the oscillating tube at the proper potential with respect to the filament. Plate potential for the oscillating tube is supplied from a source 12, through an audio-frequency choke coil 13 in series with a radio-frequency choke coil 14.

A second thermionic device 16, having a filament 17, a grid 18 and a plate 19, is so disposed that plate potential therefor is also supplied from the source 12 through the audio-frequency choke 13. Filament power for both thermionic devices is supplied from

a source 21, which may be a battery or a motor generator. Connected between the grid and the filament of the thermionic device 16 is an audio-frequency transformer secondary 22 in series with a grid-biasing battery 23. A primary 24 of this transformer is connected in series with a microphone 25 and a source of current 26, and the secondary 22 may be shunted by a variable resistance 27, for modulation control.

In the practical operation of this type of modulation system, both the oscillating tube and the modulating tube are replaced by a plurality of power tubes connected in parallel, usually an equal number of each being used.

Assuming the oscillator tube 1 to be energized, and an oscillating, high-frequency current to exist in the circuit comprising the inductor 5 and the condenser 6, it is obvious that the amplitude of the oscillations depends upon the plate potential.

Upon energization of the microphone 25, the grid potential of the modulator tube 16 is caused to vary above and below the potential fixed by the bias battery 23. Such variation in grid potential, in turn, causes the plate current in the modulator tube to vary at audio frequency, and, due to the action of the choke coil 13, which prevents an audio-frequency variation in current from the source 12, the plate potentials of both modulator and oscillator tubes vary in unison.

It will be noted that the potentials on the grid of the modulating tube are alternating in character, swinging first above and then below the average grid potential fixed by the grid-bias battery. If these variations of grid potential were to cause variations in the plate current strictly proportional thereto, there would be no distortion. Such is not the case, however, it being established by experiment that, when the grid potential swings above or below a certain reference potential, the plate-current increments or decrements are not proportional to the increments or decrements of the grid potential, and it is further noted that the relation of plate current to grid potential also varies with the direction and amount of grid-potential swing. It is accordingly apparent that the plate potential of the oscillator tube is not strictly proportional, at all times, to the signal being impressed on the modulator tube but has a non-linear relation thereto. By reason of this non-linear relationship, the amplitude of the high-frequency output is not truly representative of the signal impresed on the grid of the modulator but is decidedly distorted.

The manner in which my invention prevents distortion in the modulated output may perhaps be best understood by reference at this point to Fig. 2 of the drawings, which shows a circuit electrically equivalent to the circuit involving the oscillator and modulator tubes. Considering the modulator tube as a source of alternating voltage, it is represented by a generator 30, across which are connected the audio-frequency choke coil 13 and the oscillator tube 16. Let E represent the voltage available across the modulator tube, Z the impedance of the modulator tube, E^1 the voltage available across the choke coil and the oscillator tube, Z^1 the impedance of the choke coil and Z^2 the average impedance of the oscillator tube. The impedance of the choke coil must be high, compared with that of the oscillator tube, even at the lowest frequency encountered. If, under such conditions, the ratio of

$$Z \text{ to } \frac{Z^1 \times Z^2}{Z^1 + Z^2}$$

considered vectorially, is quite small, the effect of changes in Z due to the grid-potential swing will be also small, and the percentage of the modulator voltage, E, impressed as E^1 on the oscillator, will be practically constant. This is the condition that is required for distortionless modulation, which obtains only when the potential E^1 is proportional to the signal potential E, and the antenna current consequently also proportional thereto.

Fig. 3 illustrates graphically the amount of distortion present when modulator tubes having differing characteristics are employed.

Modulator grid potentials are represented by distance measured along a reference axis OX, and the oscillator plate potentials corresponding thereto are represented by distances along an axis OY. Distances along the OY axis, to a different scale, are also representative of antenna currents. Assuming a modulator tube having a grid biased to minus 10 volts, with reference to its filament, it is further assumed that the grid potential is caused to swing between minus 15 and minus 5 volts by the signal. Oscillator plate potentials corresponding to the modulator-grid swing are plotted, curve AD being found representative of conditions when modulator tubes having high impedance are used, and a curve EF characteristic of low impedance modulators. If the tube impedances were constant, a line GD would represent plate-potential conditions for the high-impedance modulator tube, and a line HF those for the low-impedance tube. A line IJ represents the total plate-potential change in the oscillator tube when low-impedance modulators are used, and a line KL the same change when high-impedance modulators are employed.

The departure of the curve AD from the line GD, represented by a distance MN, is a measure of the distortion resulting when high-impedance modulators are used, while a distance PQ is a measure of the distortion when low-impedance modulators are used.

The latter distance is seen to be substantially negligible.

This distortion factor is represented by the ratio

$$\frac{PQ}{IJ}$$

for the low-impedance modulators, and by the ratio

$$\frac{MN}{KL}$$

for the high-impedance modulators, and is a measure of the magnitude of extraneous harmonics introduced into the output with each type of modulator.

For ordinary use, the modulator impedance should be kept less than 5% to 10% of the oscillator impedance, causing less than 2% to 3% distortion at 75% modulation, an amount that is inappreciable. In systems such as were employed prior to my invention, in which the same number of oscillator as of modulator tubes was utilized, distortion was often as high as 10% to 30% for the same percentage modulation.

It will thus be understood that a system embodying my invention is radically different from those of the prior art. Instead of using the same number of modulator as of oscillator tubes, I preferably use a number sufficient to keep the modulator impedance below 10% of the oscillator impedance, and obtain a modulated high-frequency output that is substantially distortionless.

Although I have described a specific method by which my invention may be practiced, I am aware that many modifications will suggest themselves to those skilled in the art. My invention is not to be limited, therefore, except insofar as is necessitated by the prior art or by the spirit of the following claims.

I claim as my invention:

1. In a radio system, thermionic means for generating oscillations, and thermionic means for varying the amplitude of the generated oscillations, the impedance of the second named means being substantially of the order of 5% of that of the first named means.

2. In combination, a plurality of thermionic devices so disposed as to be capable of generating sustained oscillations, and means, including a plurality of thermionic devices, for varying the amplitude of the oscillations generated, the impedance of the second named group of thermionic tubes being of the order of 5% of that of the first named group.

3. In a radio system, thermionic means for generating oscillations, and thermionic means for varying the amplitude of the generated oscillations in response to a signal, the impedance of the amplitude-varying means being substantially less than one-tenth of the oscillation-generating means.

4. In combination, a plurality of thermionic devices having plates and filaments and disposed in parallel for the generation of high-frequency oscillations, and a plurality of thermionic devices having plates and filaments, the second group serving to vary the amplitude of the oscillations generated by the first group and having a total plate-filament impedance substantially less than 10% of the combined plate-filament impedance of the first named group.

In testimony whereof, I have hereunto subscribed my name this 5th day of August, 1926.

FRANK CONRAD.