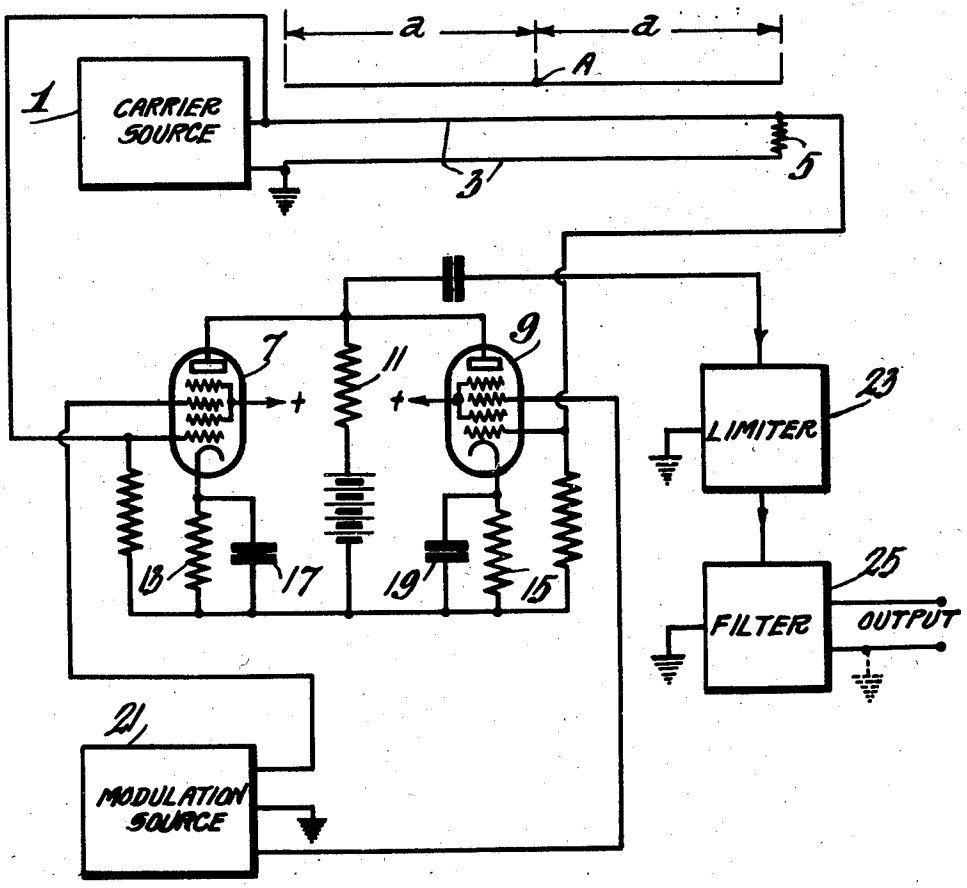
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PHASE MODULATION SYSTEM

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PHASE MODULATION SYSTEM

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1

This invention relates to phase modulation systems, and its principal object is to provide a system for phase modulating a carrier linearly with respect to a modulating voltage, to any desired extent.

The invention will be described with reference to the accompanying drawing, which is a schematic circuit diagram of an embodiment thereof.

A source 1 of carrier energy is connected to a transmission line 3 of arbitrary length $2a$. The line 3 is terminated by a resistor 5, of a resistance equal to the characteristic impedance of the line 3. The line 3 is made short enough to introduce negligible attenuation at the carrier frequency, and is much shorter than the wavelength corresponding to the highest modulation frequency to be used.

A pair of electron discharge tubes 7 and 9 are provided with their anodes connected together to a common load resistor 11. Each of the tubes 7 and 9 includes two control grids as well as the anode and cathode, and may include further elements such as screen and suppressor grids. The tubes 7 and 9 may be of the type designated in the radio art as 6L7's. The tubes 7 and 9 are provided with self-bias resistors 13 and 15, bypassed by capacitors 17 and 19 respectively in accordance with conventional practice.

The inner control grid of the tube 7 is connected directly to the carrier source 1. The inner control grid of the tube 9 is connected to the terminating resistor 5, and through the line 3 to the source 1. The outer control grids are connected to opposite terminals of a source 21 of modulation voltage. The source 21 is provided with a center-tapped output circuit, with the center tap grounded, so as to excite the outer control grids of the tubes 7 and 9 in push pull. The source 21 may include a push pull output transformer, a phase inverter circuit, or any other known means for providing balanced-to-ground output voltages.

The load resistor 11 is coupled to the input of a voltage limiter 23. The output circuit of the limiter 23 is coupled through a filter 25 to the utilization circuit, not shown. The filter 25 is designed to reject harmonics of the carrier frequency, passing only the phase modulated carrier.

The operation of the described system is as follows:

The unmodulated carrier voltage provided by the source 1 is

$$e=E\sin\left(\omega t+\frac{2\pi a}{\lambda}\right)$$

where E is the carrier amplitude, ω is 2π times the carrier frequency, a is one-half the length of the

2

line 3, and λ is the wavelength at the carrier frequency. The initial phase angle

$$\frac{2\pi a}{\lambda}$$

is introduced merely for convenience in the following analysis.

Since the line 3 is so short that its attenuation may be neglected, the voltage across the line at its midpoint, A, is:

$$e_A=E\sin\omega t$$

and the voltage across the terminating resistor 5 is:

$$e_1=E\sin\left(\omega t-\frac{2\pi a}{\lambda}\right)$$

The voltage at the inner control grid of the tube 7, referred to the cathode, is

$$e'=E_1\left[1+m\sin\left(\omega t+\frac{2\pi a}{\lambda}\right)\right]$$

where E_1 is the bias between grid and cathode and

$$m=\frac{E}{E_1}$$

where E is as above, the carrier amplitude. Similarly, the voltage at the inner control grid of the tube 9, referred to its cathode, is:

$$e_1'=E_1\left[1+m\sin\left(\omega t-\frac{2\pi a}{\lambda}\right)\right]$$

The voltage, referred to the cathode, at the outer control grid of the tube 7, is

$$e_2=E_2(1+m_2\sin\beta t)$$

where E_2 is the bias on the grid with respect to the cathode, m_2 is the amplitude of the modulating voltage divided by E_2, and β is 2π times the modulation frequency. In the circuit as shown in the drawing, E_2 and E_1 are equal, but it will be apparent without further illustration that they may be made different by providing separate bias circuits for the inner and outer control grids. The voltage at the anode of the tube 7 is:

$$\begin{aligned}e_3&=kE_1E_2\left[1+m\sin\left(\omega t+\frac{2\pi a}{\lambda}\right)+m_2\sin\beta t+\right.\\&\left.mm^2\sin\beta t\sin\left(\omega t+\frac{2\pi a}{\lambda}\right)\right]\\&=kE_1E_2\left[1+m\sin\omega t\cos\frac{2\pi a}{\lambda}+m\cos\omega t\sin\frac{2\pi a}{\lambda}+\right.\\&m_2\sin\beta t+mm_2\sin\beta t\sin\omega t\sin\frac{2\pi a}{\lambda}+\\&\left.mm_2\sin\beta t\cos\omega t\sin\frac{2\pi a}{\lambda}\right]\end{aligned}$$

Similarly, the voltage at the outer control grid of the tube **9**, referred to its cathode, is:

$$e_2' = E_2(1 - m_2 \sin \beta t)$$

and the voltage at the anode of the tube **9** is:

$$e_3' = kE_1E_2\left[1 + m \sin\left(\omega t - \frac{2\pi a}{\lambda}\right) - m_2 \sin \beta t - mm_2 \sin \beta t \sin\left(\omega t - \frac{2\pi a}{\lambda}\right)\right]$$

or:

$$e_3' = kE_1E_2\left[1 + m \sin \omega t \cos \frac{2\pi a}{\lambda} - m \cos \omega t \sin \frac{2\pi a}{\lambda} - m_2 \sin \beta t - mm_2 \sin \beta t \sin \omega t \cos \frac{2\pi a}{\lambda} + mm_2 \sin \beta t \cos \omega t \sin \frac{2\pi a}{\lambda}\right]$$

The voltages e_3 and e_3' are combined to produce a voltage e_4 on common load impedance **11**:

$$e_4 = 2kE_1E_2\left[1 + m \sin \omega t \cos \frac{2\pi a}{\lambda} + mm_2 \sin \beta t \sin \frac{2\pi a}{\lambda} \cos \omega t\right]$$

This may be rewritten as:

$$e_4 = 2kE_1E_2\left\{1 + m\sqrt{1 + \sin^2 \frac{2\pi a}{\lambda}(m_2^2 \sin^2 \beta t - 1)} \times \sin\left[\omega t + \tan^{-1}\left(m_2 \tan \frac{2\pi a}{\lambda} \sin \beta t\right)\right]\right\}$$

In the above expression, m_2 lies between 0 and 1, i. e. the amplitude of the modulating voltage is no greater than the bias voltage E_2 on the outer control grids, and

$$-1 \leqq \sin t \leqq 1$$

Since the length $2a$ of the line **3** is short compared to λ, as stated above,

$$\tan \frac{2\pi a}{\lambda} \cong \frac{2\pi a}{\lambda}$$

and

$$\tan\left(m_2 \tan \frac{2\pi a}{\lambda} \sin \beta t\right)$$

is substantially equal to:

$$m_2 \frac{2\pi a}{\lambda} \sin \beta t$$

Thus

$$e_4 \cong e_4'$$

where

$$e_4' = 2kE_1E_2\left\{1 + m\sqrt{1 + \sin^2 \frac{2\pi a}{\lambda}(m_2^2 \sin^2 \beta t - 1)} \times \sin\left[\omega t + \frac{2m_2\pi a}{\lambda} \sin \beta t\right]\right\}$$

Since the carrier frequency

$$\frac{\omega}{2\pi}$$

is constant,

$$\frac{2\pi a}{\lambda}$$

is some constant phase displacement, ϕ. Accordingly, e_4' may be written as:

$$e_4' = 2kE_1E_2\{1 + m\sqrt{1 + \sin^2 \phi(m_2^2 \sin^2 \beta t - 1)} \times \sin[\omega t + m_2\phi \sin \beta t]\}$$

The coefficient

$$\sqrt{\sin^2 \phi(m_2^2 \sin^2 \beta t - 1)}$$

represents amplitude modulation. This is removed by the limiter **23**. The limiter **23**, however, acts to introduce various harmonics of the carrier frequency

$$\frac{\omega}{2\pi}$$

These are removed by the filter **25**. Thus the final output voltage is:

$$e_4'' = E_4 \sin(\omega t + m_2\phi \sin \beta t)$$

which represents a carrier voltage of amplitude E_4 and frequency

$$\frac{\omega}{2\pi}$$

varying in phase through an angle $m_2\phi$ at a rate

$$\frac{\beta}{2\pi}$$

cycles per second.

It will be apparent without further illustration that the described system will operate with complex modulation, such as that derived from speech or music, in the same manner as with simple sinusoidal modulation. The modulation factor $m_2\phi$ is limited only by the maximum signal amplitude which can be applied to the grids of the tubes **7** and **9**, and the length of the delay line **3**.

Thus I have provided an improved phase modulator system including a pair of modulator tubes with their output circuits in parallel, and excited in push pull by the modulation voltage. Carrier voltage is applied to one tube directly and with a fixed delay to the other tube. This provides an output which is both phase modulated and amplitude modulated. The amplitude modulation is removed by a limiter, providing a pure linearly phase modulated output.

I claim as my invention:

1. A phase modulation system including a carrier source of nominally constant frequency but subject to undesired variations, a pair of electron discharge tubes each having at least an anode, a cathode and two control grids, means for applying the output of said carrier source directly to the first control grid of the first of said tubes, and means applying the output of said carrier source with a delay time which is substantially independent of said variations in frequency of said carrier source to the corresponding control grid of the other of said tubes, a source of modulation voltage, means for applying said modulation voltage to the second control grids of both of said tubes in push pull, a common load impedance connected to the anodes of both of said tubes in parallel, a voltage limiter connected to said load impedance, and filter means connected to the output circuit of said voltage limiter.

2. A phase modulation system including a carrier source of nominally constant frequency but subject to undesired variations, a pair of electron discharge tubes each having at least an anode, a cathode and two control grids, means for applying the output of said carrier source directly to the first control grid of the first of said tubes, and means applying the output of said carrier source with a delay time which is substantially independent of said variations in frequency of said carrier source to the corresponding control grid of the other of said tubes, a source of modulation voltage, means for applying said modulation voltage to the second control grids of both of said tubes in push pull, and a common load circuit connected to the anodes of both of said tubes in parallel.

LOWELL E. NORTON.

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